THE EFFECT OF WATER CONSUMPTION ON SCHOOLCHILDREN'S FINE MOTOR SKILLS, COGNITIVE FUNCTION AND MOOD

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Abstract

Previous research has suggested that dehydration may have a negative effect on some aspects of mood, cognitive performance and motor skills (Benton, 2011). Furthermore, a large proportion of children arrive at school in a dehydrated state (Baron, Courbebaisse, Lepicard, & Friedlander, 2015). The present work investigated whether supplementing children with water may, as a consequence of reducing dehydration, improve their cognitive performance and motor skills.

In studies 1, 2, 3 and 5, it was found that tasks that predominantly tested motor skills, were improved in children who had a drink, compared to those who did not. Furthermore, study 3 showed that this effect was moderated by hydration status. One theoretical explanation for the poorer performance of dehydrated children is that they may lack the neurological resources to sustain their effort and thus performance does not improve over time. In support of this, these studies showed that, when re-hydrated, performance on these tasks improves to the level of non-dehydrated children. Study 2 showed that the number of errors increased in a StopSignal task in children that had high self-rated levels of thirst, compared to low levels: and hydration status did not moderate this effect. A possible explanation for the increased number of errors in children with high self-rated thirst is that the thirst sensation diverts attention away from the task, causing task performance to deteriorate. In study 4, it was observed that there was a large variation in intra-individual and inter-individual hydration scores throughout the day, which was not related to volume drank or levels of thirst.

Further studies should use imaging techniques to study brain activity during dehydration and rehydration, and during periods of high thirst, to help to further elucidate the mechanism underlying the negative effect of dehydration on motor performance, and the effect of self-rated thirst on attention.

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Definitions

Actual Intake: amount of fluid consumed in beverages and food by an individual

Adequate Intake: amount of fluid that is experimentally determined by assessing healthy individual's average daily water consumption in both food and beverages

Dehydration: process of losing water from the body

Euhydration: water balance

Extracellular fluid (ECF): is the fluid surrounding cells (plasma) outside blood vessels (interstitial fluid). One third of body fluid is in the ECF.

Fat Free Mass (FFM): is the mass of your body without the fat, which can also be called lean body mass. Lean body mass includes lean muscle tissue, fluid, organs and bones and is composed of 73 % water.

Freezing point depression: the freezing point of pure water is zero degrees. Adding solutes to pure water will cause the solution to remain liquid at zero degrees. The freezing point of the solution will therefore be lower than pure water. The osmotic concentration can be calculated by measuring the temperature at which the solution freezes.

Homeostasis: a balance to maintain physiological parameters such as body temperature and water balance by physiological processes

Hypertonic: a higher concentration of electrolytes in the extracellular fluid (ECF) rather than intercellular fluid (ICF). The osmotic pressure difference between ICF and ECF will cause water to flow out of the cells, which will then shrink

Hyperhydration: an excess of water within the body

Hypertonic dehydration: dehydration caused by insufficient water being consumed or by a large water loss

Hypohydration: a water deficit within the body

Hyponatraemia: is a condition caused by abnormally low sodium levels in the extracellular fluid. Water flows from a low sodium concentration into a higher sodium concentration in the intracellular fluid which causes the cell to swell systemically. This can cause symptoms such as vomiting, fatigue, seizures and coma.

Hypotonic dehydration: dehydration caused by a loss of sodium often due to diarrhoea or sickness

Hypovolemia: state of decreased blood volume

Intracellular Fluid (ICF): is the fluid within a cell

Ion: an atom or group of atoms that has an electric charge

Ionic: related to or using ions

Isotonic dehydration: results from an imbalance of salt (ions) when the volume of water and sodium decrease equally

Macronutrient: A nutrient which is required in large amounts to ensure the development and normal growth of an organism

Milliosmole (mOsm): 1/1,000 of an osmole

Millimole: 1/1,000 of a mole

Mole (mol): is a unitary measure of substance

Osmolality: the concentration of particles in a solution and is measured in milliosmoles of solute (ion) per kilogram of solvent. A high concentration of particles in urine would equate to dehydration.

Osmolarity: the concentration of particles in a solution and is measured in milliosmoles of solute (ion) particles per litre of solution

Osmoles: is the number of solute particles in a specific amount of liquid. To explain the difference between a mole and an osmole, a salt particle (NaCl) is one mole, but it is composed of Na and Cl so is 2 osmoles. 1 mol of NaCl gives 2 osm

Osmosis: the movement of water through a membrane

Osmotic gradient: the difference in concentration between two solutions on either side of a membrane

Oxidation: the combination of a substance with oxygen

Preformed water : the water input within beverages and food moisture

Rehydration : the process of gaining water

Sodium electrolytes: salts that conduct electrical impulses

Solute: a substance that is dissolved by a solvent, for example salt is dissolved by water into sodium and chloride

Solution: a liquid mixture formed by a solvent, for example water, and one or more solutes, for example salt

Solvent: a substance that dissolves solutes

Thermoregulation: temperature control

Total Body Water (TBW): TBW is the percentage of your total body weight that is composed of water.

Total Water Intake: water in drinks + food moisture + oxidation

Voluntary Dehydration: water deficit that results from not drinking enough

X-ray absorptiometry: an x-ray is used to measure soft tissue composition and bone mineral density

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Conflict of Interest Statement

This PhD was fully funded by Nestec Ltd. Initially, the funder was fully involved in the PhD, attended supervisory meetings and contributed ideas for the registration document and specific design of Study 1. The company provided a large number of bottles of water, which were used throughout the study and partially contributed to an osmometer which was purchased. The remaining cost of the osmometer was provided by a grant from the University of East London. However, after Study 1 there was a change of staff at Nestec Ltd and the role of the funder changed. They had no further input into the design of any studies and made no comment on any outcomes or results. The funder was sent details of study outcomes, plans for future studies and conference abstracts in an annual report, as a gesture of goodwill, but Nestec Ltd had no further involvement or influence over the PhD.

CHAPTER 1

Introduction

1.1 General Rationale for Studying the Effect of Water Consumption on Children's Cognitive Function, Mood and Behaviour

Particularly in western society, people are now bombarded with information about the benefits of drinking water, which range from losing weight to protecting against cancer, and the negative consequences of not drinking enough, such as constipation and depression (Google, 2016). As a consequence, bottled water sales are at an all-time high with 262 billion litres sold world-wide (Holdsworth, 2014) and sales continuing to grow every year (Mintel, 2016).

Many of the assertions in the media are not evidence based. However, some of these statements do have a large body of research to support them. For example, the physical consequences of not drinking enough (Grandjean & Grandjean, 2007; Popkin, D'Anci, & Rosenberg, 2010) and the effect of hydration on sports performance (Shirreffs, 2005) are well researched. Chapter 2 will present a detailed review of the literature on hydration status and cognitive performance. In brief, there have been some studies which have investigated how not drinking enough may affect cognitive performance and mood in adults, but the results from these studies are inconsistent. A very small body of work shows that children may be experiencing cognitive deficits at school (Masento, Golightly, Field, Butler &van Reekum, 2014). Furthermore, evidence does show that children are at particular risk of dehydration, that a large proportion of children are arriving at school in a dehydrated state and that children may have difficulty accessing water at school (Baron, Courbebaisse, Lepicard, & Friedlander, 2015). The focus of this thesis is how hydration status may affect children's performance at school.

Some research, still in its infancy, has studied the question of whether water consumption may benefit cognitive performance and mood in children and adults. So far, it has not been established whether specific modes of cognition or mood may be sensitive to water consumption. Additionally, it is unknown whether the effects of water consumption are moderated by hydration status or other variables such as the sensation of thirst and consequently what mechanisms may be responsible. Therefore, there is lots of scope for research in this field and these issues were explored throughout the studies reported in this thesis. The outline of the thesis is described below.

1.2 Outline of the Thesis

- Chapter 1 introduces the role of water in the human body by describing the necessity for water balance, the biological mechanisms in the body that control water balance and the consequences of drinking too much or too little. This is followed by a description of methods of measuring hydration status and the rationale for choosing the method used. Lastly, a description of the recommendations for fluid intake and actual fluid intake of water in the different populations is given.

- Chapter 2 presents a literature review of the effects of both dehydration and water consumption on cognitive performance in adults and children. Additionally, a rationale for the experimental design used is presented. This is followed by a discussion of the issues raised in the dehydration literature and a description of the possible mechanisms that may explain why hydration status has an effect of cognitive performance, motor skills and mood. Lastly, the rationale and aims of the PhD are presented.

- Chapters 3 to 7 present the experimental studies carried out.

- Chapter 8 presents the conclusions of the study and the implications of this work for further research.

1.3 Water and its Role in the Human Body

This thesis discusses the effects of hydration status on cognitive performance, motor skills and mood. Therefore, it is necessary to understand the role of hydration in the body and the physiological mechanisms involved because they will be discussed throughout the thesis. To understand how and why changes in hydration status occur, and the physiological consequence of these changes, a detailed explanation of the function of water in the body and water balance is given in the next section. Furthermore, definitions of the terminology used to discuss hydration and the measurement of hydration are given in the following section as these terms will be used throughout the thesis.

1.3.1 Function of Water in the Body

Every living organism requires water to survive (Makieg, Siegel, Olsen, Gabanski & Carlson, 2005). A large proportion of a human body consists of water; a baby's bodyweight consists of 75 % water which reduces to 60-70 % in adults (Popkin et al., 2010). Water has many purposes such as: transporting nutrients and waste and substances such as blood cells and enzymes around the body; acting as a solvent for minerals and vitamins and as a constituent of other structures such as protein and glycogen (EFSA, 2010; Kleiner, 1999). It is the main component of cells and tissue and is necessary for any biochemical reaction to take place (Kleiner, 1999). Water is involved in every process in the human body, in every organ, such as the brain, kidneys and the liver, and in every system, such as the respiratory system, reproductive system, peripheral nervous system and cardiovascular system (Jéquier & Constant, 2010). Additionally, water plays a crucial role in temperature control (thermoregulation) because a water molecule is able to absorb heat without its own temperature rising. Consequently, it acts as a thermal buffer by absorbing heat produced by metabolism or the external environment, thus preventing rapid rises in body temperature (Boyle and Senior, 2002). When sweat is lost from the body this helps to dissipate heat which assists in maintaining a stable body temperature (Seeley, 2011).

1.3.2 Structure of Water

To understand how the function of water in the human body can be understood more clearly, a more detailed description of water molecules and how they interact with other minerals is given here.

Each water molecule has two positively charged hydrogen atoms and one negatively charged oxygen atom. Water molecules ‘stick together’ because the negatively charged oxygen atoms in one water molecule attract the positively charged hydrogen atoms in another water molecule, which form a hydrogen bond. The water molecules also stick to other types of particles making it a very useful solvent in which other substances called solutes, such as minerals, can be dissolved to make a solution. For example, water (the solvent) dissolves salt (the solute) into sodium and chloride particles to form a solution (body fluid) (Benelam & Wyness, 2010).

1.3.3 Body Fluid

Often hydration status is assessed by measuring the concentration of body fluid. This section will explain how body fluid concentration is measured and the terms used. As explained above body fluid contains water and solutes. Solutes, such as salt, can be measured in millimoles or milliosmoles. The amount of a substance in a solute, for example salt (NaCl), is defined as one mole but in a solution the salt would disassociate to become a particle of sodium and a particle of chloride and these different particles are called osmoles. Therefore, in this example one mole of salt is equal to two osmoles. If a substance dissociated to form three different particles, then one mole would be equivalent to three osmoles. In this thesis descriptions of body fluid are restricted to milliosmoles. The number of osmoles of solute (for example salt) per kilogramme of solvent (for example water) is termed the osmolality of a solution (Armstrong, 2007). A similar measure is osmolarity which is the term for the concentration of particles of solute per litre of a solution. These measurements will be used interchangeably in the text dependent on the measure of choice in the study under discussion.

1.3.4 Concentration of Sodium in Body Fluid

Hydration status is dependent on the concentration of body fluid both within body cells and outside of body cells. One third of body fluid is found in extracellular fluid (ECF), mostly within the plasma, which is the fluid surrounding the cells inside the blood vessels and the interstitial fluid, which is the fluid found outside the blood vessels. The fluid inside cells is intracellular fluid (ICF) and accounts for two thirds of body fluid. Approximately 95 % of the sodium is found in the ECF. To prevent changes to cell size and for processes in the body to function effectively there has to be a balance of sodium within the ECF and ICF. A balance between the input and output of water is required, defined as euhydration, to maintain the concentration of sodium in intracellular and extracellular fluid (Cheuvront & Kenefick, 2014).

1.3.5 Water balance

This section will discuss how water balance can be maintained, the consequences of water excess or deficit and the terminology used. Water balance, defined as euhydration, is not a static state because the body is in a continual state of losing water, defined as dehydration, and gaining water, defined as rehydration. There is a constant shift between water excess, which is defined as hyperhydration and water deficit which is defined as hypohydration (Greenleaf, 1992; Shirreffs, 2000). However, for the purposes of simplicity, and to be consistent with most previous studies looking at the effects of water deficit, this thesis will use the term dehydrated/dehydration to define humans that have a water deficit.

1.3.5.1 Water Input

Water input is achieved by consuming water in beverages and the water content in food, additionally a small amount of water is produced by the body during the oxidation of macronutrients (Jequier & Constant, 2010). Humans drink water as a response to thirst and although this is an important part of why humans drink water there are also more complex social reasons such as habits and customs (McKinley & Johnson, 2004). The amount of fluid consumed is to an extent a learned behaviour which can be culturally determined (Jequier & Constant, 2010).

1.3.5.2 Consequences of Water Excess

Generally, excess water intake is excreted by the kidneys but if water retention occurs a condition named hyponatraemia may result. Severe hyponaetremia can result in brain swelling, seizures, coma and death (Whitfield, 2006). Hyponaetremia occurs when sodium osmolarity falls below 135 mmol/L, with acute or critical hyponaetremia occurring if sodium osmolarity falls below 120 mmol/L (Whitfield, 2006). Only very rarely are cases due purely to overconsumption of water as hyponaetremia usually occurs in hospitalised patients who are taking medications which cause water excretion to be impaired. Additionally, athletes involved in endurance sports such as marathons may be at risk. Recent evidence suggests that hyponatraemia may be due to increased AVP (arginine vasopressin) secretion during exercise which results in water retention even if drinking volumes are not excessive (Hew-Butler et al., 2008).

1.3.5.3 Water Output

On average adults lose 1 to 2 litres (L) of urine per day (EFSA, 2010), and in addition, lose fluid from the water in faeces, evaporation from the skin via sweat and from the respiratory tract (Jéquier & Constant, 2010). Sweating is an important mechanism for cooling body temperature and between 0.3 litres per hour (L/h) and 2 L/h of water can be lost in sweat alone (Popkin et al., 2010).

The rate of sweating increases with the ambient temperature; thus there is a higher risk of dehydration in a hot climate.

1.3.5.4 Types of Dehydration

Different types of dehydration can occur. In this thesis children that are dehydrated are suffering from intracellular hypertonic dehydration. Hypertonic dehydration occurs due to a water deficit which may be due to not consuming enough water or sweating. The water loss occurs initially in the ECF which causes the sodium concentration to increase in the ECF, consequently water moves across the cell membrane by osmosis from ICF to the ECF causing the cell to shrink. Figure 1.1 shows the different types of dehydration dependent on the concentration of sodium. Hypotonic dehydration occurs when sodium concentration decreases in the ECF and may occur due to adrenal or kidney dysfunction as a consequence of medical conditions such as Addisons disease. The water moves across the cell membrane from the ECF to the ICF causing the cell to swell. If sodium and water volume decrease equally, for example due to vomiting or diarrhoea the dehydration is termed isotonic (Wilson, 2010). When a balance between sodium and water intake and output is maintained this is called euhydration. The maintenance of euhydration will be discussed below.

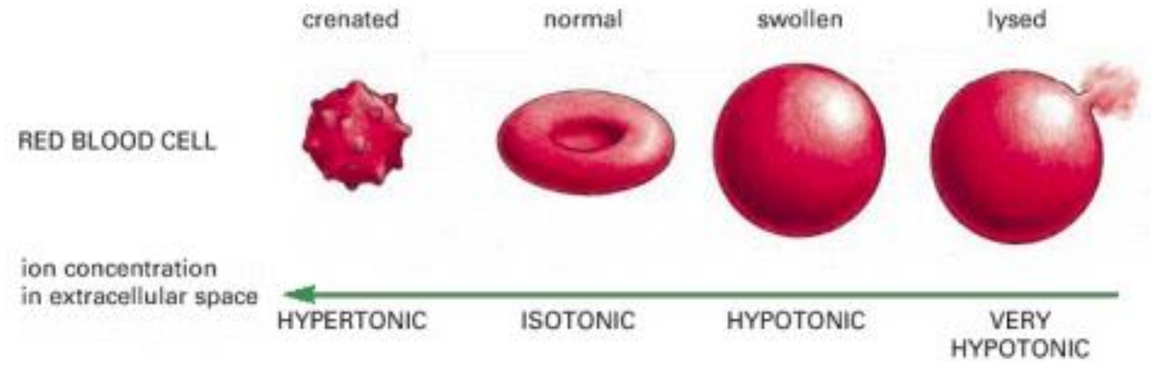


Figure 1.1 Showing the Effects of Differing Electrolyte Concentration, in ECF, on Cells (Alberts, Johnson & Lewis, 2002. Copyright (2010) by National Library of Medicine (NLM). Reprinted with permission)

1.3.5.5 Consequences of Dehydration

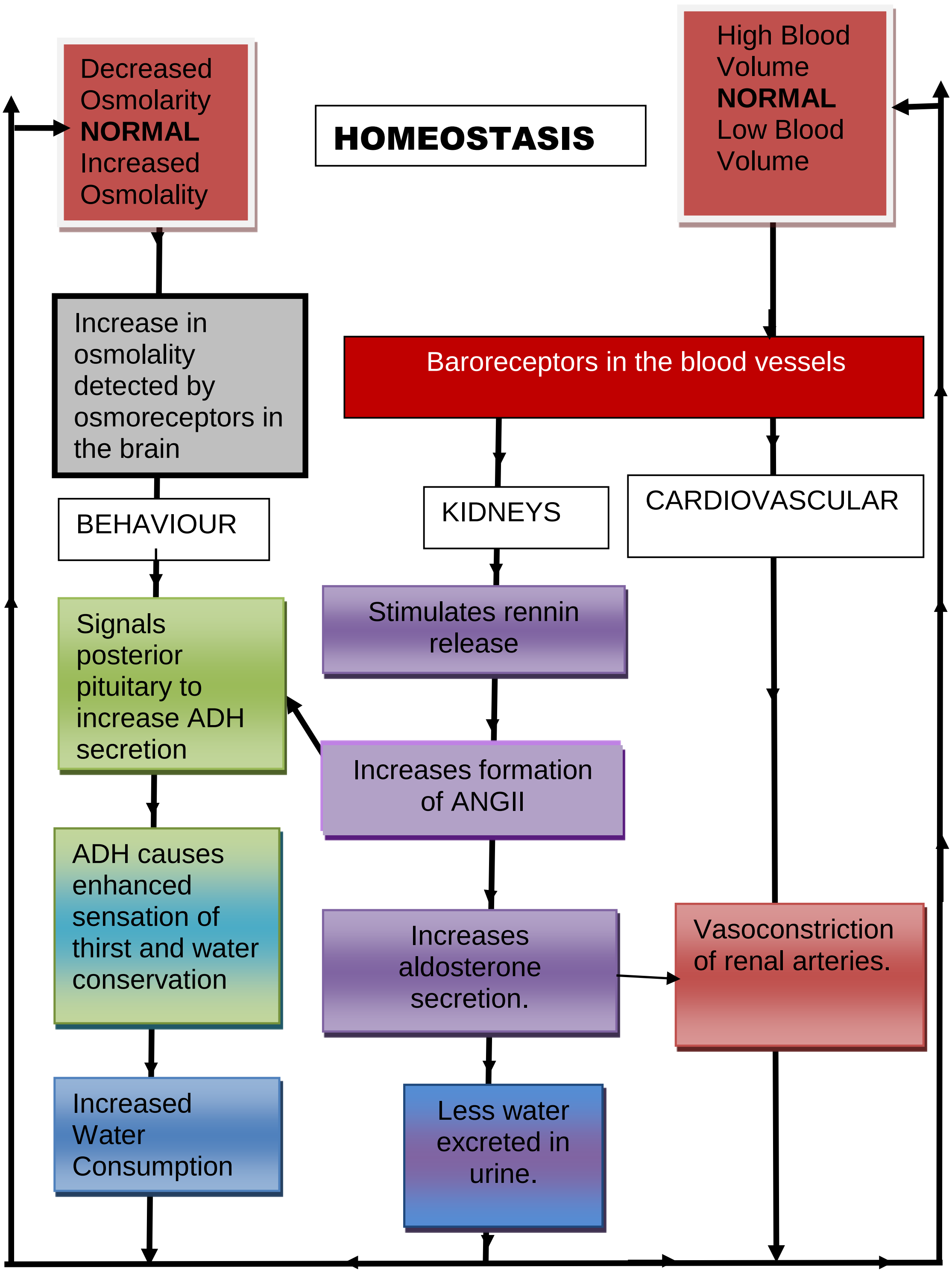
As water is essential to all processes in the human body, it is not surprising that dehydration is thought to be a factor in illness and disease. The evidence suggests that even chronic mild dehydration may increase the risk of urinary tract infections, hyperglycaemia, chronic kidney disease, hypertension, fatal coronary heart disease, chronic kidney disease, and bladder and colon cancer; although more research is necessary to corroborate studies carried out so far (Grandjean & Grandjean, 2007; Popkin et al., 2010). More short term effects of dehydration include dry mouth and sunken eyes, headache, constipation and low blood pressure. Symptoms of severe dehydration include muscle cramps and weakness, deep and rapid respiration and it can be life threatening (Benelam & Wyness, 2010; Gorelick, 1997; Popkin et al., 2010). Consequently, physical and cognitive performance may deteriorate as dehydration increases.

Evidence shows dehydration may have a negative effect on both cognitive and exercise performance. There has been a lot of research carried out on people who undertake a high level of physical performance, such as athletes, to determine the effect of dehydration on performance. The evidence supports the argument that performance levels and exercise capacity decrease if dehydration is present (Cheuvront & Sawka, 2005; Dougherty, Baker, Chow & Kenney, 2006; Murray, 2007; Singh, 2003). Strength, endurance and power are reduced (Judelson et al., 2007), as well as motivation and perceived effort, whilst fatigue increases (Cian et al., 2000; Szinnai, Schachinger, Arnaud, Linder & Keller, 2005). Dehydration also has an adverse effect on performance skills, for example, bowling accuracy in cricket (Devlin, Fraser, Barras & Hawley, 2001). To date there have been fewer studies on the effects of dehydration on cognition but studies do suggest that dehydration has a negative effect (this is reviewed in Chapter 2). When insufficient fluid is consumed to maintain water balance there are biological mechanisms which are triggered to prevent further water loss and encourage water input, these are discussed below.

1.3.5.6 Regulation of Water Balance

This section will discuss the physiological mechanisms that maintain water balance. There is a possibility that these mechanisms may also be causal in the changes that occur in cognitive performance, motor skills or mood due to hydration status. Thus, understanding these mechanisms is an important part of this thesis and will be discussed here. To prevent changes in cell size and maintain water balance various mechanisms interweave to regulate osmolarity and fluid volume. Figure 1.2 shows a visual representation of how water balance is maintained.   ICF osmolarity is maintained by the osmotic gradient between the ICF and ECF. ECF osmolarity is regulated by the kidneys, behaviour and the cardiac system. If blood plasma osmolarity rises above approximately 280 milliosmoles per litre (mOsm/L) (Jéquier & Constant, 2010) osmoreceptors in the hypothalamus signal the posterior pituitary to secrete an anti-diuretic hormone (ADH) from the posterior pituitary gland. The ADH increases the sensation of thirst, encouraging water consumption. As water is consumed so osmolarity will reduce. The ADH also acts on the kidney, causing it to reabsorb water which concentrates the urine. Subsequently urine osmolarity increases up to a maximum of 1200mOsm/L and the amount of urine excreted is reduced which conserves water (Jéquier & Constant, 2010). Although, it should be noted that dehydration cannot be reversed by this mechanism but any worsening can be delayed.

If blood volume reduces due to a deficit in water intake, blood pressure will decrease. Low blood pressure should be avoided because it is associated with insufficient oxygen in the body. Arterial baroreceptors and voloreceptors, found in the atrium and great veins, detect any decrease in blood pressure which initiates vasoconstriction of renal arteries. Receptors in the kidneys detect the reduced blood volume which stimulates rennin release which increases the formation of angiotensin II (ANG II) in the circulatory system. The angiotensin triggers aldosterone secretion which acts on the blood vessels to increase vasoconstriction which increases blood pressure. Moreover, ANG II stimulates the pituitary which increases ADH secretion. ADH causes thirst which encourages water consumption and directs the kidney to conserve water. Consequently, blood volume increases, ECF osmolality decreases and homeostasis is restored (Seeley, 2011; Silverthorn, 2010).



Note: ADH =antidiuretic hormone; ANGII = Angiotensin II

Figure 1.2. Regulation of Water Balance and Osmolality (adapted from Seeley, 2011; Silverthorn, 2010)

To prevent over-drinking, as fluid is consumed the sensation of thirst is thought to be reduced by sensory neurons relaying the message to the hypothalamus that the throat is now wet, after having previously been dry. The hypothalamus is also sent a message from stretch receptors in the digestive tract which are stretched as water increases the volume. The hypothalamus decreases the thirst sensation and inhibits ADH secretion (Seeley, 2011; Silverthorn, 2010). Thus, the body has many regulatory mechanisms that work together to prevent dehydration and maintain homeostasis.

1.3.5.7 Summary

This section has explained the structure of water and the function within the human body and the regulatory systems in place to help maintain water balance. It has discussed how concentration of body fluid is measured and described the different terms used. Additionally, the types of dehydration that occur have been explained and the consequences of not maintaining water balance have been discussed. This section has also identified that the type of dehydration discussed in this thesis will be intracellular hypertonic dehydration which occurs if not enough water is consumed.

1.4 Measuring Hydration

Measuring hydration status is a difficult operation as water balance is constantly fluctuating. Choosing one method of measuring hydration status is a contentious subject because all methods have limitations as well as advantages. Additionally, one gold standard method has yet to be identified that can measure hydration status in all individuals, over any time period, in any circumstances (Armstrong, Johnson, McKenzie & Munoz, 2013). Cheuvront, Ely, Kenefick and Sawka (2010) suggest that because any one marker of dehydration is not reliable at least two different methods are needed to ascertain if dehydration is present. Measuring hydration status is one of the objectives of this thesis and so finding a practical and reliable method is important. This section will discuss the reliability and accuracy of different methods of measuring hydration status. The type of methods to be used will be identified and a rationale given for choosing them.

1.4.1 Measuring Dehydration by Loss of Body Weight

The majority of studies that have assessed the effects of dehydration on the cognitive performance and mood of adults have used body weight (BW) changes as the method of choice. If using body weight changes as a measure of hydration it is essential that normal body weight can be ascertained, before any losses due to urinating and sweating or gains due to fluid consumption are measured. Using body weight changes as the method of measuring dehydration during a study may be problematic because; the participant must not eat or defecate during testing, it is unknown as to whether fluid has been assimilated or is in the stomach and it may be difficult to establish a measurement of hydration at baseline.

An advantage of using body weight loss as a method of assessing dehydration is that the method is easy and cheap. However, there are no globally accepted body weight loss categorisations of levels of dehydration. The US National Institutes of Health (NIH, 2002) define mild dehydration as a loss of 3-5 % of normal body weight (Howard & Bartram, 2003), while Kleiner (1999) argues that a person who loses 1-2 % of body weight due to fluid deficits is mildly dehydrated, and losses greater than 1-2 % is indicative of severe dehydration. In contrast, the US NIH do not class dehydration as severe until 9-15 % of normal body weight is lost. Body weight loss is not a suitable method of assessing hydration status in this PhD because children may be arriving at school in a dehydrated state, making it impossible to determine baseline euhydrated body weight, before further changes in hydration status take place.

1.4.2 Total Body Water

Dehydration can also be measured by assessing the volume of water within the body (Total Body Water) divided by fat free mass (FFM). Total Body Water (TBW) is estimated by the participant swallowing a tracer, such as deuterium oxide, and then analysing the concentration of the tracer in a sample of the participant's body fluid. The percentage of body mass constituted from water is dependent on the amount of fat in the body (Boyle & Senior, 2002). Fat body mass will typically consist of approximately 10 % water compared to approximately 73 % in lean body mass (Sawka, Cheuvront, & Carter Iii, 2005). Consequently, females tend to have a lower percentage of body mass constituted from water than men as they have a higher percentage of body fat (EFSA, 2010). X-ray absorptiometry indicates what percentage of the body is composed of fat, lean body tissue and bone and hydration levels are calculated by dividing TBW by FFM (Ogle et al., 1995).

However, this method of dehydration measurement is insensitive (Raman et al., 2004). Errors consistently occur in body composition calculations if there are fluid balance changes (Pietrobelli, Wang, Formica, & Heymsfield, 1998), and because measurements take 3 to 5 hours to collect and analyse, fluid volume changes are likely, thus impeding hydration status calculations. Therefore, this method is impractical and inaccurate (Armstrong, 2007).

A more common method of measuring TBW and FFM is by electrical bio-impedance. An electrical current is run through the body and the resistance presented by the body tissues and water is measured (Thomas, Ward, & Cornish, 1998). This method also has disadvantages because it assumes that the body has a uniform density (Armstrong, 2005), which is not the case. Additionally, changes in posture, plasma osmolarity and plasma sodium concentration, exercise, skin temperature, skin blood flow, recent fluid ingestion and composition of ingested fluids can make the results unreliable and inaccurate. Further difficulties can be encountered in positioning the electrodes correctly (Armstrong, 2005) although some bio-impedance machines embed the electrodes into handles and the foot plate of a machine on which patients stand and hold the handles. Both devices have been criticised for being sensitive to individual errors when measuring small changes in TBW and body composition (Jensky-Squires et al., 2008). Thus, measuring changes in TBW as a measure of hydration changes will not be considered for this PhD because it would not be sufficiently sensitive to detect the subtle changes in hydration status.

1.4.3 Physical Signs

Despite some physical symptoms occurring as a result of dehydration, these symptoms cannot be used to reliably indicate hydration status. This is because symptoms suggestive of dehydration could also be caused by other factors, for example, headaches may be caused by stress (Nash & Thebarge, 2006) and rapid respiration may be a result of suffering from a fever (Altschule, Freedberg, & McManus, 1945).

1.4.4 Thirst

The sensation of thirst has been considered a proxy measure of dehydration because it is a key component in the mechanism for maintaining homeostasis. Indeed, Rogers, Kainth and Smit (2001) stated that perceived thirst was a good proxy measure of hydration status in their study of adults. Furthermore, other studies found that levels of self-rated thirst were significantly reduced in participants that had a drink and increased in participants that did not have a drink, suggesting that self-rated thirst is associated with fluid intake and thus hydration status (Edmonds & Jeffes, 2009; Edmonds & Burford, 2009). MacGregor (2014) argues that to maintain water balance the volume and frequency of fluid drank should be dependent on the thirst sensation. However, other research suggests that self-rated thirst is not a reliable proxy of hydration status as the thirst sensation is not felt until a person is already dehydrated (Baylis & Robertson, 1980) and once a person starts to drink, the thirst sensation ceases before the fluid deficit is replaced (Kavouras, 2012). Furthermore, it has been argued that humans are now dishabituated to the sensation of thirst (Thornton, 2012). However, as the subjective thirst sensation is quick and easy to measure and has been used previously in similar research studies (Edmonds & Burford, 2009; Rogers et al., 2001) self-rated thirst scores will be collected , but alongside other methods of determining hydration status. A primary aim of this thesis will be to test whether self-rated thirst scores are associated with fluid drank and biomarkers of hydration to determine whether it is a viable method of measuring hydration status in children.

1.4.5 Osmolality

Another possible method of assessing hydration status is to measure osmolality, which is a component of the water regulation mechanism. Osmolality is measured using an osmometer. An osmometer compares the freezing point depression of pure water (which is known to be 0ºC) to the solution being analysed. Adding solutes to a solution decreases the temperature at which the solution freezes, thus the more concentrated the solution the lower the freezing point, so a measure of osmotic concentration can be determined. Osmolality of plasma, urine and saliva can all be measured and reference values are available for these (Armstrong et al., 2010; Armstrong, 2012). However, population based reference values have been shown to be unreliable (Cheuvront et al., 2010) and scores from a biological marker can vary largely within one individual (intra-individual) without any known physiological cause or variable (Harris, 1974). Reference values, therefore, need to have a range of values that take into consideration both the intraindividual variation and the variation within the population (interindividual).

1.4.6 Plasma Osmolality

Plasma osmolality is considered by some to be the most reliable measurement of hydration (Cheuvront et al., 2010; Moran, Heled, Yanovitch, Margaliot, & Shapiro, 2003; Oppliger, Magnes, Popowski, & Gisolfi). A study, in which measures of plasma osmolality (Posm) were taken from 18 individuals over 3 days, showed that the range in which participants were euhydrated was relatively small and so a reference value range of 275-295 Posm (mmol/kg) would be applicable to 95 % of a healthy, adult population (Cheuvront et al., 2010).

Similarly, when measures of Posm from participants who were euhydrated on Day 1 then dehydrated on Day 2 were compared (dynamic assessment) the results showed that a reading of 301 Posm (mmol/kg) or above would indicate dehydration in 95 % of the population. Therefore, a static reading from one individual when compared to a reference range could potentially indicate whether that individual was dehydrated. However, a reading of 296-300 Posm (mmol/kg) would be problematic as hydration status could not be determined (Cheuvront et al., 2010). Additionally, Francesconi et al. (1987) reported that changes in Posm do not occur until a certain threshold of dehydration has occurred. Indeed, in a study by Perrier et al., (2012) no differences were observed in Posm between drinkers who habitually drank a high volume compared to those who drank a low volume and were likely to be chronically dehydrated. It was argued that physiological adaptations maintain a stable Posm during fluctuations of water output and intake, suggesting that severe changes in water balance would need to happen before changes in Posm occurred. Furthermore, Bohnen, Terwel, Markerink, Ten Haaf & Jolles (1992) argue that results are only reliable if samples are analysed immediately without being left at room temperature or frozen for storage. Thus the superiority of plasma as a source of hydration status has been questioned.

Measurement of plasma osmolality to determine hydration status was not considered because it was expected that participants would only be mildly dehydrated and that fluctuations in water balance would be relatively small. Additionally, the participants in the studies reported here were children and collecting samples was assessed as being too invasive for large samples of children to be recruited. Furthermore, collecting and analysing such samples would be too labour intensive, particularly when more appropriate methods are available.

1.4.7 Saliva Parameters

Saliva osmolality is easy and cheap to collect and non-invasive. A study by Walsh, Montague, Callow, & Rowlands (2004) showed that changes in saliva osmolality correlated highly with body weight changes, total protein concentration and salivary flow in adults during dehydration. Additionally, saliva osmolality has been used as a measure of dehydration in children (Santos et al., 2010), but there has been no validation of this measure in this population.

Moreover, collection and measurement of saliva has some limitations. Results may be invalidated if food, chewing gum or tobacco has been in the mouth immediately before testing (Cheuvront et al., 2010) and there are large intraindividual variations in saliva osmolality. Cheuvront et al., (2010) dismissed saliva osmolality as a useful marker of either static or dynamic dehydration assessment and a review by Baron et al. (2015) states that saliva osmolality is the least sensitive biomarker of hydration status. Furthermore, only a limited amount of research has investigated the validity of saliva osmolality or protein concentration. In view of these limitations saliva osmolality was dismissed as a method of assessing hydration status.

Saliva flow rates can also be measured to assess hydration status. During periods of dehydration saliva flow rates have shown to reduce (Walsh et al., 2004). However, there is some suggestion that it is not very sensitive to rehydration (Baron et al., 2015) thus it was deemed unsuitable for this PhD, as rehydration is an important part of the study design.

1.4.8 Urine Parameters

There are three different parameters of urine that can be used to measure dehydration. Urine osmolality (Uosm), urine colour (Ucol) and urine specific gravity (Usg) will all be discussed and the advantages and limitations presented. Uosm is a measure of how much water is being excreted by the kidneys (Silverthorn, 2010). When the body is in a state of hyperhydration the kidneys help to get rid of excess water by producing more urine which has a lower osmolarity (a minimum of 50 mOsm/kg). When the body is in a state of dehydration and needs to conserve water the kidneys produce less urine and it has a higher osmolality (a maximum of 1200 mOsm/kg). Some limitations of using Uosm as a biomarker of hydration status have been reported. Jequier and Constant (2010) noted that a large volume of water may be drank and excreted as dilute urine by the kidneys, which would lead to a low Uosm reading, while dehydration could still be present. Additionally, a study by Cheuvront et al. (2010) found that intraindividual variability in Uosm was large. Conversely, Armstrong et al. (1998) argues that Uosm is as effective a measure as plasma osmolality (Posm). In a study of 9 males who underwent a dynamic assessment over a 42-hour period, during which they lost a mean of 5.2 % body mass in water and then rehydrated gradually, Uosm, Ucol and urine Usg correlated strongly with body mass loss, more so than Posm. Additionally, in a study by Perrier et al., (2012) Uosm, Usg and Ucol measures tracked well with changes in fluid intake, whereas Posm remained stable despite fluctuations in water balance.

Uosm was chosen as the biomarker of hydration status for this PhD for a number of reasons. Firstly, urine samples are relatively easy and quick to collect which is imperative when collecting data in a school environment. Urine collection is non-invasive and older children are able to collect the samples independently and a clinical setting is not required.

Secondly, there is a precedent in the literature for the use of Uosm in children. Previous studies (Bar-David, Urkin, & Kozminsky, 2005; Fadda et al., 2012) have investigated the effects of water consumption and voluntary dehydration on cognitive performance in children and have used Uosm as the measure of hydration status. Additionally, there have also been a number of studies that have investigated the mean Uosm reading of children as they arrive at school (Barker et al., 2012; Bonnet et al., 2012; Stookey, Brass, Holliday, & Arieff, 2012), thus, it would be possible to determine whether the children used in the current study had an average morning Uosm measure similar to other children of the same age.

Thirdly, the threshold for dehydration for measures of Uosm is consistently defined in the literature as being a reading of Uosm 800 mOsm/kg or above, whilst euhydration is defined as a measure of Uosm below 800 mOsm/kg. Consequently, it would be easy to define children in this thesis as either hydrated or dehydrated and these labels would be consistent with the literature.

Fourth, a review by Baron et al. (2015) recommended urine osmolality as the hydration measure of choice for detecting small changes in hydration status. In this thesis participants will only be subtly changing their hydration status over a short period of time, thus urine osmolality is the most appropriate measure.

In line with Cheuvront et al.’s (2010) suggestion that two or more methods of measuring hydration status are used, the third method for measuring hydration status was analysis of Ucol. Ucol is assessed by comparing a sample to a urine colour chart (Armstrong, 2005), with a higher score representing a darker urine colour and indicating a higher concentration of urine, and thus dehydration. This method has the advantage of being quick and easy to administer, it is also cheap and non-invasive. Previous research literature has found that Ucol is effective in tracking changes to hydration following fluid intake and is as sensitive as Uosm and Usg (Armstrong, 2005; Perrier et al., 2012). However, results may be affected by diet or unreliable if large amounts of fluid have recently been consumed (Jequier & Constant, 2010).

Urine specific gravity (Usg) can also be used as a measure of dehydration. Urine specific gravity is a measure of the density of urine compared to pure water which is assessed using a refractometer. Oppliger et al. (2005) reported that Usg was marginally superior to Uosm although other literature suggests they are fairly equal in their measurement of hydration status (Armstrong, 2005: Cheuvront et al., 2010). Conversely, Francesconi et al. (1987) suggests that density of the urine increases when the body is concentrating urine with the purpose of preventing dehydration. Therefore, it is unable to be determined if the Usg measure may be reflecting impending dehydration or the prevention of dehydration or actual dehydration. Usg was considered as a plausible method of measuring hydration status but urine osmolality seemed to be the most appropriate biomarker for this thesis.

1.4.9 Summary of Rationale for Choice of Hydration Measurement

Thirst rating was identified as a method to be used in this thesis because it has been used in studies of the effects of water consumption previously (Rogers et al., 2001) and is quick and easy to collect. It is also a key component in the mechanism for maintaining water balance. Ucol was also chosen because of the ease of collection and rating urine colour is quick and simple to administer. However, both these measures are subjective and it was felt necessary to add an objective measure. Analysis of Uosm was deemed the most appropriate method because it has been used in previous studies that have measured the effects of dehydration on cognition. Additionally, a recent review of dehydration methods (Baron et al., 2015) recommended that Uosm was the best option for measuring small changes in hydration levels. Cheuvront et al. (2010) suggest that using two or more methods of dehydration analysis is necessary and it was considered that having three different methods of comparison was ample. Additionally, the volume of fluid to be drank during each experiment was recorded thus giving a measure of water input.

1.5 Fluid Intake

Thus far, this chapter has discussed the necessity for maintaining euhydration, the dangers of drinking too much or too little, and methods for measuring hydration status. Fluid requirement and intake, including the estimated water intake of different populations will now be explored and the recommendations for daily water consumption.

1.5.1 Fluid Requirement

Different agencies give different recommendations about the appropriate amounts of fluid to be consumed daily. They also use different reference values, for example, the Food Standards Agency (FSA) advises on how much fluid to consume in drinks only whereas the European Food Safety Authority (EFSA) recommends a volume of water to be consumed in food and beverages. Table

1.1 shows the guidelines for different populations from the different organisations.

The World Health Organisation (Howard & Bartram, 2003) give a range of intake requirements, targeted at different age ranges but also for populations living in different climates and participating in different activity levels. The World Health Organisation (WHO) also make it clear that that this wide range of intakes takes into consideration that some people will not be consuming water within food due to food shortages and thus there may be some over-estimation for those obtaining fluid from food. For people in average temperatures participating in moderate activity 2.2 Litres per day (L/d) for women and 2.9L/d for men is adequate. For those living in a hot climate and partaking in high levels of activity a volume of 4.5L/d is recommended.

The Food Standards Agency (FSA) also recommend a fluid intake but instead of the 2-4.5L recommended by The WHO they recommend that "an apparently healthy individual adult, with an average diet and average daily activity" (Food Standards Agency, 2010, para 8) drinks 1.2L per day which amounts to 6 to 8 glasses of fluid per day. However, average diet and average daily activity are not quantified. Furthermore, the proportion of the population that meet the FSA's criterion as an "apparently healthy individual adult, with an average diet and average daily activity" is unknown and thus the recommendations maybe valid for a limited number of people. Additionally, evidence suggests that the public are confused about whether the 6 to 8 glasses of water per day is in addition to the beverages and food normally consumed, or whether it includes non-water drinks such as tea and soft drinks

(Lunn & Foxen, 2008). To clarify, the recommended 6-8 glasses a day includes other beverages such as tea and coffee.

Table 1.1
Daily Water Intake Recommendations by Age Group from EFSA, FSA, WHO and IOM

	mL per day EFSA(2010) [1] Adequate Intake	mL per day FSA [2] Daily recommended amount of drinking water	mL per day WHO (2003) [3] Volume of water required for hydration	mL per day IOM (2004) [4] Adequate Intake
0-6 months (recommendations based on observed daily milk intake)	100-190			700
6-12mths	800-1000			800
1-2 years	1100 – 1200		1000 per 10 kg body weight	1300
2-3 years	1300		1000 per 10 kg body weight	1300
Children 4-8 years	1,600			1700
Boys 9-13 years	2,100			2400
Girls 9-13 years	1,900			2100
Adult females	2000		2200	2700
Adult males	2500		2900	3700
Adults		1200		

Note: Adequate Intake is the median amount of water consumed from beverages and food moisture in a healthy group.
Data sourced from EFSA(2010);FSA(2010), (Howard & Bartram, 2003), National Academies Press (2004).

1. The European Food Safety Authority
2. Food Standards Agency
3. World Health Organisation
4. Institute of Medicine of the National Academies, Washington DC

The European Food Safety Authority (EFSA, 2010) and Institute of Medical Academies (IOM, 2004) do not recommend a standard amount of water to be drank daily. Instead EFSA and IOM only give a recommended Adequate Intake (AI). AI is a measure of daily water consumption in both food and beverages. EFSA calculated AI by using data from European studies in which the participants were healthy individuals who 'consumed average diets and partook in moderate levels of physical activity' (EFSA, 2010 pg37) and had acceptable levels of urine osmolality. AI is problematic because there are large individual differences in daily water consumption from food and drink (Sichert-Hellert, Kersting, & Manz, 2001) because of variables such as: ambient temperature; physical activity; weight; body fat; age; gender; personal preference and some conditions and illnesses such as diabetes mellitus, cystic fibrosis and diarrhoea. Furthermore, people may have difficulty in quantifying how much fluid they consume in food. A more detailed discussion about AI can be read in Chapter 8.

In summary, the current recommendations of fluid intake are different depending on the recommending organisation and confusing. There can be no one recommended amount as individual differences, diet and environment vary.

1.5.2 Fluid Consumption

Having discussed the recommendations for fluid intake, the volumes of fluid consumption in different populations will now be considered. It is difficult to make cross-study comparisons when considering the volume of water consumed because of the different methods of measurement employed. Some studies measure water intake as water in drinks and beverages, while others measure preformed water in the diet; preformed water is the water within both beverages and food moisture. Another measure, total water intake is sometimes measured which is water in drinks, food moisture and water produced during oxidation.

1.5.2.1 Fluid Moisture in Food

As preformed water and total water intake are dependent on how much water is consumed from food, it is important to have an understanding of the different levels of water content in different food types. Table 1.2 shows the proportion of water in different foods. Cow's milk contains 90 % water, fruit and vegetables contain 70-80 % (EFSA 2010), bread and cereal contain less than 40 % water whilst products such as confectionery and snacks less than 10 % (Grandjean, Campbell & Institute, 2004). The European Food Safety Authority (EFSA, 2010) report that in the majority of diets only 20 % of the water input required is consumed in food with the remaining 80 % of water being consumed in drinks and beverages. However, there is a wide variety in this figure due to individual and cultural differences in diet and drinking behaviour. For example, Sichert-Hellert et al. (2001) report that German children between the ages of 2 - 13 years old consumed 33-38 % of their total water intake from food.

Table 1.2
Percentage of water in food.

Water Content In Food and Drink	Food and Drinks
85-100 %	Non Alcoholic Beverages
60-85 %	Fruit and vegetables
	Yoghurt
	Fish and Seafood
	Eggs
	Rice and pasta
	Casseroles, pasta and meat dishes
40-60 %	Ice-cream
	Pizza
	Meat
	Cheese
	Bread and Biscuits
1-10 %	Snacks , popcorn, crisps, ready to eat breakfast cereals, seeds and nuts

1.5.2.2 Types of Beverages Consumed

There is also considerable cultural variation in the type of beverages consumed. Social customs play an important role in how much, when and what is drank (Greenleaf, 1992) as well as individual differences in diet, age, changes in fashion or trends and level of education (Kant, Graubard & Atchison). For example, the volume of water drank in the western world has increased exponentially, following the successful marketing campaign of the bottled water companies (BBC, 2010). In America in 2001 no more than 16-19 % of all beverages were consumed as water, (Sichert-Hellert et al., 2001), whereas between 2007 and 2008 this had increased substantially with 25 to 30 % of fluid obtained in the diet coming from tap and bottled water. In contrast, in France, water was 50 % of all drinks consumed and the other 50 % consisted of beverages such as soda, dairy, alcohol, tea and coffee. The type of beverage most often drank in France, other than water, was dependent on the age group of the consumers. Bellisle, Thornton, Hebel, Denizeau and Tahiri (2010) reported that, in France, drinks were mostly consumed with meals, which is consistent with the view that eating is a stimulus for drinking (Benelam & Wyness, 2010). Conversely, in the UK only 30 % of drinks were consumed with meals (Vergne, 2012).

It should be noted that drinking beverages other than water can have negative consequences (Kant et al., 2009). Some beverages contain extra calories which have implications for weight gain and sugar may have negative dental effects (Marshall et al., 2003). Other substances found in drinks other than water include caffeine and alcohol, which have diuretic properties (Benelam & Wyness, 2010).

1.5.2.3 Estimates of Actual Water Intake in Adults

Recommendations of fluid consumption by various agencies will now be compared with actual fluid intake of different populations. Research by Gandy (2012) reported that the mean intake of fluid in the UK that came from just beverages (and not including food), was 2.36 litres per day (L/d) for women and 2.25 L/d for men and that between 25 % and 35 % of adults were not achieving the AI recommended by EFSA. In contrast, a survey in France reported that adults drank an average of 1.3 L/d (Bellisle et al., 2010). Lower still, adults in Hungary were only consuming 0.72 L/d in beverages in 2003 and 2004. Further abroad, in 2010, adults in Japan were drinking 1.5 L/d and in Indonesia, where the climate is tropical with high humidity, and people will tend to sweat more than in temperate climates, adults were drinking 1.84 L/d (Vergne, 2012). Thus, the volumes for all countries other than Hungary did exceed the FSA recommendations, of 1.2 L/d. However, even when AI was reduced by 20 % to account for fluid intake in food, volumes of fluid actually consumed were less than the AI recommended by EFSA (2010) and IOM (2004) and the volume required for hydration according to WHO guidelines (Howard & Bartram, 2003). Furthermore, the WHO (cited in Howard & Bartram) suggest that almost 18 % of the world's population are likely to be drinking less than an adequate intake because they do not have access to a clean water supply within 1 kilometre of their home. A problem with studies of water intake is that they report the mean intake of the sample tested, while there may be extreme variation in the water intake of individuals within a population. In the National Diet and Nutrition Survey (1999-2002) in the USA the difference between the amount of total water intake between the 5^{th} and 95^{th} percentile of the range of intakes was 4.2 L/d in men and 3.7 L/d in women (Fulgoni III, 2007). This represents a substantial individual difference in water intake and suggests that mean measures of water intake for a population may be misleading.

1.5.2.4 Estimates of Actual Water Intake in Children

Young children may be at particular risk of drinking insufficient fluid. They are dependent on others to supply them with drinks rather than being able to help themselves when thirsty and they may be less likely to drink adequate fluid in response to thirst (Kenney and Chiu, 2001). Results from a large global survey of fluid intake in children supports the notion that some children drink insufficient fluid (Iglesia et al., 2015). The survey, which was undertaken between 2009 and 2014, included data from 11,720 children between the ages of 3 and 18 years from 13 countries in Europe, Asia and Latin America. Children or caregivers recorded all beverages that the children drank over a period of seven days. There was a large variation in volume drank between countries, for example females between the ages of 4 and 9 years old in Uruguay drank a mean volume of 2.47 L/d whereas in Belgium females in the same age group drank 0.73 L/d. In the UK children between the ages of 4 and 9 years old were drinking 1.56 L/d and children aged 10 to 18 years old were drinking 1.67 L/d.

The percentage of children not adhering to EFSA AI guidelines was high. EFSA AI recommendations includes fluid intake from food and drinks, but as this survey only measured the intake of fluid in drinks the EFSA AI recommendations were reduced by 20 % to account for fluid intake in food. Consequently, a comparison could be made between actual fluid intake in the children in this survey and EFSA guidelines. Thus, in some countries where a volume of fluid higher than 20 % is consumed in food these comparisons of fluid intake from beverages and EFSA AI minus 20 % will be inaccurate. In the UK, the percentage of 4 to 8 year olds not adhering to EFSA AI was 30 % for males and 40 % for females. In the 9 to 18 year old category approximately 55 % of the children sampled did not adhere to the recommendations in the guidelines. The survey found no country or age group that had a 0 % of non-adherence but Uruguay had the lowest proportion with only 10 to 20 % not adhering whilst in Belgium over 90 % of the children did not adhere to EFSA AI guidelines Additionally, another survey showed that in Europe 10 % of children drank no water at all, as part of their fluid intake, but consumed all of their fluids in other beverages such as sweetened drinks, thus consuming a large amount of energy along with the fluid (Gandy, 2012).

To assess whether UK children drink sufficient fluids within a school day Kaushik, Mullee, Bryant and Hill (2007) used the Expected Fluid Intake (EFI). The EFI for a child spending 6 hours at school was calculated by using bodyweight and a recommended fluid intake (source unnamed). Kaushik et al., (2007) calculated the fluid intake of 298 children, aged 6-7 and 9-10 years from six different primary schools in UK schools by recording fluid consumption. Only 29 % of the children consumed the minimum EFI or above. Importantly, children who attended schools in which they were allowed free access to water (water on their desk) consumed much more water when compared with children who attended schools in which access to water in the classroom was banned or restricted. Only 46.5 % of children in free access classes drank less than the minimum EFI compared to 81 % and 80 % of those who had prohibited and limited access to water. The government guidelines have recently changed from schools having to provide a supply of drinking water (Statutory Instruments, 2007) to ensuring that it must be provided at all times (Dept. of Education, 2014). However, these guidelines are still vague and are open to interpretation as to whether that is at the child' request or always available in the classroom.

1.5.2.5 Summary

This section has discussed the different measures of fluid intake, the current recommendations for fluid intake from various regulatory bodies and the difficulties associated with this concept. Estimates of water intake in both adults and children were explored illustrating the wide variations in water intakes due to individual differences in drinking behaviour. Variables which can affect drinking behaviour such as ambient temperature, illness, diet, culture and school rules were also discussed.

1.5.3 Prevalence of Dehydration

The section above has discussed the water intake in children and adults. However, levels of hydration cannot be determined even if preformed water (water intake from food and drink) is accurately measured, because other factors such as environmental heat and activities also affect hydration status. A biological marker of hydration is required, in addition to volume of water drank, in order to determine whether the volume of fluid drank is adequate to maintain euhydration. The next sections discuss the prevalence of dehydration in adults, as well as samples who may be more susceptible to dehydration for physiological, psychological and social reasons, such as older adults and children.

1.5.3.1 Dehydration in Adults

In the Cooperative Study: Nutrition Survey and Risk Factor Analysis, the mean fluid intake from beverages for males was 2.2 L/d and for females was 1.9 L/d, which was above the FSA recommendations. Rather surprisingly, despite water intake exceeding FSA recommendations, 39 % of men and 20 % of women were found to be inadequately hydrated (Manz & Wentz, 2005) when urine osmolality was measured (a mean reading of higher than 830 mOsm/kg within a 24 hour collection). The Cooperative Study showed, that even though a sample may be consuming above the recommended amounts, there is evidence of dehydration in a large percentage of the sample. These statistics are consistent with a UK study that showed that 37 % of 52 adult gym members had a urine osmolality reading higher than 900 mOsmol/kg upon arrival at the gym (Peacock,Thompson and Stokes, 2011). These results suggest that a large proportion of the general public may be dehydrated, even those who might be expected to be particularly concerned with their health.

1.5.3.2 Dehydration in Older Adults

Studies of naturally occurring dehydration in older adults report that a large proportion is dehydrated (Bossingham, Carnell, & Campbell, 2005). Older adults, particularly females, may be more likely to deliberately drink less in order to prevent the likelihood of incontinence (Mentes, 2006). Furthermore, older adults are more likely to be dependent on others to provide drinks because of reduced mobility, problems with eyesight, cognitive deficits and a higher likelihood of taking medications such as sedatives (Jéquier & Constant, 2010). Older people are also less aware of feeling thirsty (Kenney & Chiu, 2001) and as fat free mass reduces with age, there is less storage space for fluid leading to a higher likelihood of dehydration (Benelam & Wyness, 2010). Additionally, the kidneys are less efficient and consequently are less able to concentrate urine, leading to a greater water loss (Lindeman, Tobin, & Shock, 1985). A study by Wotton (2008) reported that between 52-90 % of a sample of institutionalised elderly had an inadequate fluid intake to maintain euhydration.

1.5.3.3 Dehydration in Children

Children are another group that is more likely to suffer from dehydration than adults. This is for a number of reasons. A higher proportion of children's body weight is composed of water, requiring a higher volume of water intake to maintain homeostasis (Benelam & Wyness, 2010). They have a higher respiratory rate, which increases the amount of water lost through evaporation from the respiratory tract. Their bodies are less able to concentrate urine because their renal function is immature (Gorelick, 1997), so they will lose more water in their urine than adults. Further, they have a higher surface area to body mass ratio, which may mean that they are likely to lose more body fluid in sweat, although children have a lower rate of sweating than adults (Bar-Or, 1989). A lower sweating rate may mean children find it harder to maintain a constant body temperature as they are unable to lose heat through sweating. However, some have suggested that children can lose a higher amount of body heat through dry heat loss because children have a higher skin to surface ratio than adults through which heat can dissipate into the surrounding air (Popkin et al., 2010). Children are dependent on others to provide drinks, are less likely to recognize thirst and have a lack of recognition as to when they should replace fluids (Bar-Or, Dotan, Inbar, Rothstein, & Zonder, 1978; Box & Landman, 1994; Kenney & Chiu, 2001)**.** All these factors combine to make children at risk of dehydration and a particularly relevant group to study .

There is evidence from formal assessment of hydration status that children are likely to be dehydrated. In the UK, a study of 452 primary children in Yorkshire reported that 60 % arrived at school dehydrated (defined as having a Uosm higher than 800 mOsm/kg)**.** Studies of children in Israel have shown that 67.5 % of 8-10 year olds (Bar-David, Urkin, Landau, Bar-David & Pilpel, 2009) and 55 % of 10 – 12 year olds (Bar-David et al., 2005) were moderately to severely dehydrated on arrival at school. In Sicily, Fadda et al., (2012) reported that 84 % of children were dehydrated at the start of the school day and in the USA between 63-66 % of children arrived at school in a state of dehydration (Stookey et al., 2012). Thus it is likely that a large proportion of children arrive at school every day in a dehydrated state.

1.5.3.4 Summary

In this section the literature measuring dehydration in adults, older adults and children was discussed. The results suggest that a large percentage of all populations may be dehydrated on a daily basis, but that children are particularly susceptible to dehydration. The percentage of children who are dehydrated is of particular interest and the implications of these findings are that a large proportion of children may be able to improve their performance at school if they have a drink of water.

1.6 Chapter 1 Summary

This chapter has discussed the fundamental role of water in the human body by describing the role of water within the body's processes and systems. The processes of maintaining water balance and the consequences of not doing so have been discussed. The literature investigating water intake in various populations and the prevalence of dehydration has been reported. Additionally, methods of measuring hydration status have been explored and a rationale given for choosing urine osmolality, urine colour and self-rated thirst as the methods of measuring hydration status . Having established that children are at particular risk for dehydration, and presented a rationale for the methods used to assess dehydration, the next chapter reviews the current literature on the effects of dehydration and water consumption on the cognitive performance and mood of adults and children.

CHAPTER 2

Literature Review

2.1 Introduction

This chapter reviews the research into the effects of hydration on motor skills, cognitive performance and mood. Papers from both the water consumption and dehydration literature in children and adults are discussed and the sections are formatted so that each cognitive domain is considered in turn. Literature on the effect of hydration on moods is then reviewed and methodological issues which may have affected results are discussed. This chapter then turns to theories that attempt to explain how dehydration may cause changes in cognitive performance and mood. Lastly, the rationale and aims of this PhD are presented.

2.2 The Effects of Hydration on Cognitive Performance

This section will focus on the effects of water consumption and dehydration on healthy young men, women and children. In the studies on adults that are reported below, dehydration was deliberately induced by the use of exercise, heat, water deprivation or diuretic drugs (see Table 2.1 for details of each dehydration method for each study). The implications of using these methods to dehydrate participants are discussed in section 2.5.1. The measure of dehydration used was generally the percentage of body weight loss due to fluid loss. Studies on the effects of dehydration in cognitive performance of children differ from the adult studies because in adults dehydration is generally deliberately induced. In comparison, the children were naturally dehydrated at the time that they took part in the studies as a consequence of consuming insufficient fluid: this state is termed voluntary dehydration. There are only two studies published on the effect of dehydration on cognitive performance in children (Bar-David et al., 2005; Fadda et al., 2012).

Alongside this literature on the effects of dehydration, there is a growing body of literature on the effects of water consumption on children and adults (Edmonds & Jeffes, 2009; Edmonds, Crombie & Gardner, 2013). In these studies participants are given a bottle of water to drink and a comparison made with those who have not been given a drink. The literature will now be reviewed by discussing how hydration has had an effect on each cognitive domain.

2.2.1 Psychomotor Performance

There is much literature to support the argument that water consumption improves sporting performance (Shirreffs, 2005) and that gross motor performance is sensitive to levels of hydration. However, as this thesis is focused on the effects of water consumption on children in a classroom, rather than athletes, the focus is on fine motor skills. To date, only one paper has studied the effect of dehydration specifically on fine motor performance. Montain and Thurion's (2010) study investigated the effect of dehydration in adults on thumb contractions. In this study 14 adults took part in two conditions, spaced one week apart. In both conditions, before the thumb contraction test, the participants performed exercise for 3 hours and were exposed to heat. In the drink condition the participants replaced lost fluid during the exercise and in the no drink condition participants were not supplemented with fluid. The results showed that there was no difference in performance when participants were dehydrated compared to when they were euhydrated, but dehydrated participants felt more fatigued when the exercise was completed, perhaps suggesting that they expended more effort.

Most of the research investigating the effects of hydration on fine motor skills have used tasks which also require cognitive skills, and the results from these studies are inconsistent. In Gopinathan, Pichan & Sharma's (1988) study 11 healthy young men exercised in heat and were deprived of water on four different occasions until they reached either 1 %, 2%, 3% and 4 % body weight loss. Participants completed a battery of tests (see Table 2 for details) at baseline and again when they reaching the allotted percentage of bodyweight loss on each occasion and after having rested until their heart rate returned to the pre-exercise rate. In the trail-making test, in which adults had to draw a line through consecutive numbers and letters, participants performed worse when in a dehydrated state than when euhydrated. Similarly, in another study (Sharma, Sridharan, Pichan, & Panwar, 1986) eight young male participants exercised in heat and either had lost fluid replaced (euhydration condition) or were deprived of fluid (dehydration condition) and completed a symbol substitution test, concentration test and psychomotor task. Performance in the psychomotor task, which consisted of moving a stylus along a groove, deteriorated under conditions of dehydration, but only when they lost more than 2 and 3 % bodyweight, and not at 1 % bodyweight. (Results from the other tasks can be seen in Table 2.1).

Table 2.1
Details of Dehydration Methods and Cognitive Tasks Used in Studies.

Authors	*n*=	Sample Age	Design	Dehydration Method	Cognitive Tasks	Difference in DH group compared to EU.
Adam et al. (2008)	8	Mean 24 y		Heat FR Heat FD	Scanning visual vigilance Sentry duty task	ns ns
Bar-David et al (2005)	51	10-12 y	Independent samples	EU - Uosm< 800 mOsm/kg DH – Uosm> 800 mOsm/kg	Hidden figures Auditory digit span Making groups Verbal analogies Number addition	ns reduced recall ns ns ns
Bradley & Higenbottam (2003)	7	unknown	Repeated-measures	Study 2 Exercise + heat Until 1, 3 or 5 % DH FR EU –FR	Multi-Attribute Task Battery consists of system monitoring, communications, tracking & resource management Sustained attention CRT Memory Recall Digit Symbol Substitution	Increased errors (tracking) Increased missing responses (system monitoring) ns Longer reaction time ns ns
				Study 3 DH – diuretic FD EC – diuretic FR EC – diuretic & sodium FR E - FR	Multi-Attribute Task Battery consists of system monitoring, communications, tracking & resource management Sustained attention CRT Memory Recall Digit Symbol Substitution	ns ns ns ns ns

Cian et al. (2000)	8	Mean 27.4 y	Repeated-measures	Phase 1 EU – passive, FR DH1 – heat FD DH2 – exercise FD HYP – glucose solution Phase 2 – arm cranking	Picture recall test CRT Perceptive Discrimination Task Digit Span Unstable Tracking Task	ns ns ns Phase 1. Reduced recall. HYP recalled more than EU. Phase 2 – ns Less tracking errors in EU and HYP in Phase 1 & 2
Cian et al. (2001)	7	Mean 25 y	Repeated-measures	Phase 1 EU – passive, FR DH1 – heat FD DH1 – heat FD DH2 – exercise FD DH2 – exercise FD Phase 2- glucose plus EU - 100 % FR DH1 -100 % FR DH1 – 100ml FR DH2 – 100% FR DH2 – 100 ml FR	Picture recall test CRT Perceptive Discrimination Task Digit Span Unstable Tracking Task	ns ns ns Phase 1 reduced recall Phase 2 ns ns
D'Anci et al (2009)	54	Mean 19.8Y	Independent samples	Exercise EU –FR DH-FD	Digit span SRT CRT Map planning Mathematical addition Vigilance Mental Rotation Task	increased recall ns ns ns ns increase in reaction time ns

Fadda et al (2012)	168	9-11y	Independent measures	Voluntary	Auditory digit span Verbal analogy Deux de Barrage Number Addition	Negative correlation between Uosm & score Positive correlation between Uosm & score ns ns
Ganio et al (2011)	26	Mean 20y	Repeated measures	Exercise EU-FR DH-diuretic FR DH-diuretic FD	Scanning Vigilance Psychomotor Vigilance (SRT) CRT Match to Sample Repeated Acquisition Test Grammatical Reasoning	False alarms Ns ns Increased response time ns ns
Gopinathan et al. (1988)	11	20-25 y	Repeated-measures	3hrs exercise + heat Until1,2,3 or 4 % DH	Word recognition test Serial addition test Trail-making task	More incorrect Deterioration <2% DH Speed decrease
Montain & Thurion(2010)	14	Mean 22 y	Repeated-measures	3hrs exercise + heat EU - FR DH - FD	Thumb Contractions	No change but felt more fatigued
Petri et al	10	Mean 25 y		24 hour FD	Battery	Slower
Sharma et al. (1986)	8	21-24 y	Repeated-measures	Exercise + heat EU –FR DH – FD	Symbol substitution test Concentration test Stylus/Groove test	Slower to complete Lower scores Worse at 2 & 3 %
Szinnai et al (2005)	16	Mean 26 y	Repeated-measures	DH -28h FD EU - FR	CRT Auditory serial addition task Stroop task Tracking task	ns ns ns ns
Tomporowski et al (2007)	11	Mean 26.5y	Repeated measures	Exercise FR FD	Brown-Peterson test Category Switching Test	ns Errors increased

Note: EU = Euhydrated; DH = Dehydrated; FR= Fluid Replacement; FD= Fluid Deprivation

Furthermore, another study which used heat and exercise to dehydrate participants found an effect of hydration status on tracking performance. Cian et al. (2000) found that when adults were euhydrated they performed better in an unstable tracking task than when they were dehydrated. In this study eight males participated in a repeated measures experiment in which they completed a baseline battery of tests which consisted of the unstable tracking task as well as a picture recall test, Choice Reaction Time task (CRT), perceptive discrimination task and a digit span (see Table 2.1 or results). The men participated in four conditions on four different occasions when they were: euhydrated by sitting passively for 2 hours and replaced lost fluid by drinking water; hyperhydrated by drinking a glycerol and water solution; dehydrated by sitting in a heated environment without fluid replacement or were dehydrated by exercising for 3 hours without fluid replacement. After a recovery phase, participants completed another battery of tests (test 1). At test 1 when the participants were euhydrated or hyperhydrated they had less tracking errors in the unstable tracking task than when they were dehydrated. After test 1, on every occasion the participants completed an arm pedalling exercise and after a recovery period completed another battery of test (test 2). The results for the unstable tracking task were consistent with the test 1 results.

Conversely, a similar study (Cian, Barraud, Melin, & Raphel, 2001) found no effect of dehydration on unstable tracking performance. In this repeated measures experiment, seven males participated in a control condition, and four dehydration conditions in which they were either exposed to heat on two coccasions or exercised on two occasions. An identical battery of tests to that used in Cian et al. (2000) was used. After test 1, in each condition, the participants were given a solution to drink that contained glucose and either 100% of the volume of water lost through dehydration or 100ml of water. Two hours after the intervention the participants completed the cognitive battery again (test 2), and again there were no differences between conditions for performance in the unstable tracking task.

When Bradley and Higenbottam (2003) induced dehydration in participants by getting them to exercise in a hot environment the tracking error scores increased in the Multi-Attribute Task Battery. However, when participants were dehydrated by use of a diuretic there were no differences between the dehydration and euhydration condition, in the same task. Bradley and Higenbottam (2003) carried out three separate studies, to investigate the effects of dehydration, and each had seven male participants who completed a battery of tasks (for details see Table 2.1). In study 2 (see section 2.5.1 for a description of study 1), the men completed a battery of tasks on four occasions, in which they carried out exercise in a hot environment until they lost either 1, 3 or 5 % in body weight or they remained euhydrated by replacing lost fluids. In the third study participants randomly completed the same tasks on four different occasions in four different condition which were: administration of a diuretic medication and water deprivation; administration of a diuretic medication and ad libitum water supplied; ad libitum water with no medication given and administration of the medication plus a sodium supplement; ad libitum water. Dehydration by water deprivation for 28 hours also had no effect on psychomotor performance, compared to when participants were not deprived of water (Szinnai et al., 2005).

The inconsistency in results suggests that the results may be unreliable due to limitations such as the small participant number and the difference in dehydration methods (see section 2.5). Furthermore, the tasks from the various studies measured performance in different ways. In the unstable tracking task, participants had to move a joystick to keep a cursor on a target on screen and the distance between the cursor and the target was measured. This is different to the measure adopted by Gopinathan et al. (1988), who measured motor performance in terms of speed. Thus, it may be that hydration affects the speed of motor performance rather than accuracy.

Some of the results from the literature examining water consumption in children and adults are consistent with the notion that motor speed is particularly sensitive to hydration. When adults completed cognitive tasks (see Table 2.2 for details of tasks) before and after a long-distance walking event and had their water and nutrient intake recorded, the results showed that participants who had a higher water intake performed faster on a trail-making task (Benefer, Corfe, Russell, Short, & Barker, 2013).

In children, those that had a drink got a better score, on a 'whack-a-mole' game on the Wii, than those that did not have a drink (Booth, Taylor & Edmonds, 2012). In this study, 15 children, aged between 8 and 9 years old, completed some tasks on two occasions. On one occasion they had no drink and on the other occasion they were supplemented with a 250ml bottle of water. In the Wii game the children had to move a handheld remote in a downward movement as quickly as possible whenever they saw a rabbit pop up. The score was a combination of speed and the number of rabbits hit. The game tested hand/eye coordination, motor speed, reaction time and speed of processing. Additionally, the children completed a letter cancellation task (see section 2.2.4 for task results), ball catching and some step- ups. There was no difference in the number of step-ups completed but children that drunk over 200ml of water had a better score in the ball catching task than those that did not have a drink.

However, when the effects of water consumption on speed and accuracy were assessed in children in a line drawing task , there were no differences found in performance between children that had a drink compared to those who did not (Edmonds & Burford, 2009; Edmonds & Jeffes, 2009). In Edmonds and Burford (2009) study, 58 children aged 7 to 9 years old were either given a 250ml bottle of water to drink or they were not. Twenty minutes after the drink the children completed a story memory task, a letter cancellation task, a spot the difference task and a line drawing task (see Table 2.2 for all task results) Similarly, in Edmonds and Jeffes (2009) study twenty three 6 to 7 year olds completed a letter cancellation, spot-the-difference and line drawing task. The design differed from Edmonds and Burford's (2009) study as it had a repeated measures design and the children were given 500ml to drink and completed the tasks 45 minutes after water consumption. In the line drawing task, the children had to draw a line between two parallel lines as accurately and quickly as possible. It is considered that the additional cognitive skills required to complete the line drawing task and the Whack-a-mole game may have contributed to the inconsistency in results in children. Research will attempt to isolate the motor component and determine whether hydration status has a differential effect on motor speed and accuracy in children.

Table 2.2

Details of Tasks Used and Volume Supplemented in Water Consumption Studies.

Authors	*n*=	Sample Age (years)	Design	Volume Supplemented	Testing	Cognitive Tasks	Performance Change
Benefer et al (2013)	35	Mean 43.2y	Independent samples	Mean 1,727ml Drank over 6.11hrs	Before & after walk mean 6.11 hrs	Simple Reaction Time Word recall Trail-making test	ns ns Higher water intake had faster performance.
Benton & Burgess (2009)	40	8-9 y	Independent measures	300ml	BL & 20-35 mins after intervention	Immediate object recall Delayed object recall Sustained attention	Drink condition performed better than no drink ns ns
Benton & Davis	22	Mean 9 y	Repeated measures	Nothing 200ml	Monitored for 30 mins after water	Classroom behaviour	More time on task when had a drink
Booth et al (2012)	15	8-9y	Repeat measures	250ml		Whack-A-Mole Letter Cancellation Ball catching Step-ups	Drink group better score Drink group higher score Drink group (over 200ml fluid) performed better than no drink ns
Edmonds & Burford (2009)	58	7-9y	Independent samples	250ml	20 minutes after intervention	Story memory task Letter Cancellation Spot-the-difference Line drawing	If drank <250ml did worse than drank >250ml Drink group higher score Drink group higher score ns
Edmonds et al (2013)	44	18-57y	Independent samples	200ml	BL & 20 & 40 mins after intervention	Digit span Reverse digit span Letter cancellation Simple Reaction Time	ns ns Drink group higher score ns

Edmonds, Crombie & Gardner (2013)	34	Mean 29y	Repeated measures	500ml	Not specified	Simple Reaction Time Choice Reaction Time Paired Associate Learning Big Little Circle Verbal recognition Memory Intra-Extra Dimension Shift Set Rapid Visual Processing	Improvement in drink condition ns ns ns ns Drink group did worse but dependent on drink order. ns
Edmonds & Jeffes (2009)	23	6-7y	Repeated measures	500ml	BL & 45 minutes after intervention	Letter Cancellation Spot-the-difference Line drawing	Drink group higher score ns ns
Neave et al (2001)	24	Mean 20.1y	Repeated measures	P1. 150ml P2.150ml	BL & 20 mins after P1 & 20 mins after P2	Rapid Visual Information Processing Word Recall SRT Digit vigilance Choice Reaction Time Spatial Working Memory	ns ns ns ns ns
Rogers et al (2001)	60	Mean 26 y	Independent samples	Nothing 120ml 330ml	BL and 20 & 50 mins	Rapid Visual Information Processing	Performed improved in thirsty participants that had a drink

Note ; BL = Baseline

In summary, in adults psychomotor tasks in which speed was prioritised over accuracy tended to be more sensitive to hydration status. However, it is difficult to compare the results of the different psychomotor tasks because the cognitive skills required were subtly different. The unstable tracking tasks and tramline tasks require hand/eye coordination and motor control, whereas the trail making tasks also require other cognitive components such as speed of processing necessary to find and process consecutive numbers and letters. More research is required to delineate whether it is the fine motor component or the other cognitive components such as speed of processing or attention that are sensitive to hydration status.

2.2.2 Memory

Many studies have examined the effect of hydration status on memory. Memory in this section has been divided into three types; short-term memory (STM), working memory and long-term memory (LTM). Tasks used to measure STM in the literature were generally tests that required participants to repeat back sequences of numbers or to look at pictures or words and verbally recall what they have seen. Working memory requires not only storage of information but that the information is manipulated or processed (Cowan, 2008). The literature in which working memory was tested has used tasks such as the repeated acquisition task in which participants had to learn a sequence of key presses on the keyboard. Long term memory (LTM) has been tested by showing participants pictures of objects that were initially shown to them as a test of STM but then require recall again after a longer period of time.

2.2.2.1 Short Term Memory

Previous research literature investigating the effects of voluntarily dehydration on STM in children show that dehydrated children performed worse in STM tasks than children that were euhydrated (Bar-David et al., 2005; Fadda et al., 2012). The study by Bar-David et al. (2005) was the first to look at the effects of voluntary dehydration on children’s cognitive performance. Urine samples were collected from 51 children between the ages of 10-12 years old. When the children arrived at school at 8am urine osmolality was determined. Children with urine osmolality of above 800 milliosmoles per kilogram (mOsm/kg) were assigned to the dehydrated group (mean Uosm 997 mOsm/kg) and those with urine osmolality below 800 mOsm/kg (mean Uosm 620 mOsm/kg) were assigned to the hydrated group. The children were given a battery of cognitive tasks to do (details of the battery can be observed in Table 2.2) when they arrived at school and after lunch. During the morning children were able to drink and eat normally, and intake was not recorded. Uosm remained relatively stable and by lunchtime, mean Uosm had decreased to 935 mOsm/kg in the dehydrated group and 607 mOsm/kg in the hydrated group. While there were no statistical differences in task results found between groups in the morning (possible reasons for this are discussed in 2.6.6), the lunch-time test results, with the morning results as a covariate, showed that the children in the hydrated group had better recollection of number sequences than those in the dehydrated group. No other statistical differences between groups were found. A limitation of this study was that food and beverage intake was not standardised or recorded before or during the study.

The results from Bar-David et al. (2005) are consistent with findings from a study by Fadda et al. (2012), which showed that there was a significant relationship between urine osmolality and memory of auditory number sequences, with those that were better hydrated having better recollection. In Fadda et al. (2012) children were randomly assigned to either the control group in which they continued with normal drinking behaviour or a drink group in which they were supplemented with 1000ml over the day. Food intake was standardised across the groups during the study. At baseline mean Uosm in dehydrated children (children with a Uosm above 800 mOsm/kg) was 1301 mOsm/kg in the drink group and 1279 mOsm/kg in the control group. By the end of the day Uosm had increased in the control group to 1418 mOsm/kg and decreased in the drink group to 1248 mOsm/kg. This study, rather than assessing the difference between hydrated and dehydrated children, assessed the relationship between change scores in children's cognitive performance and Uosm levels.

In the children's water supplementation literature, beneficial effects of water consumption on memory skills were found in children. The first study in this field (Edmonds & Burford, 2009) had children listen to a story and answer questions at the end: they were divided into a drink and no drink group. No significant differences between groups were initially found for the story recall task. However, when the drink group were divided into those who drank less than 250ml water and those who drank more than 250ml of water, those that drank less than 250ml did significantly worse in the story recall compared to those that drank more than 250ml. This suggests that a specific volume of water must be consumed before improvements in STM occur.

In another study (Benton & Burgess, 2009) 40 children, aged between 8 and 9 years, had to verbally recall pictures of objects immediately after they were shown them and thirty minutes later. Additionally, they completed a test of sustained attention (see section 2.2.3.2 for results). The tasks were completed in a no drink condition or a drink condition in which they were tested 20 to 35 minutes after consuming 300ml of water. Those in the drink condition performed significantly better in the immediate object recollection test than those in the no drink condition, supporting the argument that drinking water results in improved STM.

Results from the adult dehydration literature also support an effect of hydration status on STM. A dose response effect of dehydration, due to water restriction and exercise in heat, was found on a word recollection task; the more dehydrated the participants the more incorrect answers (Gopinathan et al., 1988). Two very similar studies investigated the effects of dehydration, by use of heat and exercise, on recollection of number sequences (Cian et al., 2000; Cian et al., 2001). Additionally, Cian et al. (2000) administered a group of participants with a glucose solution so that there was a hyperhydration condition. Number recall tests (test 1) were given 30 minutes after the intervention of exercise, heat, relaxing quietly or having a glucose drink. In both studies performance was significantly worse in the dehydration condition than in the euhydrated condition at test 1. Furthermore, participants in the hyperhydration condition performed better than those in the euhydration condition, suggesting that water consumption is not just beneficial for reversing cognitive deficits caused by dehydration but can also improve performance in hydrated adults. However, glucose was used to hyperhydrate participants, rather than water, which may have a differential effect on cognition (Smith, Riby, van Eekelen & Foster, 2011). After test 1, participants were either dehydrated further, were rehydrated or euhydration was maintained (Cian et al., 2000) or they completed 15 to 20 minutes of exercise (Cian et al., 2001), then tested again (test 2). Both studies found there were no significant differences in STM performance between euhydrated, hyperhydration and dehydration conditions. Participants in the dehydration conditions had improved their performance irrespective of whether they had remained dehydrated or been rehydrated. Cian et al. (2001) suggests that dehydration caused 'a general drop in performance which disappears in time (p.250).' However, methodological issues such as consuming glucose or having further exercise between test 1 and test 2 make the results difficult to interpret.

Conversely, a study of either rowing or lacrosse college teams showed that, paradoxically, after participating in sport, those deprived of water performed significantly better in a recollection of number sequences task, than athletes supplemented with water (D'Anci, Vinhakar, Kanter, Mahoney, & Taylor, 2009). As discussed later in section 2.5.1, exercise can also affect cognitive performance, but in this study the effect of exercise was controlled by having participants in both groups undergo the exercise part of the study. As the participants only took the test after the intervention and not before it was not possible to look at how performance changed due to the intervention. Thus it may be that participants in the dehydration group were simply better at the digit span task; rather than showing an increase in performance associated with dehydration. The participants also completed a SRT,CRT, map planning, mathematical addition, vigilance and visual perception task (See Table 2.1 for results).

Studies of adults have not found a beneficial effect of water consumption on recognition and recollection of words (Benefer et al., 2013; Edmonds, Crombie & Gardner, 2013; Neave et al., 2001). In Edmonds, Crombie and Gardner's (2013) study, 34 participants completed a series of tests (see Table 2.2 for details) in the morning, after having not eaten or drink since the previous evening, in a repeated samples design in which they were offered 500ml of water to drink or no water. Furthermore, a study by Edmonds, Crombie, Ballieux, Gardner and Dawkins, (2013) found no effect of water consumption on recollection of number sequences. In this study, one group of participants were given 200 ml of water to drink and the other group had no drink. They completed a selection of cognitive tasks at baseline (see Table 2 for details) and 20 and 40 minutes after the intervention.

A possible explanation for the inconsistencies in results maybe that water consumption only improves STM if deficits have already occurred due to dehydration. The adults who took part in these studies may not have been sufficiently dehydrated to suffer any STM deficits and thus water consumption did not improve performance. However, this explanation contradicts Cian et al. (2000) who found hyperhydrated participants performed better than those who were euhydrated. Future research needs to measure hydration status at baseline to determine whether hydration status moderates the effects of water consumption.

In summary, there is substantial evidence that dehydration impairs STM in adults and children. Furthermore, there is evidence that water consumption improves STM performance in children, but studies have shown no STM improvement in adults that have been given a drink of water. It is hypothesized that as children may be more susceptible to dehydration than adults it is more likely that they were dehydrated at baseline and were suffering from STM deficits and so water consumption reversed these deficits.

2.2.2.2 Working Memory and Long Term Memory

Results from studies of the effect of hydration on working memory in adults and children are inconsistent. Findings in studies of children, show that those who had a drink performed significantly better in a spot-the-difference memory task (Edmonds & Burford, 2009). This task was used to measure both memory and perceptive discrimination as well as attention. Instead of showing the children the pictures simultaneously as is often the case in these sorts of tasks, the children were given two pictures one after another and one minute was allocated for the children to find 10 differences between the pictures. The performance of the children in the drink group improved significantly more than the children in the no drink group. Conversely, in Edmonds and Jeffes (2009) there were no significant differences in changes between baseline and test, but this is likely to be a result of a large proportion of the children performing at ceiling.

In studies of adults supplemented with water there were no differences in working memory performance between adults that had a drink and those that did not (Edmonds et al., 2013; Edmonds, Crombie & Gardner, 2013; Neave et al., 2001). In a study in which dehydration was induced in adults by use of exercise and a diuretic medication, no effect of dehydration was found in a

Brown Peterson task in which participants were shown collections of three letters which they later had to recall, and in between recollections they had to count backwards (Ganio et al., 2011). However, in the same study when participants were dehydrated they became slower in a match-to-sample task than when they were euhydrated. In this task participants have to choose one design from a choice of four, that matches a design seen previously. In the study by Ganio et al (2011) 26 males participated on three occasions. On each occasion they participated in exercise, but in the euhydration condition all fluid loss was replaced, in the DN condition the fluid was not replaced and in the DD condition fluid was replaced but a diuretic was given to each participant which resulted in water loss and dehydration. Participants mean body weight loss was 1.4%.

When examining the findings for effects of dehydration on mathematical addition performance there is again inconsistencies in outcomes. In children that were voluntarily dehydrated, there were no differences in number addition (Bar-David et al.,2005). In adults, that were deliberately dehydrated by varying methods, some studies have found no differences in the mathematical addition test (Bradley & Higenbottam, 2003; D'Anci et al., 2009; Szinnai et al.,2005). However, Gopinathan et al. (1988) found that when participant's levels of dehydration, induced by exercise and heat, reached a mean of 2.2-2.3 % BW loss their performance deteriorated. Below this level of dehydration no differences between dehydrated and euhydrated participants occurred. These results are consistent with another study which also found that mathematical ability deteriorated only after a 2% BW loss occurred (Sharma et al.,1986). This suggests that there may be a critical level of dehydration before deficits in working memory occur.

The effects of hydration on LTM are mixed. In children, when Benton & Burgess (2003) asked the participants to recall objects 30 minutes after having viewed them there was no difference in performance on the occasion they had a drink compared to when they did not have a drink. No other studies have investigated the effects of water consumption or dehydration on LTM in children. Furthermore, to-date there have been no research into the effects of water consumption on LTM in adults.

In adults those that had been deliberately dehydrated by heat and exercise show no effects of the intervention on their ability to recall and recognise pictures, thirty minutes after being initially shown them (Cian et al., 2000; Cian, et al., 2001). This suggests that children may be more sensitive to the effects of hydration status on long-term memory than adults.

In summary, there is again some suggestion that children are more sensitive to the effects of water consumption on working memory and LTM than adults. Dehydration does not seem to affect LTM in adults and performance is only affected in specific working memory tasks, where it may be that cognitive components of the task other than working memory are susceptible to dehydration. It will be investigated whether the beneficial effect of water consumption on memory in children is robust and replicable.

2.2.3 Attention and Reaction Time

O'Connor and Burns (2003) suggest that measures of reaction time are composed of motor decision time and motor response time. Simple reaction time (SRT) tasks require the participant to press a response key as soon as they see a stimulus on the screen. The continuous performance test differs from the SRT test because it is longer, which means the participants have to sustain attention and be vigilant for a lengthier period of time. Choice reaction time (CRT) tasks are similar to SRT tasks but require participants to respond to a choice of stimuli with a choice of possible responses. For example, participants may be required to press either a left or right button as quickly as possible when a circle appears at random intervals either to the left or the right of the screen (Cian et al., 2001).

2.2.3.1 Simple Reaction Time

To date, studies that examine the effect of hydration on SRT tasks have only been carried out on adults and they show inconsistent results. Some studies found no differences between euhydrated and dehydrated participants in a SRT task (D'Anci et al., 2009; Ganio et al., 2011) and the study by Benefer et al. (2013) showed that volume of water drunk did not predict cognitive performance. Moreover, in some studies no differences in performance were found between groups of adults that had a drink and those that did not have a drink (Edmonds et al., 2013; Neave et al., 2001). Conversely, Edmonds, Crombie and Gardner (2013) study did find that adult's SRT performance improved after having a drink. Furthermore, the effect of water consumption was moderated by self-rated thirst. Participants that rated themselves as being high on the thirst scale and had a drink became significantly faster than those that rated themselves as low on the thirst scale and had a drink or those that did not have a drink.

2.2.3.2 Sustained Attention and CRT

Similarly, in a test requiring sustained attention it was found that cognitive performance only improved in participants that were thirsty and had a drink and not participants that were not thirsty and did not have a drink (Rogers et al., 2001). Those participants who were not thirsty, but had a drink, had a dose-related impairment in performance suggesting that water consumption in participants that are not dehydrated can be detrimental. Rogers et al. (2001, p.57) likened this effect to the “post-lunch dip” when cognitive performance deteriorates due to the “physiological cost” of processing food eaten at lunch. However, Neave et al. (2001) and Edmonds, Crombie & Gardner (2013) did not replicate this finding.

In the dehydration literature, some studies have found an effect of dehydration, induced by exercise, on sustained attention. In a study by D’Anci et al. (2009) there was a significant increase in reaction time in the dehydration condition between start and finish indicating poorer performance over time, but reaction time was stable over time in the euhydrated condition. Bradley and Higenbottam’s (2003) study also found that participants in the dehydration by exercise and heat condition took significantly longer to respond than those in the euhydrated condition. However, when the study was repeated and participants were dehydrated with the use of a diuretic medication, no differences between conditions were found. Moreover, dehydration by means of exercise and a diuretic, had no effect on reaction time in a scanning vigilance test but there was a significant increase in premature errors, compared to the euhydrated group (Ganio et al., 2011). This finding was not replicated in a study by Adam et al., (2008) in which participants were dehydrated by heat exposure.

Staying attentive and on-task is particularly important at school and Benton and Davis (2010) studied the effects of drinking water on classroom behaviour in children. Twenty-two children were given a drink on three occasions and no drink on another three occasions. The children were then observed for 30 minutes, at 1 minute intervals. At each minute interval they were assessed as either being on task or not on-task, for example scratching, talking, looking around and fidgeting. Benton and Davis (2010) found that when children drank 200ml of water they were on task for a mean of 78.8 % of the time compared to a significantly worse 53 % of the time when they had not been given a drink. Conversely, Benton & Burgess, (2009) found no effect on water supplementation on performance in a sustained attention task. However, the task used to test attention in the Benton and Burgess study had a very different design. In this study the children had to hit a button in response to a warning signal and a light. The tasks differed from a SRT task as there was a delay in between the warning signal and the light, requiring children to sustain their attention.

No significant effects of dehydration or water consumption on CRT have been found in adults (Bradley & Higenbottam, 2003: Cian et al., 2001; D'Anci et al., 2009; Edmonds, Crombie & Gardner, 2013; Ganio et al, 2011; Neave et al., 2001; Szinnai et al., 2005). To date, the effect of voluntary dehydration or water consumption on CRT in children has not been examined.

In summary, results for reaction time are inconsistent. There is no robust evidence to suggest that simple and choice reaction time are sensitive to dehydration. In the longer continuous performance test dehydration did affect performance in studies which used heat and exercise to induce dehydration (Bradley & Higenbottam, 2003; D'Anci et al., 2009; Ganio et al., 2011). These results were not supported by the findings from Adam et al. (2008) which used long exercise periods and Bradley and Higenbottam's (2003) study which used diuretic to induce hydration. An effect of water consumption was found on SRT but not CRT (Edmonds, Crombie & Gardner, 2013) which could indicate that it may be the motor response time component that is more sensitive to hydration rather than the decision time. Additionally, reaction time and attention seem to be sensitive to the sensation of thirst (Rogers et al., 2001; Edmonds, Crombie & Gardner, 2013). To date, no studies have been carried out to investigate the effects of water consumption, or the moderating effects of subjective thirst, on SRT and CRT in children and this will be addressed in this PhD.

2.2.4 Perceptive Discrimination

A small body of work has looked at the effect of hydration on perceptive discrimination, which is the ability to distinguish between similar sensory stimuli (Binder, Hirokawa & Windhorst, 2009). Results examining the effects of dehydration on perceptive discrimination are inconsistent. Sharma et al.'s (1986) study found that dehydrated participants were slower to complete a

Symbol Substitution task, than when they were euhydrated. In this task participants have to match symbols from a list or table to a digit. However, no effect of dehydration was found on performance in that task in Bradley and Higenbottam's (2003) studies. When comparing accuracy, in a line perception task, no significant differences between conditions were found (Cian, et al., 2000; Cian et al., 2000). In these studies participants were presented with an instruction which said 'longer' or 'shorter' on their computer screen. Two lines of varying length then appeared and the participants had to press the corresponding button on the computer to confirm which line was longer or shorter, dependent on the instruction.

Decision time is just one factor in what is called speed of processing (Roberts & Stanov, 1999). There are many different models of speed of processing but O'Connor and Burns (2003) consider that speed of processing includes movement time, decision time, visualisation speed and perceptual speed. These skills are utilised to a greater or lesser degree, depending on the task. Indeed, speed of processing components are inherent in any cognitive task. For example, in the 5 minute vigilance test (Ganio et al., 2011), which tests attention and reaction time, the higher response time taken by the participants in the dehydrated condition could be due to a slower visualisation or perceptual speed, decision time or motor response.

Perceptive discrimination seems particularly sensitive to water consumption in children and adults. In the water consumption studies the letter cancellation task was employed as the method to measure perceptive discrimination. In the letter cancellation task, participants are required to locate a particular letter, such as the letter 'U' in a grid containing lots of other similar letters, such as ‘C’ and ‘O’. In studies of children, the children in the drink group had a significantly larger improvement in performance than the no drink group (Edmonds & Jeffes, 2009). These results are in line with findings from other studies of children (Booth et al., 2012; Edmonds & Burford, 2009). Although Fadda (2012) found no correlation between levels of hydration and performance in a similar test named Deux de Barrage. In a study of adults, performance in the letter cancellation task improved on the occasion that adults had a drink (Edmonds et al., 2013).

In summary, perceptive discrimination seems very sensitive to water consumption but further research needs to be carried out to determine whether it is also consistently affected by dehydration. Future investigation is needed to assess which aspect of perceptive discrimination is predominantly affected by water consumption, for example whether it is the motor action required or the visualisation speed.

2.2.5 Executive Function

Some studies have investigated the effects of dehydration on executive function. Executive function tasks require higher-level cognitive skills, such as planning and decision making, which allow the participant to deal with unique and complex situations (Adan, 2012). Results from the studies, in which dehydration was induced by exercise, were very inconsistent with some finding no effect of dehydration (D’Anci et al., 2009; Ganio et al., 2011) and some finding a negative effect of dehydration (Tomporowski, Beasman, Ganio & Cureton, 2007). In Bradley and Higenbottam’s (2003) study when participants were dehydrated by use of heat and exercise, participants had significantly more missed responses, in the scales indicators monitoring task (part of a Multi-Attribute Task battery), than when they were euhydrated. When participants were dehydrated by use of a diuretic no differences in performance were found in the same task.

When participants were dehydrated by means of 24 hour and 27 hour water deprivation respectively, they became slower in a battery of tests requiring a spectrum of cognitive skills (Petri, Dropulic, & Kardum, 2006) but there was no effect on performance in a Stroop test (Szinnai et al., 2005) which has an inhibition component. Furthermore, there were no effects of dehydration on a ‘sentry duty’ task which also requires inhibition (Adam et al., 2008). Although, the task also tests sustained attention and psycho-motor coordination and the dehydration was induced by heat exposure rather than water deprivation.

In a study in which participants were supplemented with water on one occasion and given no water on another, no differences were found on performance tests of learning, comprehension and reversal (Edmonds, Crombie & Gardner, 2013). However, participants performance deteriorated in a task which tested rule acquisition and reversal on the occasion that they had a drink but only if they completed the drink condition first. If they completed the drink condition second there was no effect.

It is very difficult to compare studies in which executive function has been tested as a different collection of cognitive skills may be tested in each task. Thus the inconsistent results suggest that only specific cognitive skills may be susceptible to hydration status and that the method used to dehydrate participants may be a factor. To date, there have been no studies of the effects of hydration status on executive function in children, which merits further research. Therefore, the effects of hydration status on executive function in children will be investigated.

2.2.6 Summary

In summary, when looking at studies investigating the effects of dehydration on the cognitive performance of adults there is a suggestion that STM and psychomotor speed are impaired by dehydration. However, it is very difficult to compare studies which use such differing methods and often have a variety of confounding factors (see section 2.5). The results suggest that water consumption, rather than dehydration, in adults may have a beneficial effect on perceptive discrimination and reaction time and that reaction time or attention may be moderated by levels of thirst. At present, only a small number of studies have been carried out on the effects of water consumption on adults and hydration status has not been formally assessed, so the relationship between water consumption and dehydration on cognitive function is unknown. More research needs to be carried out in this area to clarify the effect of self-rated thirst on reaction time and attention and of water consumption on perceptive discrimination.

Evidence does suggest that overall children may be more sensitive than adults to deficits due to dehydration and that having a drink is able to reverse these impairments. It may be that adults are more able to adapt to dehydration. To date, studies in children show that task performance requiring STM, working memory and perceptive discrimination are all affected by hydration status, but further research needs to be carried out to explore whether reaction time, executive function and fine motor skills are also susceptible to dehydration or water consumption. The effect of hydration status on these cognitive domains are reported in this thesis.

2.3 The Effects of Hydration on Mood

Many of the studies above investigated not only the effects of hydration on cognitive performance, but also mood. States such as hunger, thirst and fatigue will be referred to as ‘moods’ in this thesis to remain consistent with previous literature, although in a literal sense the term is incorrect. Mood has been measured in various ways, for example, in the children’s studies visual analogue scales were used that were anchored at each end by a picture and a statement. When measuring mood in adults some studies asked participants to score subjective feelings on a ten-point mood scale (Petri et al., 2006) whereas other studies used a 5 point Likert scale (Szinnai et al., 2005). Many studies used a POMS Profile of Mood State in which participants had to rate their answers on a 5 point scale to 65 questions (Adam et al., 2008; Armstrong et al., 2012). These questions were grouped into six subscales which are fatigue-inertia, vigour-activity, tension-anxiety, confusion-bewilderment, depression-dejection and anger-hostility. This section will look at the results of hydration on each separate mood subscale.

Results from studies measuring fatigue, using varying methods of dehydrating participants, consistently show that dehydration increases levels of fatigue in adults (see Masento et al., 2014 for a review). Additionally, participants that habitually only drank a low volume of water, and thus were probably dehydrated, had a decrease in self-rated fatigue when their volume of water intake was increased over 3 days (Pross et al., 2014). However, at baseline participants with low and high fluid intake did not have a difference in subjective fatigue levels suggesting that over a longer period of time adult participants adjust to their level of hydration and levels of fatigue stabilise. Cian et al. (2001) only found a beneficial effect of water on subjective fatigue if participants had been deliberately dehydrated and had an initial increase in fatigue before being provided with a drink. Conversely, results from Pross et al (2013) did not show a decrease in fatigue when dehydrated participants were rehydrated. However, self-rated fatigue was measured in these participants only 5 minutes after having a drink so it is possible that this was too short a timeframe to allow for changes. Moreover, there was no difference in self-rated levels of tiredness in adults that either had a drink or did not have a drink (Edmonds et al., 2013; Edmonds, Crombie & Gardner, 2013). It is suggested that water consumption had no beneficial effect on fatigue ratings because the participants in these studies were not sufficiently tired at baseline.

The evidence suggests that dehydration does increase levels of fatigue (Bradley & Higgenbottam, 2003; Ganio et al, 2011; Armstrong et al., 2012; Pross et al., 2013; Ely, Sollanek, Cheuvront, Lieberman & Kenefick, 2013; Szinnai, et al., 2005; Cian et al., 2001; Cian et al., 2000, D'Anci et al., 2009; Patel et al., 2007) and that these deficits can be reversed over a period of time if participants have a drink (Pross et al., 2014). However, drinking fluid offers no reduction in subjective fatigue to participants that are euhydrated. To date the effects of dehydration and water consumption on self-rated fatigue in children has not been investigated.

The effect of dehydration on subjective alertness in adults is also fairly consistent. Dehydration reduced subjective ratings of alertness, compared to when participants were euhydrated (Bradley & Higenbottam, 2003; Pross et al., 2014; Szinnai et al., 2005). Moreover, when dehydrated participants were given a drink, the reduction in alertness following dehydration was reversed (Pross et al., 2014). Further, Rogers et al. (2001) found that all participants had a dose-related improvement in alertness immediately after the intervention, but not 25 minutes later. These findings were consistent with those reported by Neave et al., (2001). However, Bradley and Higenbottam (2003) found no reduction in subjective alertness in participants dehydrated by use of an anti-diuretic drug rather than heat and exercise. The results show that generally dehydration reduces levels of alertness and that having a drink can reduce this effect, but only for a short time.

When looking at the effects of hydration status on vigour and activity, previous research shows that the results are mixed. In adults, Armstrong et al., (2012) and Pross et al., (2013) found that when women were dehydrated they had reduced self-rated vigour scores. Pross et al., (2014) reported that participants with a naturally high fluid intake rated themselves as having less vigour when fluid intake was restricted. Conversely, Adam et al., (2008) and Ely, Sollanek, Cheuvront, Lieberman and Kenefick (2013) did not find a negative effect of dehydration on self-rated vigour. Moreover, supplementing adults with a drink did not improve self-rated levels of vigour or energy (Pross et al., 2013; Edmonds, Gardner & Crombie, 2013; Edmonds et al., 2013). Studies in children found that levels of vigour decreased as children became more dehydrated

(Fadda et al., 2012). Further research needs to be carried out to determine under what circumstances self-rated vigour is reduced or enhanced.

There is some suggestion that hydration status may have a negative effect on feelings of wellbeing in a healthy adult population. Previous research shows increased self-rated scores in depression (Ely, Sollanek, Cheuvront, Lieberman, & Kenefick, 2013), anxiety (Ganio et al., 2011) and anger and hostility (Ely et al., 2013; Armstrong et al., 2012) in dehydrated participants. However, the majority of studies have found no differences in mood between participants that are dehydrated or euhydrated (Adam et al., 2008; Ely et al., 2013; Ganio et al., 2011; Petri et al., 2006; Pross et al., 2013,) or when participants have a drink compared to not having a drink (Edmonds, Crombie & Gardner, 2013; Edmonds et al., 2013).

The results of the effects of hydration status on self-rated confusion are mixed. Edmonds, Crombie & Gardner (2013) found that generally participants were more confused the first time that they completed a mood scale, but less so if they had a drink of water compared to if they didn't have a drink of water. Furthermore, Pross et al. (2014) found that participants that had a habitual low intake had a reduced self-rated score in confusion when they were supplemented with extra water and Ely, Sollanek, Cheuvront, Lieberman & Kenefick (2013) found an increase in levels of confusion in dehydrated participants. However, some studies found no effect of water consumption or dehydration on self-rated confusion scores (Adam et al., 2008; Armstrong et al., 2012; Edmonds et al., 2013; Ganio et al., 2011).

There is a consistent effect of hydration status on perceived effort and concentration in adults. Dehydrated participants rated themselves as having to make more effort or concentrate more when carrying out a task than when they were hydrated (Armstrong, 2005; Kempton et al., 2011; Petri et al., 2006; Szinnai et al., 2005). To date, it has not been investigated as to whether water consumption can improve levels of concentration and reduce effort.

Pross et al. (2013) found that adults that were dehydrated had a reduction in happiness scores which was reversed after having a drink. Edmonds and Jeffes (2009) found an increase in self-rated happiness in children that were given a drink, compared to those children that did not have a drink. More research needs to be carried out to investigate whether these changes in happiness may moderate the effects of dehydration or water consumption on cognitive performance.

In summary, results show that dehydrated participants consistently perceive that they have to make more of effort and subjectively feel more tired and less alert than euhydrated participants. Having a drink increased feelings of alertness, but fatigue does not seem to be reversed in the short-term. The results are less clear for the effect of hydration on vigour and well-being. This thesis presents results of studies that investigate the effects of water consumption and dehydration in children on some of the mood states discussed above.

2.4 Summary of Rationale for Choice of Experimental Design

To date, as discussed above, there have been few studies that have investigated the effects of water consumption and dehydration on cognitive performance, motor skills and mood in children (Bar-David et al., 2005; Benton & Burgess, 2009; Edmonds & Burford, 2009; Edmonds & Jeffes, 2009; Fadda et al., 2012). The present literature in this area of research needs to be expanded upon so that it can be observed whether results are robust and replicable. Therefore, the experimental method used will be based upon the design used in these previous studies so that results can be compared. Most of the studies have used a pre-intervention, post-intervention design and the intervention has been a drink or no drink. This design has been successful and shown statistically significant effects on performance, with very large effect sizes, when comparing drink and no drink conditions. Thus, this design will be used as the foundation for the majority of studies carried out.

2.5 Methodological Issues

As mentioned above, the studies on the effects of dehydration on cognitive performance and mood have used many different methods of dehydrating participants, some of which may potentially confound results. In addition, there are other factors such as participant expectation, small cohort numbers and diet which may had have an effect on the results. The next section will discuss and expand on each of these factors.

2.5.1 Interventions

One of the major differences between the studies cited is the variety of ways in which participants reach a state of dehydration. In children dehydration is termed voluntary because it has not been deliberately induced by the researcher. Instead, the children were tested in their natural, everyday state and happened to be dehydrated because they consumed insufficient fluid and may have lived in a hot climate. In the adult studies the dehydration was generally deliberate and induced.

One method of dehydration is to withhold fluid consumption but this can be problematic as it can take a considerable time to induce levels of dehydration significantly. For example, participants in studies by Petri et al. (2006) and Szinnai et al, (2005) were deprived of water for a 24-hour period to ensure that participants became dehydrated. Being exposed to such a long period of deprivation may result in participants feeling uncomfortable and suffering from other symptoms such as a dry mouth and a headache, which may distract participants and have an effect on cognitive performance and mood (Cheuvront & Kenefick, 2014). Thus this is not a desirable method of inducing dehydration.

Dehydration has been induced considerably quicker by using a diuretic drug (Bradley and Higenbottam, 2003). The use of an antidiuretic drug causes a different type of dehydration than the use of the other interventions used, such as water deprivation, heat or exercise. Dehydration due to water deprivation or sweating, induced by exercise or heat, will cause a loss of fluid in the ICF, called intracellular hypertonic dehydration. However, antidiuretics cause a loss of volume to the ECF and thus isotonic dehydration will occur (Cheuvront & Kenefick, 2014). The physiological response to ICF dehydration and ECF differs and thus it is a possibility that these different types of dehydration will have differential effects on cognitive performance and mood.

The types of intervention most commonly used to dehydrate adult participants are exercise and heat exposure (Cian et al., 2001; Cian et al., 2000; Gopinathan et al., 1988; Sharma et al., 1986). Heat exposure and exercise will in themselves have effects on the body even when the participants are not dehydrated (Gaoua, 2010). Thus, it is difficult to extricate the effects of dehydration from those of exercise and heat unless those in the control condition are also exposed to these conditions. For example, Cian et al., (2001) and Cian et al., (2000) used exercise and heat to dehydrate participants whilst the control condition rested in an ambient temperature for two hours. Participants in the dehydrated conditions showed significant differences in performance to the control condition in some cognitive tasks but these differences may be attributed to due to physiological changes or mood changes induced by the heat and exercise rather than solely by dehydration.

When the effects of heat alone, dehydration alone or a combination on cognitive performance were investigated, the findings suggested that it was a combination of heat and exercise plus dehydration that was causing the deficits in performance (Bradley & Higenbottam, 2003). In Bradley and Higgenbottam's first study participants were either in an ambient temperature condition or in a condition in which the temperature was elevated to above 33ºC, but dehydration were not induced. No differences in performance between conditions were found, suggesting that heat alone does not affect cognitive performance. However, when participants were in the hot condition, they perceived that they had to make a greater effort to achieve the same cognitive results as when they were in the ambient condition. In Bradley and Higgenbottam's third study performance was compared in a euhydrated condition and a dehydration condition in which a diuretic was used to induce dehydration. No differences were found between the two conditions, suggesting that dehydration induced by an antidiuretic does not affect cognitive performance. In Bradley and Higgenbottam's second study, participants performed exercise and were exposed to heat and in one condition were deprived of water and in the other condition they had to drink sufficient water to remain euhydrated throughout the heat and exercise regime. In this study significant differences in sustained attention and tracking errors were found between the two conditions, but memory and choice reaction time were not affected. The findings in this series of studies suggest that dehydration induced by an antidiuretic or heat alone do not affect cognitive behaviour, but that both heat, exercise and dehydration are needed before sustained attention is affected.

Additionally, the different types of heat may have different effects. Environmental heat may be dry or humid, although Sharma et al. (1986) found no statistically significant differences in cognitive performance between heat conditions. There may also be different effects depending on core body temperature that may or may not be influenced by environmental heat. Maughan, Shirreffs and Leiper (2007) hypothesized that a high core body temperature may cause cognitive deficits due to a greater permeability in the blood brain barrier. The high core temperature results in molecules such as valuable nutrients being able to pass through the blood brain barrier and out of the brain and non-beneficial molecules may pass in to the brain, which can impair cognitive performance.

In a review of the literature, Gaoua (2010) was unable to establish what the effects of heat alone, or a combination of heat and dehydration, were on cognitive performance due to the large variety in methods used and the high number of confounding factors. At this time point it is, therefore, not possible to extricate the effects of heat and dehydration from one another and indeed cognitive performance may only be susceptible to a combination of both heat and dehydration.

In the studies reviewed in this chapter, exercise was another common method of inducing dehydration. As with heat, exercise could have confounded these studies because of the effects that exercise alone also has on cognition (Tomporowski et al., 2010). Exercise is a complex variable as it has different effects dependent on the type of physical activity being carried out and the cognitive domain being measured. A meta-analysis by Tomporowski et al. looked at 29 within subject designed studies in which young adults' cognitive performance had been measured after one exercise intervention. These parameters are typical of the parameters in most of the studies cited in this review. Overall, the meta-analysis showed that there was a statistically significant improvement in cognitive performance after exercise although exercise of more than 2 hours duration may cause a deficit in cognitive performance. The results also showed a larger effect of exercise in tasks measuring memory than those measuring executive function and speed of processing.

Initially Tomporowski et al. (2010) hypothesized that the effects of exercise on cognitive performance would reduce over time and so task performance would be dependent on the interval between the end of the exercise and cognitive testing. This hypothesis was not supported by the meta-analysis results but is supported when comparing the results of Cian et al. (2000) and Sharma et al. (1986) to Cian et al. (2001). Both Sharma et al. and Cian et al. (2000) left participants for 90 minutes after reaching the required level of dehydration before testing psychomotor performance, possibly reducing the confounding effects of exercise. In Cian et al. (2001) study only a 30 minute period between exposure to exercise and testing was left. After a 90 minute rest period participants in the dehydrated condition performed significantly worse than those in the euhydrated condition. No differences were found between conditions when participants had only a 30 minute interval between exercise and testing. It is possible that on occasions on which there was a short time interval between exercise and testing, the beneficial effects of the exercise and the detrimental effects of the dehydration counterbalanced each other resulting in no differences found between the euhydrated and the dehydration condition. Thus, it could be inferred that if task performance remained the same or got worse in the group that used exercise to induce dehydration this must be due to the detrimental effects of the dehydration counterbalancing the positive effects of the exercise. In the literature reviewed Cian et al. (2000) and Cian et al. (2001) used exercise to induce dehydration and participants in this condition did have worse performance in some cognitive tasks than the control condition, which did not exercise or become dehydrated. If exercise generally improves performance it would infer that the cognitive deficits were due to the effects of dehydration. However, there is no concrete evidence for this theory because the study did not have a euhydrated group to compare with which controlled for exercise.

Not mentioned so far is that dehydration due to exercise and heat exposure may also affect mood. The literature suggests that being exposed to heat may increase perceptions of fatigue and irritability and reduce perceptions of vigour and alertness (McMorris et al., 2006) and that exercise may elevate mood, increase feelings of wellbeing and increase perceptions of fatigue

(Lambourne & Tomporowski, 2010). Cognitive performance is sensitive to mood (Fredrickson & Branigan, 2005; Mitchell & Phillips, 2007). Therefore, not only will the effects of heat and exercise themselves affect cognitive performance, but so will the mood that has been induced by these interventions.

In conclusion, the evidence shows that exercise has an effect on certain aspects of cognitive performance, although the effect of heat is less certain. Therefore, it cannot be established whether differences in cognitive performance, arising from previous research studies in which the euhydrated group has not been exposed to the same stress factors as the dehydrated group, are due to dehydration. Furthermore, it appears that some cognitive skills are only sensitive to a combination of stress factors and dehydration, rather than one factor in isolation.

2.5.2 Demand Characteristics

Studies showing an effect of hydration status upon cognitive performance have been criticised because of the possibility of variables such as participant and researcher expectancy confounding the results (Benton, 2011). However, Edmonds et al. (2013) showed that adult's cognitive performance was not affected by expectations about the effect of drinking water on performance. In this study adults were either in a group in which they were given positive expectancies about the effects of water or not. After this, the participants in each expectancy group were put into water or no water condition. In the no expectancy and water condition the participants were given water surreptitiously without being aware that it was part of the study. The participants that were given water, either as an explicit part of the study or surreptitiously, performed better in some cognitive tasks than the participants in the no water condition regardless of whether they had been given a positive expectancy of the effects of water or not. This suggests that the effects of water consumption on cognitive performance is due to the properties of the water.

Effects of dehydration on cognitive performance have also been found when participants' expectancy is controlled (Ganio et al., 2011). Participants took part in an exercise regime to induce dehydration, but were unable to observe how much fluid they were given to drink, and were unaware that in one condition participants had been given a diuretic medication so that they would void more fluid inducing dehydration. As in Edmonds et al. (2013), expectancy did not have an effect on cognitive performance but those participants that were dehydrated performed worse in some cognitive tasks than those that were not.

2.5.3 Task and Measure Variation

It is problematic to make cross-study comparisons because of the variation in tasks used to measure cognitive domains. For example, in Cian et al. (2000), psychomotor performance was measured by asking the participants to use a joystick to move a cursor on a screen. When Sharma et al.'s (1986) study measured psychomotor performance, the participants had to move a stylus through a groove and Szinnai et al.'s (2005) study required participants to follow a circle on a screen using a track ball. Although these tasks are very similar, the procedure and measurement are different.

Furthermore, the task performance was measured in different ways. Sharma et al. (1986) measured both number of errors and time taken to produce a final score, Cian et al. (2000) and Cian et al. (2001) only measured the number of errors and Szinnai et al. (2005) measured the distance between the ball and the tracker. The variation in tasks used is also common when testing performance in other cognitive domains. It is, therefore, unsurprising that results are inconsistent. In the studies reported in this thesis, the tasks chosen were those used in existing research on the effects of water consumption on children, in order that results would be comparable across studies.

Moreover, most tasks utilise more than one cognitive domain. For example, in a task when memory of a changing sequence of buttons on the keyboard was required dehydrated adults had a longer response time than euhydrated participants suggesting that it was a component of processing speed that was sensitive to dehydration rather than memory. The studies carried out in this programme of research sought to isolate which specific cognitive domains were affected by hydration status.

2.5.4 Effects of Diet

Some studies investigating the effects of water consumption on cognitive performance in children have allowed food consumption during the testing period (Bar-David et al., 2005; Fadda et al., 2012) and the type and amount of food eaten may have had a short-term effect on the result (Bellisle et al., 2010; Veasey, Gonzalez, Kennedy, Haskell, & Stevenson, 2013). In the studies reported upon in this thesis food eaten was controlled for during the testing period.

2.5.5 Statistical Issues

A possible issue was that many of the studies reviewed used very small numbers of participants and thus data may not have been normally distributed. If the analysis used in the study requires normal distribution but this assumption was violated there was a higher risk of getting a Type 1 error. Another issue was that most of the studies in the dehydration literature only had fit, young men as their cohort and that induced dehydration was often quite severe. Therefore, the results from this literature cannot be applied to the general population who are not healthy, young men and may only be mildly dehydrated.

2.5.6 Summary

The literature supports that both dehydration and water consumption may cause changes in cognitive performance. However, due to the many inconsistencies in both methods and results it is not possible to robustly argue which specific areas of cognition or mood are affected by dehydration. There are fewer issues associated with studies of the effects of water consumption but, to date, this area of research is very small. Therefore, this thesis has sought to expand upon the water consumption literature, which is a very new and exploratory area of research and control for the confounding factors identified in the dehydration literature. The next section will discuss the mechanisms which have been suggested that may produce cognitive or mood changes in consequence to changing hydration levels.

2.6 Dehydration Mechanisms that Impact on Cognitive Performance and Mood

Very little research has been carried out to investigate the effect of dehydration in the human brain although some research has been carried out in animals. Therefore, some of the ideas discussed below are supposition rather than supported by empirical evidence. More research is needed in the future to explore these theories further.

2.6.1 Brain Function and Structure

Research into the effects of dehydration on mood shows that dehydrated participants often feel that have to make more effort to achieve the same standard of performance as when they are euhydrated (Armstrong, 2005; Petri et al., 2006; Szinnai et al., 2005). These findings are consistent with a study (Kempton et al., 2011) in which10 adolescent participants completed a cognitive task whilst in a hydrated and dehydrated condition whilst having an fMRI scan. The fMRI scan recorded the blood-oxygen-level-dependent (BOLD) response in the fronto-parietal area (the part of the brain utilised to perform executive function tasks). There was a significantly stronger BOLD response during the dehydration condition despite there being no difference in cognitive performance between the two conditions suggesting that participants expended more effort in the dehydration condition. Kempton et al. (2011) theorised that a 'higher level of neuronal activity' (Kempton et al., 2011, p.71) is required when working in a state of dehydration to achieve the same results compared to when working in a hydrated state. Kempton et al. also suggest that the level of cognitive performance may, therefore, be reduced over a longer period during of time in which a constant high level of neuronal activity is not achievable because the brain has only a limited availability of resources. In support of this are findings from other studies that show no effect of dehydration on cognitive performance at baseline but deteriorating performance over time (Bar-David et al., 2005; Fadda et al, 2012).

Structural changes to the brain also occur during periods of dehydration. Both Kempton et al., (2009) and Duning et al. (2005) found that brain volume in humans reduces and ventricular volume expands during periods of induced acute dehydration. These changes are transient and reverse when rehydration occurs. Reduction in brain volume has been associated with changes in motor performance (Seidler et al., 2010).

If dehydration is sufficiently severe to cause a reduction in blood plasma volume (hypovolemia) then underperfusion can occur (D'Anci, Constant, & Rosenberg, 2006); a reduction in blood delivered by the arteries to the capillary beds in biological tissue. Brain resources may be reduced during dehydration because of underperfusion, which has been associated with confusion and lethargy (D'Anci et al., 2006).

2.6.2 Neurotransmitters and Enzymes

Studies of rats show that dehydration may increase release of glutamate and GABA and that noradrenaline action may be enhanced, which may have an effect on certain aspects of cognitive performance such as concentration and memory (Di & Tasker, 2004). Additionally, dehydration up-regulates nitric oxide synthase (NOS) in rats. NOS is an enzyme that instigates the production of nitric oxide (NO), which is an important process in basic cellular activity and action (Aguila, Oliveira-Pelegrin, Yao, Murphy, & Rocha, 2011; Calka, Wolf, & Brosz, 1994). Some association has been found between increased NOS levels and memory and spatial learning performance (Zhang, Chen, & Wang, 1998). This argument is supported by studies of humans which show that having a decrement in NOS due to a disability impairs memory performance (Paul & Ekambaram, 2011). Further research into the effects of NOS on cognition during dehydration in humans should be carried out before theories can be robustly supported.

2.6.3 Arginine Vasopressin

Arginine vasopressin (AVP), also known as antidiuretic hormone (ADH) is a hormone that plays a key role in maintaining homeostasis (D’Anci et al., 2006). During dehydration AVP is released and levels increase with dehydration and urine osmolality (Hew-Butler, 2010; Montain & Tharion, 2010). In a study of participants that drank the same volume of fluid daily, high fluid intake drinkers showed low levels of AVP whereas habitual low fluid intake drinkers showed high levels of AVP (Johnson, 2012). AVP when administered artificially has been shown to improve memory performance in rats (Croiset, Nijsen, & Kamphuis, 2000). This evidence suggests that memory performance may be improved during periods of dehydration which is contrary to the results from many of the studies investigating the effects of dehydration on memory performance.

2.6.4 Cortisol

There is evidence to support that levels of serum cortisol increase, known as hypercortisolemia, during periods of dehydration (D'Anci et al., 2006; Judelson et al., 2007) and some studies have supported the detrimental effects of hypercortisolemia on cognitive performance, particularly on short-term memory and active learning (Het, Ramlow, & Wolf, 2005). However, studies that examine the effect of dehydration on cortisol have all used exercise and/or heat to induce dehydration, therefore, it is not possible to determine if dehydration alone without the effects of exercise or heat has an effect on cortisol levels. To date, there have been no studies which looked at the sole effects of dehydration on cortisol levels. Moreover, a study by Hoffman et al., (1994) which investigated the effects of hydration on mild exercise found that the cortisol levels were not affected by dehydration. More research needs to be carried out to determine if cortisol levels change when dehydration occurs due to insufficient water intake. Furthermore, the relationship between cortisol levels and cognitive performance needs further investigation.

2.6.5 Distraction

Deficits in cognition may not be due to the physiological effects of dehydration but may be due to a simpler, more psychological reaction. It has been suggested that discomfort experienced due to dehydration, such as a dry mouth, the sensation of thirst or a headache may cause participants to be distracted and thus cognitive performance may suffer (Cheuvront & Kenefick, 2014).

Additionally, as dehydration has been shown to impact on mood states such as fatigue and happiness this may have in turn affect task performance. Yet to be explored is whether the act of giving children and adults a bottle of water may increase positive affect or motivation, which might contribute to the physiological effect of drinking the water on cognitive performance. This notion will be investigated further in Study 1.

2.6.6 Summary

Several physiological mechanisms that may explain why hydration status has an effect on cognitive performance have been proposed here, as well as psychological factors such as mood. However, very little research has been carried out to test these different theories. Furthermore, it is plausible that cognitive deficits that occur during dehydration may have more than one underlying cause that may interact with one another. In this thesis mechanisms were discussed that seemed plausible, dependent on the results in each study, but further investigation needs to be carried out to provide more empirical evidence in this area of research.

2.7 Thesis Rationale and Aims

During the course of chapter 2, it has been shown that there are many gaps in the literature studying the effects of hydration status on cognitive performance in children. There are very few studies on water consumption and these studies have not tested to determine whether dehydration will moderate the effects of water consumption on cognition (Benton & Burgess, 2009; Edmonds & Burford, 2009; Edmonds & Jeffes, 2009). Therefore, the prime rationale for undertaking this PhD was to extend the literature in this area of research to bring more clarity to which aspects of hydration, either dehydration or water consumption, were having an effect on cognition and which cognitive domains were more susceptible to changes in hydration status.

A reason for the recent research interest into the effects of drinking water on children's cognitive performance is related to concerns that children are more likely to become dehydrated than adults. Furthermore, a large proportion of children arrive at school in a dehydrated state, meaning that they are more likely to underperform at school. The research presented in this thesis assessed whether drinking water facilitates better cognitive performance, and consequently, school performance. Thus, the results may be applicable to current government policy and school policy about the availability of drinks in schools.

In the previous chapter the reasons for measuring hydration status using a measurement of urine osmolality, urine colour and self-rated thirst were established and the rationale for using a pre- and post- intervention study design were discussed. During the course of the literature review the effect of hydration status on certain cognitive domains in children was identified as requiring either further investigation or new and original investigation. The specific aims of the PhD are listed below:

The basic rationale and aims of the PhD were:

- To investigate whether water consumption improved performance in cognitive tasks, motor skills and mood and whether this effect was specific to certain domains or was more general (All studies).
- To investigate whether the psychological effects of being given a bottle of water contributed to the effects of water consumption on cognitive performance, motor skills and mood (Study 1).
- To determine whether water consumption effects were moderated by hydration status (Study 3 & 4) or the sensation of self-reported thirst (Study 2, 4 & 5).
- To determine if thirst was a proxy measure of hydration status (Study 3).
- To describe possible mechanisms for the effects of hydration status on cognitive performance (All studies).

Chapter 3 presents study 1 which was designed to assess whether being given a bottle of water, but not drinking it, increased positive affect and contributed to the physiological effect of drinking water on cognitive performance, motor skills and mood. Chapters' 3 to 7 reported studies 1 to 5, and a general discussion was presented in Chapter 8.

CHAPTER 3

Study 1: Being Given, but Not Drinking a Bottle of Water, Does not Contribute to the Effect of Water Consumption on Mood and Cognitive Performance In Children

3.1 Introduction

The primary aim of this study was to investigate:

- Whether children's cognitive and motor performance improved after a drink of water compared to an occasion on which they did not have a drink of water.
- Whether being given a free gift of a water bottle contributed to the effect of water consumption on cognitive performance.

An exploratory aim of this study was to investigate:

- The relationship between self-rated thirst and cognitive performance.

There is a strong suggestion that dehydration has a negative effect on cognitive performance (see Chapter 2). However, results from the previous literature into the effects of dehydration on cognitive performance are inconsistent (see Chapter 2). These inconsistencies may be in part due to the different methods of dehydrating participants, the different tasks used and the different ways in which performance was measured (see Chapter 2). Thus, it is difficult to substantiate whether dehydration has an effect on specific cognitive skills and reviews of research in this area are unable to state with any certainty that there is an association between dehydration and cognitive performance (Benton, 2011; Masento et al., 2014).

Recently, there has been some research of the effects of water consumption, rather than dehydration, on mood and cognitive performance in schoolchildren. When this study was planned the investigation into the effects of water consumption on cognitive performance was in its infancy. Only three studies (Benton & Burgess, 2009; Edmonds & Burford, 2009; Edmonds & Jeffes, 2009) had been published, all of which studied the effects on schoolchildren rather than adults, and these showed that drinking water was beneficial to some cognitive skills. However, at the time of planning this study, published studies had not been replicated in order to ensure that results were reliable and consistent. There had been a recent crisis in psychological research in which notable publications had not been able to be replicated successfully (Shanks, 2013). Therefore, it was viewed as important to replicate this research in order to check that the observed phenomenon was reliable and robust before embarking on further studies. Therefore, a main aim of the study was to partially replicate previous studies to assess whether water consumption had a consistent effect on cognitive performance in schoolchildren.

Additionally, it was considered that changes in cognitive performance after being supplemented with water could be partly due to the indirect effect of variables such as positive affect, interest and improved motivation. These changes in cognitive performance may have occurred as a result of positive emotions that were associated with simply being given the bottle of water, rather than due to the effects of actually drinking the water. Findings from previous research support the notion that being given a free gift may induce a positive mood (Nielson & Bryant, 2005). Furthermore, when the effects of a positive mood are being investigated in a study, the mood is often induced by giving participants a free gift. For example, in Erez and Isen (2002) one group of participants were given a bag of sweets at the beginning of the experiment and told not to eat them but put them away for later, whilst another group were not given any sweets. Those participants in the group that were given sweets had significantly higher scores on a test of positive affect, tried for longer and scored higher on self-perceived effort and motivation scales, despite not eating the sweets. Additionally, free gifts do not have to be particularly exciting to warrant a change in mood. In a study by Isen (1984), participants were unexpectedly given a free gift in a shopping mall, such as a pair of nail clippers. Participants who received the gift rated themselves as having an improved positive state. It is, therefore, entirely plausible that giving a free bottle of water to participants may induce a positive mood. This notion is supported by the findings from Edmonds and Jeffes (2009) study, in which participants that were supplemented with water rated themselves as being happier than those children not supplemented with water.

Moreover, research suggests that increases in positive affect and motivation may in turn affect cognitive performance (Erez & Isen, 2002). Referring back to Isen's (1984) study, those participants that had been given a pair of nail clippers, not only rated themselves as being happier but also performed better in cognitive tasks, when compared to those not given a free gift. The results from Isen's (1984) study are similar to those of Erez and Isen (2002) in which participants that were given a bag of sweets to eat later answered more anagrams correctly, than those participants not given a bag of sweets. The findings from this research suggest that being given a free gift, such as a bottle of water, may improve mood and motivation, which may lead to improvements in cognitive performance. Thus, in previous studies (Edmonds & Burford, 2009) performance may have been improved by the psychological effect of being given a bottle of water to drink, rather than the physiological properties of the water. A main aim of the present study was to evaluate whether being given a free gift of a bottle of water increased positive affect and whether this effect contributed to the possible effect of water consumption on cognition.

In addition, previous research has found that ratings of thirst moderate the effect of water on cognitive performance. In Rogers et al. (2001) study, participants who had a high thirst at baseline had a bigger improvement in performance after a drink than participants who had a low thirst at baseline. Rogers et al. (2001) suggested that self-rated thirst may be a proxy measure of hydration, thus participants that were dehydrated and had a drink improved more than those that were hydrated at baseline. In this study, using ratings of thirst as a proxy measure of hydration, some exploratory analyses will be carried out to investigate whether ratings of thirst have an association with cognitive performance and mood at baseline and test. This is a purely speculative exercise and the results will be used to inform the design of further studies.

3.1.1 Rationale for Mood Scales and Tasks

A primary aim of this study was to investigate whether being given a free gift in the form of a bottle of water increased self-rated happiness, and consequently, whether increased positive affect would impact upon cognitive performance. To measure subjective ratings of happiness a Visual Analogue Scale (VAS) was employed. A VAS is a simple way for children to indicate their happiness, with evidence showing that this method is successful at eliciting information about emotions in children (Reips & Funke, 2008) . VAS have been used effectively in studies in children in the water supplemention literature previously (Edmonds & Burford, 2009; Edmonds & Jeffes,2009).

A measure of self-rated thirst was included to determine whether ratings of thirst correlated with cognitive performance at baseline and test. Previous research (Rogers et al., 2001) has shown that thirst may be a proxy measure of hydration status. Self-rated thirst scores were measured using a VAS. As the sensation of hunger and thirst are sometimes associated (Buehrer et al., 2014) and to assess whether fluid intake would reduce perceived hunger, as well as thirst scores, a VAS was also used to measure self-rated hunger scores.

As previous studies have shown that fatigue is sensitive to hydration level (Benton, 2011) and that fatigue has a detrimental effect on cognitive performance (Kahol et al., 2008) we also asked children to rate their subjective tiredness, again using a VAS. Ratings of fatigue were very relevant to this thesis as many studies have found that a large proportion of children come to school in a dehydrated state and so could potentially also have high levels of fatigue which might be affecting cognitive performance (Barker et al., 2012; Bonnet et al., 2012; Stookey et al., 2012).

In the present study, cognitive tasks were chosen that have previously been shown to be affected by water consumption. The reasons for this were twofold. Firstly, it was an aim of this study to determine whether results from previous studies were replicable and robust. Secondly, cognitive tasks were needed that have been shown to be sensitive to water consumption, so that it could be assessed whether performance may have been improved as a result of mood changes due to being given a free gift, rather than a result of physiological changes due to the water.

The letter cancellation task was chosen as it has been consistently sensitive to water consumption (Booth et al., 2012; Edmonds & Burford, 2009; Edmonds & Jeffes, 2009). This task requires the participant to differentiate between the distractor and target stimuli and to draw a line through as many target stimuli as possible in the time provided (Eysenck & Keane, 2005). This task measures mainly perceptual speed, and to a lesser degree movement time (O’Connor & Burns, 2003).

Visual memory has also been shown to be sensitive to water consumption. Both object recall tasks and spot-the-difference require visual memory, and scores in both object recall tasks and spot-the-difference tasks have improved after water consumption in previous studies (Edmonds & Burford, 2009). In the object recall task, participants try to recall objects immediately after seeing them which utilises STM, and after a delay, which utilises retrieval (Dumont, Willis, & Elliott, 2008). In the version of the spot-the-difference task used by Edmonds & Burford (2009) the task also requires attentional skills (Yuhong & Olson, 2000).

In the task children were shown a picture for a fixed period of time, the picture was then removed and replaced with another picture in which several changes had been made and the children were required to circle the changes. Edmonds and Burford (2009) found that children who were supplemented with water improved significantly more than those who did not have a drink. However, Edmonds and Jeffes' (2009) study did not replicate this finding, but this was considered to be due to a large proportion of children performing at ceiling before the intervention.

The digit span task was chosen for the present study, because it has been shown to be sensitive to dehydration in previous studies. The previous studies found that children that came to school voluntarily dehydrated did less well in the digit span task than children that were euhydrated (Bar-David et al., 2005; Fadda, 2012). The digit span task requires the participant to listen to a list of numbers and to repeat them back in their original order. It tests short term auditory sequential memory and attention (Dumont et al., 2008).

Psychomotor tasks have been shown to be sensitive to dehydration (see Chapter 2). However, as different psychomotor tasks require a variety of cognitive skills it is difficult to interpret whether cognitive domains or motor performance were affected by hydration status. Therefore, this study used a task with very little demand for cognitive skills to determine whether water consumption has an effect on fine motor skills. Bead threading was chosen, which assesses fine motor control (Ramus, Pidgeon, & Frith, 2003).

Hypotheses were tested:

1. That consuming water would improve cognitive performance compared to not consuming water.
2. That being given a bottle of water to drink later (free gift) would improve cognitive performance compared to not being given a bottle of water.
3. That consuming water would increase subjective ratings of positive affect compared to not consuming water.
4. That being given a bottle of water to drink later (free gift) would increase subjective rating of positive affect compared to not being given a bottle of water.
5. That self-rated thirst scores would correlate negatively with mood and cognitive performance**.**

3.2 Method

3.2.1 Design

The study had a single blind, independent measures design. The between subjects variable was the drink condition (DRINK/NO DRINK/GIFT) and the dependent variables were the task and mood scores. The children were tested in classes and each class was randomly assigned to a drink, no drink or gift condition. In the drink condition children were given a 330ml bottle of water to drink, in the no drink the children were not given a drink and in the gift condition children were given a bottle of water to put away and drink later. The researcher was blind to the condition when administering the tasks. Participants completed tasks before and 20 minutes after the drink intervention and effects on cognitive performance and mood were assessed. Timings were the same as those used in the study by Benton and Burgess (2009). A more detailed justification for the absorption period can be read on page 189. Figure 3.1 shows the study design.

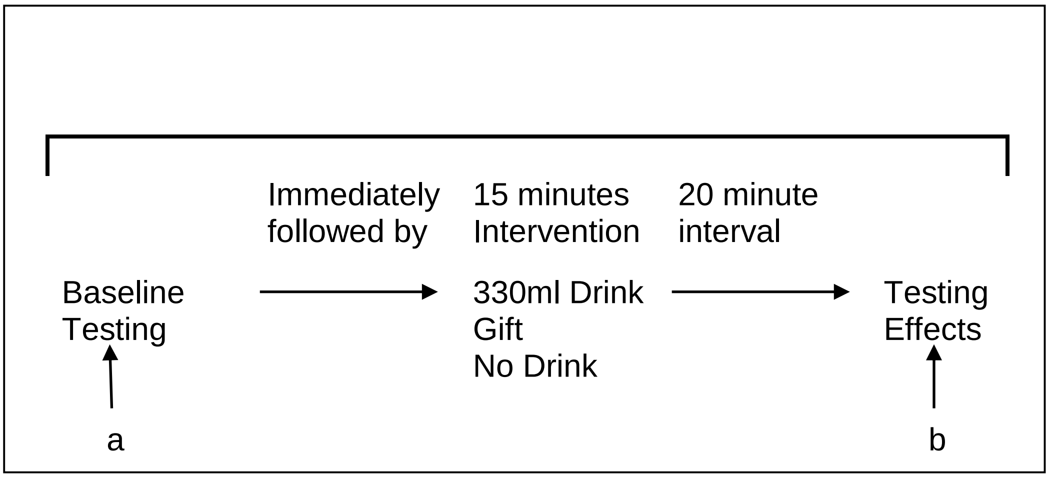


Figure 3.1 Study Design

3.2.2 Thesis Ethics

To recruit primary schools in the Essex and Newham area close to UEL, written and email invitations were sent to the head teacher. Before a school consented to take part in the study a researcher visited the head teacher to show them the study design and tasks and to answer any questions. The head teacher and class teachers involved in the study had to provide written, informed consent. Prior to participating in the study, children were given information and consent forms to take home to their caregivers/parents. An example of the parents and children's information and consent form is given in Appendix I. Both the parent and the child had to sign the consent form in order that the child could participate. If at any time a child wished to withdraw from the study they were able to do so and their data were withdrawn. If the child did not meet the criteria, but still received consent to take part and wished to do so, they were not excluded but their data were excluded from the analysis. This was to prevent the child feeling excluded. A child did not meet the criteria if they were not able to complete the tasks independently and required individual help in the tasks due to severe learning or medical disorders.

The same ethics procedure was repeated for each subsequent study and thus will not be described separately in each chapter. Each study was approved by the University Of East London School Of Psychology Ethics Committee and was carried out in accordance with the Declaration of Helsinki. The Ethics Committee approval letter can be seen in Appendix II. For study 1, a written protocol was completed for the study sponsors Nestec Ltd which was signed by myself, the Director of Studies from the University of East London and the project manager, reviewing statistician, data manager and clinical project manager at Nestec Ltd. Thereafter, the collaboration between Nestec Ltd and the University of London was terminated, and studies 2 to 5 only required ethical approval from the University of East London.

3.2.3 Participants

Three classes of Year 5 schoolchildren attending one Essex primary school were invited to participate in the study. The ages ranged between 9 years 7 months to 10 years 5 months; mean age was 10 years. The school was a large school, with a larger than average percentage of children from ethnic minorities, and children coming from a diverse range of economic and social backgrounds (Ofsted Inspection report, 2007). Eighty one children returned completed consent forms. Data from 77 children (40 male) were included in the final analysis. Three children (2 male, 1 female) had their data excluded because they did not complete the tasks. One child's (male) data were removed as he required help from an adult to complete the tasks. In this study 50 % of the children from the reduced sample were White- British, 21 % Black-African and the remainder of the children had a variety of ethnic backgrounds. Table 3.1 provides more detailed information on ethnicity and participant characteristics.

A power calculation revealed that the number of participants was adequate, as a sample size of 77 would provide an 80 % chance of a medium effect size (Cohen, 1977) being detected, with an alpha level of .05.

Table 3.1
Table of Demographic Details for Participants

Conditions		**Water** n=28	**Control** n= 26	**Gift** n = 23
Mean Age		10 y	9 y 11 m	10 y
Gender	**Female**	8	15	14
	Male	20	11	9
English as 1st Lang.	**Yes**	23	19	20
	No	3	7	3
	Missing Data	2	0	0
Ethnicity	**White English**	12	15	12
	Black African	8	4	4
	Other	8	7	7
Educational Needs	**Gifted and Talented**	2	0	1
	School Action	6	3	6
	School Action +	3	1	0

3.2.4 Measures

A battery of cognitive tasks were prepared. The tasks were presented in the order shown in Figure 3.2 and parallel forms of the task were given at baseline and test.

Figure 3.2 Tasks Included in the Task Battery in the Order That They Were Completed.

3.2.4.1 Mood Scales

Subjective feelings of thirst, hunger, happiness and fatigue were measured using visual analogue scales (VAS).Each VAS consisted of a 140mm horizontal line which was end-anchored with a picture and a statement. For example, the VAS for happiness had a sad face at 0mm and the statement ‘sad’ and a happy face at 140mm and the statement ‘happy’. Examples of the VAS used are given in Appendix III**.** For the hunger and thirst ratings 0mm depicted ‘not thirsty or hungry’ and at 140mm the statement said ‘thirsty’ or ‘hungry’. The VAS for fatigue had ‘tired’ at 0mm and ‘not tired’ at 140mm. The children were asked to mark along the line to show how they felt in that moment. The dependent variable was the self-rated score of happiness, hunger, fatigue and thirst, which was measured by the number of millimetres from one end of the line to the child’s mark. The number of millimetres was converted to a percentage, thus the score ranged from 0 to 100.

3.2.4.2 Cognitive Measures

- Object Recall Task

This task was adapted from the object recall task used in Benton and Burgess' (2009) study as it was being administered to a group rather than individuals. In this task, participants viewed a sheet on which 15 pictures of everyday items were displayed. The items were selected by finding pictures of objects that appeared in the high frequency words list (MRC Psycholinguistic database, 2010). Two different sheets were prepared, one for baseline and one for test, with different pictures on each. The sheets were counterbalanced. The participants in this study were given 30 seconds to look at the pictures. They then had to turn the sheet over and from memory recall as many pictures as possible in 1 ½ minutes. The children were instructed to write down the names of the objects and told that no marks would be deducted for incorrect spelling. The recollection time was increased from the 1 minute provided in Benton and Burgess (2009) study to 1 ½ minutes in this study, as oral recollection which was used in Benton and Burgess (2009) would take less time than writing down object names. The score was the number of correctly remembered objects. For an example of the Object Recall task see Appendix IV

- Letter Cancellation Task

The task consisted of an 18cm x 18cm square containing a 20 x 20 grid. The target stimulus was the letter U (n= 38) and distractor stimuli were similarly formed letters C, V & O (n=362), see Figure 3.3. A similar grid was used in Edmonds and Burford's (2009) study. Participants were instructed to find and draw a line through as many of the target stimuli as they could in 45 seconds. The score was the number of correct responses (maximum 38).

O	O	U	O	O	V	O	U	O	O	C	O	O	O	O	O	O	V	O	O
O	C	O	O	U	O	O	O	V	U	O	O	O	V	O	O	O	O	C	O
O	O	V	O	O	O	O	U	O	O	O	O	O	U	V	O	O	O	O	O
V	O	O	O	O	O	V	O	O	O	O	U	O	O	O	O	O	O	O	U
U	O	O	O	O	O	O	O	U	V	O	O	O	O	O	C	O	O	V	O
O	O	O	V	O	U	O	O	O	O	O	V	U	O	O	O	U	O	O	O
U	O	O	O	O	O	O	O	O	O	V	O	O	O	U	O	O	O	O	O
O	V	O	O	U	O	O	O	O	O	U	O	O	O	O	O	U	O	O	V
O	O	O	U	O	O	O	O	O	V	U	V	O	O	O	O	O	O	O	O
O	O	O	O	O	O	U	O	O	O	O	O	O	U	O	O	U	V	O	O
O	O	O	O	U	O	O	O	O	O	O	O	O	O	C	O	O	V	O	O
O	U	O	O	O	O	U	O	O	O	O	O	O	O	O	O	O	O	O	O
O	O	V	O	O	O	O	O	O	O	O	O	O	U	O	O	V	O	O	O
O	O	O	C	O	O	O	O	U	C	O	O	O	O	O	O	O	O	U	O
U	O	O	O	C	O	O	O	O	O	U	O	O	O	O	V	O	O	O	C
O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	U	O	O
O	O	O	O	U	O	C	O	O	O	O	O	V	O	O	U	O	O	O	O
O	O	V	O	O	V	O	O	O	O	O	O	O	O	O	O	O	O	O	O
O	O	U	O	O	O	O	O	U	O	O	O	O	C	O	O	U	V	O	O
O	V	C	O	U	O	O	O	O	O	O	O	V	O	O	O	O	O	O	O

Figure 3.3 An Example of the Letter Cancellation Task

- Spot the Difference

In this task the children were presented with a picture for 1 minute. The pictures were simple, cartoon pictures (Spot The Difference, 2010) see Figure 3.4 for an example. The picture was removed and the children looked at a blank sheet for a few seconds to prevent visual pop-out effects (Rensink, 2002). The children were then given another identical picture but

10 items in the picture were different, they had been changed, added or deleted (critical probes). The children had 1 minute to find the critical probes, from memory, and circle them. The score was the number of critical probes (maximum 10) that the children identified correctly minus the number of incorrect responses.

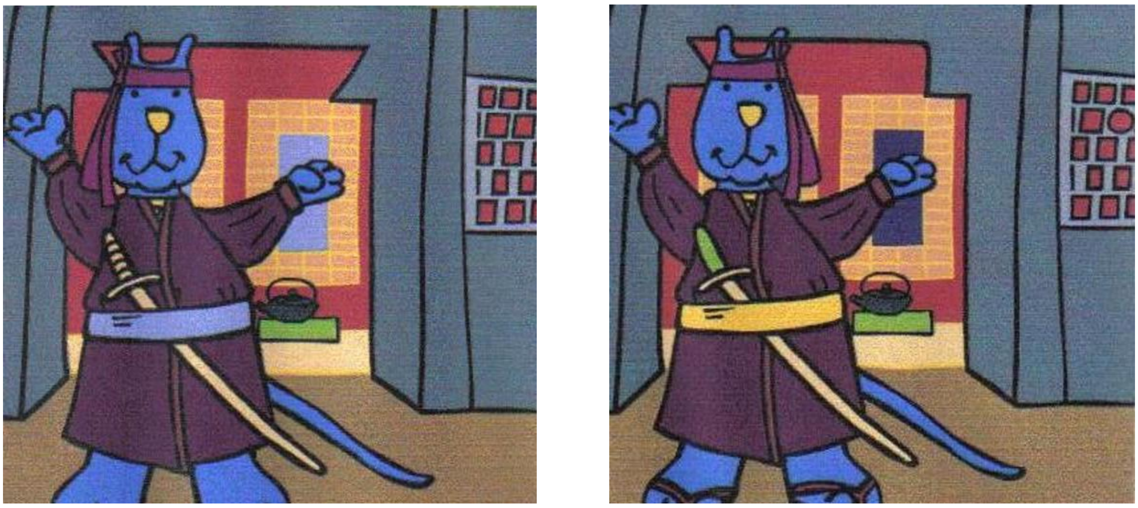


Figure 3.4 Example of Pictures used in Spot-The-Difference Task.

- Digit Span

  The task was adapted from the digit span in the Wechsler Intelligence Scale for Children III so that the task could be administered to a group rather than an individual. In the original design of the digit span task participants had to orally repeat the sequence back to the researcher but for this study the children had to write down the number sequence in a grid in the response booklet. The children were instructed to place their pencil or pen on the desk when each sequence was read out and were only allowed to pick up the pen or pencil and write down the sequence when the researcher had completed orally presenting the sequence and on the researchers command. After writing down each sequence the children placed the pen or pencil back on the desk. In the original digit span task, the task stops when an individual has incorrectly recalled two consecutive sequences, but this is not possible for a group setting and therefore, all the sequences were orally presented. There were 12 different sequences of digits and the first sequence had a length of two digits. The number of digits in the sequence increased by one digit on every second sequence. The maximum number of digits in one sequence was seven digits. An example of the digit span task is given in Appendix V. The score was the number of digit spans that the participant remembered correctly which equated to length as the more sequences the participant remembered the longer the digit span.

- Bead Threading

Each participant was given a piece of string, approximately 5cm in length with a knot at one end, and a box of plastic, barrel beads. The box contained approximately 50 beads. The participants were given 45 seconds to thread as many beads onto the string as they could. Participants were told not to create a pattern with the beads which could have delayed their progress. The score was the number of beads threaded on the string at the end of the timed period.

- Delayed Object Recall

  This task required the participants to recall, and write down, as many of the objects that they could remember from the object recall sheet which they had been presented with at the beginning of the test battery, 30 minutes previously. The score was the number of objects correctly remembered.

3.2.5 Intervention

The condition in which each class participated was assigned spontaneously by a third party and the researcher remained blind to the condition. In each class, every child was given either; a 330ml new, unopened bottle of water to drink immediately (drink condition; n = 28; 20 male), a 330ml new, unopened bottle of water to put in their bag until after the completion of testing (gift condition; n = 23; 9 male), or no bottle of water (no drink condition; n = 26; 11 male). Fifteen minutes was allowed for the intervention during which time participants also read quietly. Those in the drink condition were encouraged to drink all of the water but they were not coerced.

3.2.6 Procedure

The same testing procedure was carried out in all three classes, on consecutive days, during a one week period. Appendix VI presents a detailed description of the timetable. On the day of testing the researcher administered two parallel testing sessions, each of which lasted approximately 30 minutes. The pre-intervention session took place at 10:00am and established baseline performance. After this testing session was completed, the researcher left the classroom whilst the intervention was administered. Thus, the researcher was blind to the condition. After the intervention, the children went out to play for 15 minutes. Upon their return, the children and the researcher returned to the classroom and the post-intervention testing session was administered approximately 20 minutes after the intervention was completed.

3.3 Results

3.3.1 Primary Analysis: the Effect of Being Given a Gift and Drinking Water on Mood and Cognitive Performance (Hypothesis 1 and 2).

3.3.1.1 Data Analysis

The data from each of the mood VAS scales and cognitive tests were analysed using a one way independent measures analysis of covariance (ANCOVA). An ANCOVA was chosen because at baseline some of the task scores were significantly different between conditions. Table 3.2 shows the significance levels of baseline scores when analysed using a one-way ANOVA. An ANCOVA allowed us to be able to control for baseline differences by including the baseline score as a covariate. Additionally, the demographic variables; gender, age, language and educational issues, were added as covariates but they made no difference to the results and so are not mentioned in the statistics section. DRINK (DRINK/GIFT/NO DRINK) was the independent measure and the test scores were the dependent measure. Post-hoc comparisons were carried out to show where differences lay when a main effect of DRINK was identified. An alpha level of .05 was used for all statistical tests. Post-hoc analyses were corrected using a Bonferroni adjustment.

3.3.1.2 Data Preparation

Data were cleaned and screened. All missing data were replaced with discrete missing values. Participants that had 50 % or more missing data were removed from the analysis. The data were then checked for outliers by inspecting boxplots and it was determined if outliers were due to genuine scores or entry error, in which case re-entry of the correct value was required. Outliers were replaced with a score that was one unit higher than the next highest score to prevent them influencing the mean (Dancey and Reidy, 2004; Field, 2009). The same procedure was repeated for each subsequent study and will not be described again.

The data were checked to determine whether they met the assumptions for an ANCOVA. By visually observing scatterplots, it was confirmed that baseline and test data had a linear relationship. The interaction term for each of the cognitive task scores was not statistically significant, thus the assumption that there was homogeneity of regression slopes was met. A Shapiro-Wilk test was used to analyse the standardized residuals and results showed that group residuals were normally distributed. Observation of scatterplots of standardized residuals against predicted values showed the values were randomly distributed and thus met the assumption of homoscedasticity. The Levene's test and Hartley's F max test (Field, 2009) was used to check homogeneity of variance.

Self-rated fatigue, self-rated thirst and bead threading data did not meet the assumption for homogeneity of variance thus the data were not suitable for an ANCOVA analysis or an ANOVA analysis using baseline and test scores. As an alternative, change scores were calculated by deducting test scores from baseline scores and a One Way ANOVA was used to compare the self-rated thirst and bead threading change scores in the DRINK conditions (DRINK/GIFT/NO DRINK). However, the self-rated fatigue change scores did not meet the assumptions for a One Way ANOVA and so a Krustal-Wallis test was used for analysis instead.

3.3.1.3 Results

Data presented in Table 3.2 shows the unadjusted mean baseline scores and test scores, standard deviations (SDs) and significance levels at baseline and test for the relevant analyses. Observation of the results for the mood scales in Table 3.2 shows that the effect of DRINK on self-rated thirst approached significance ($F(2,72) = 2.81$, $p = .067$). Therefore, a post hoc t-test was carried out between the NO DRINK and DRINK group with a bonferonni adjusted level of .025 (.05/2). The thirst ratings of the NO DRINK group indicated that they rated themselves as becoming significantly thirstier than the DRINK group between baseline and test ($t(50)=-2.368$, $p= .022$). This was a medium effect size ($r =.30$). Observation of Table 3.2 shows that there were no statistically significant effects of DRINK on hunger or fatigue.

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Table 3.2

Means, SD, and Significance Levels (One-Way ANOVA at baseline and ANCOVA at test) for Mood and Cognitive Task Scores by Drink Condition

	Drink				No Drink				Gift					
	Baseline		Test		Baseline		Test		Baseline		Test		Baseline One-Way ANOVA	Test (adj-scores) ANCOVA
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	*p* value	*p* value
Self-Rated Thirst	47.89	22.97	35.00	24.92	57.40	28.16	66.42	32.83	48.78	25.03	47.13	25.47	.343	0.067*
Self-Rated Fatigue	65.07	25.60	66.75	31.44	64.64	24.12	75.57	22.18	68.78	18.33	78.78	14.96	.794	0.46**
Self-Rated Happy	72.52	21.67	66.57	31.27	75.32	24.39	71.63	24.45	78.91	18.57	77.55	23.34	.587	0 .504
Self-Rated Hunger	45.11	27.27	62.00	27.96	48.28	30.26	66.25	27.30	41.78	21.33	57.35	23.05	.703	0 .721
Object Recall	9.79	2.64	10.96	1.76	10.44	2.12	10.72	2.21	9.23	2.81	11.65	2.61	.365	0 .137
Letter Cancellation	25.67	5.65	29.79	4.97	30.43	3.65	32.81	5.45	26.86	5.00	27.23	4.75	**.003**	**0 .007**
Spot	4.31	00.97	3.65	2.60	4.43	00.35	3.78	00.33	4.30	1.42	3.87	1.60	.382	0.933
Digit Span	9.19	1.15	9.21	1.37	8.31	1.52	7.96	1.28	8.45	1.41	9.26	1.32	.052	**< .001**
Bead Threading	11.08	3.15	15.11	4.58	13.40	3.46	14.48	3.87	11.52	2.64	13.09	3.13	**.024**	**0.004***
Delayed Obj. Recall	9.38	1.98	8.42	2.67	10.58	2.48	9.96	2.85	9.57	9.38	9.76	2.79	.187	0.132

Note: * = A one way ANOVA was used to analyse the change data. ** =A Krustal-Wallis H test was used to analyse these data.

When observing the results for the cognitive tasks, it can be observed that after adjustment for baseline scores, there was a significant effect of DRINK on letter cancellation scores, $F(2,67) = 5.388$, $p = .007$, $\eta^2 = .14$. Post hoc tests showed that with an adjustment for multiple comparisons, the DRINK condition ($p = .047$) and the NO DRINK condition ($p = .009$) had a higher letter cancellation score at test than the GIFT condition. The DRINK letter cancellation scores were not statistically higher than the NO DRINK scores

Results show there was an effect of DRINK on digit span scores, $F(2,71) = 7.836$, $p < .001$, partial $\eta^2 = .181$. Post hoc analysis with an adjustment for multiple comparisons showed that the test scores were statistically significantly higher in the GIFT condition ($p < .001$) vs the NO DRINK condition. There were no significant differences between the GIFT and DRINK condition or NO DRINK and DRINK condition.

Figure 3.5, shows the change scores for bead threading. The change scores were compared using ANOVA which showed that there was an effect of DRINK, $F(2,67) = 6.001$, $p = .004$ $\eta^2 = .15$. Post hoc tests, with adjustment for multiple comparisons, showed that the number of beads threaded in the DRINK condition increased significantly more, between baseline and test, than the NO DRINK ($p = .006$), and GIFT conditions ($p = .031$). However, there was a significant difference in baseline scores with the no drink condition performing at a higher level than the drink and gift conditions. Thus these children may have found it more difficult to increase their score further at test. There were no differences between DRINK condition in scores of immediate object recall, delayed object recall or spot-the-difference.

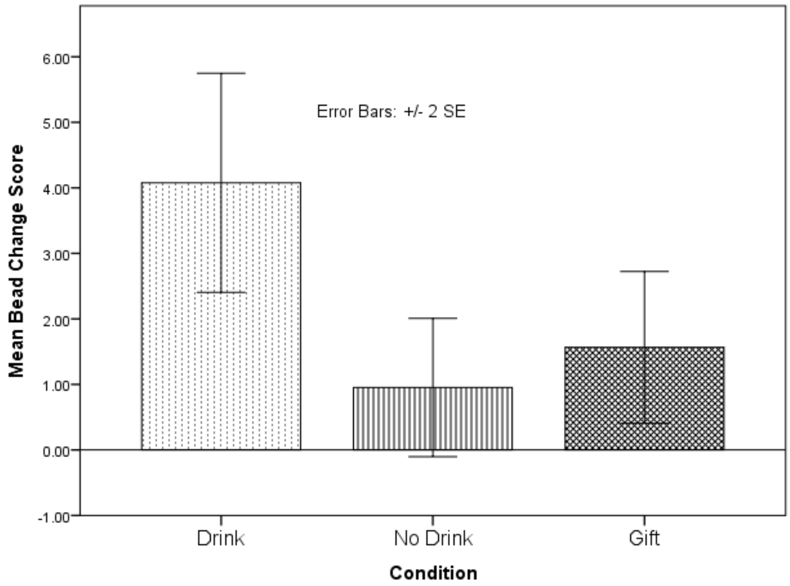


Figure 3.5 Bead Threading Change Scores

3.3.2 Primary Analysis: the Effect of Being Given a Gift and Drinking Water on Self-Rated Happiness (Hypothesis 3 and 4).

3.3.2.1 Results

Visual inspection of these data in Table 3.2 showed that all participants rated themselves as less happy at test than at baseline. There was no effect of DRINK condition on levels of self-rated happiness.

3.3.3 Exploratory Analysis: the Relationship between Self-Rated Thirst and Cognitive Performance (Hypothesis 5)

3.3.3.1 Analysis

A correlation was used to determine if the self-rated thirst scores had a relationship with mood and cognitive baseline and test scores.

3.3.3.2 Data Preparation

The data were explored to confirm that they met the assumptions for a Pearsons Correlation Coefficient. However, a Shapiro-Wilks test showed that self-rated thirst scores were not normally distributed, thus a Spearmans correlation was used.

3.3.3.3 Statistics

At test, a medium correlation was found between self-rated hunger and thirst: as participants scored themselves as thirstier they also rated themselves as hungrier ($r_s(75) = .400$, $p < .001$). There were no significant correlations in each individual drink group other than the correlation between thirst and hunger which was found in the gift and no drink group. When baseline thirst and task scores were correlated the relationship between thirst and hunger only approached significance ($r_s(76) = .225$, $p = .051$) and there were no significant correlations in each individual drink group. There were no significant correlations when baseline thirst was correlated with test scores but when correlations were carried out in each individual group, there was a significant correlation between self-rated thirst and hunger in the gift group.

3.4 Discussion

3.4.1 Summary of Findings

One of the primary aims of this study was to determine whether mood and cognitive performance would be improved by having a drink in comparison to not having a drink. The results varied dependent on the mood or cognitive task in question. In the bead threading task the participants had a greater increase in the number of beads threaded, between baseline and test, in the drink condition compared to the no drink condition. Thus, the hypothesis that water consumption improves task performance was supported. In the letter cancellation task, participants in both the drink and no drink condition performed better at test than those in the gift condition. These results were unexpected and will be discussed further in 3.4.2. There was no effect of having a drink on performance on any other cognitive tasks. Observation of the effects of water consumption on mood show that participants in the drink condition rated themselves as significantly less thirsty than those in the no drink condition. There were no effects of drink on self-rated fatigue or hunger scores.

The second primary aim was to determine whether being given a free gift contributed to the effect of water consumption on mood and cognitive performance. In the digit span task, participants performed better at test in the gift condition than the no drink condition, thus supporting the theory that the gift aspect of being given a bottle of water would result in improved performance. However, the children in the drink condition did not perform better than the children in the no drink condition, thus being given a gift did not seem to contribute to the effect of drinking a bottle of water, and therefore this result may have been an idiosyncrasy. These contradictory results are discussed further in 3.4.2. There was no effect of being given a gift for any other task. Furthermore, the results did not support the hypotheses that being given a bottle of water to drink now or later would increase levels of happiness. Indeed, the trend was for participants to become less happy between baseline and test in all conditions.

An exploratory aim was to determine if there was a relationship between self-rated thirst, mood and cognitive performance. Correlations of self-rated thirst with mood and cognitive scores at baseline and test, showed that as participants rated themselves as thirstier they also rated themselves as hungrier. However, this correlation was only found in the no drink and gift group and not the drink group. There were no statistically significant relationships between cognitive performance and self-rated thirst. Thus the hypothesis that cognitive scores would correlate negatively with self-rated thirst scores was not supported.

In summary, these results suggest that being given a drink of water, but not drinking it, does not improve happiness or contribute to the physiological effect of drinking water. Drinking the water did improve performance in some tasks when compared to not drinking the water. Children that had a drink performed better than children that did not have a drink in the bead threading task, and children that were given a gift in the letter cancellation task. There was no effect of drinking water on the other cognitive tasks, which was unexpected given the results in the previous literature. The results for each cognitive task and mood scale will be discussed individually in the next section.

3.4.2 Examination and Implications of the Findings

The literature has shown that water consumption improves performance in most of the tasks included in this study and it was expected that the results would replicate these findings. However, because a positive effect of water was not found for performance on some of the tasks, this section will discuss the results for each task individually and compare them with the findings from previous studies. Additionally, the effects of being given a gift and the relationship between self-rated thirst and task performance will be examined.

The results showed that, while there was a trend for children to rate themselves as less tired between baseline and test, there was no effect of drink condition on ratings of fatigue. As the dehydration literature shows that being dehydrated increases feelings of tiredness (see 2.3 for a review), and studies have shown that a large proportion of schoolchildren arrive at school in a dehydrated state (Barker et al., 2012; Bonnet et al., 2012), it was expected that many children would also come to school with increased feelings of tiredness. However, as the mean tiredness rating over the three conditions ranged from 64 to 69 (0 is tired), it suggests that children in this study did not feel particularly tired at baseline. Additionally, there was no significant relationship found between self-rated thirst and fatigue, which would be expected if thirst was a proxy measure of dehydration.

This study also investigated whether drinking water might reverse any feelings of fatigue that were due to dehydration. The findings suggest that water consumption does not reverse any feelings of fatigue although it should be considered that having a drink may have impacted self-reported fatigue if the children had been more tired at baseline. However, our findings are consistent with other studies in which adults supplemented with water showed no decrease in ratings of tiredness or increases in how energetic they rated themselves as feeling (Edmonds et al., 2013; Edmonds, Crombie & Gardner, 2013). Furthermore, in a study in which adults had been deprived of water for 24 hours and levels of self-rated fatigue increased, being supplemented with water showed no reversal of fatigue ratings 5 minutes later, although 5 minutes may be too short a period of time for the reversal of a water deficit (Pross et al., 2013). In the current study, participants showed no difference in happiness ratings in the drink condition compared to the no drink or gift condition. These results are not in line with the findings from Edmonds and Jeffes (2009), which showed a positive effect of water consumption on self-rated happiness scores. However, in the Edmonds and Jeffes (2009) study the significant difference between conditions may have occurred because the no drink group had higher self-rated happy scores at baseline than the drink group, so had less opportunity to improve their rates of happiness. The present findings are consistent with the results from Booth et al. (2012), which did not show improvements in happiness ratings after water supplementation. The present results suggest that any improvement to cognitive performance after being given and drinking a bottle of water was not due to increased levels of subjectively perceived happiness.

All the children in this study rated themselves as becoming progressively hungrier, between breakfast and lunchtime, which is what would be expected, with no significant differences between the conditions. However, as ratings of hunger increased so did self-rated thirst. If thirst is a proxy for dehydration, it would suggest that as children became more dehydrated they felt hungrier. This finding was supported when analysing each individual drink group as there were no significant correlations found in the drink group, only in the no drink and gift group. This is an important finding because obesity levels continue to rise in the UK and worldwide, and if being well hydrated can reduce feelings of hunger and consequently food intake it may help to counter rising levels of obesity (Corney, Sunderland & James, 2015). The relationship between self-rated thirst, hunger and hydration status will be investigated further in study 2 and 3.

In this study, participants in the drink condition rated themselves as becoming less thirsty between baseline and test, whereas participants in the no drink condition rated themselves as getting thirstier over time. It was expected that the results from the gift condition would mirror the no drink group results, because neither group had a drink, but instead the gift conditions level of thirst remained stable over time. This result is counterintuitive, because previous research shows that using a priming manipulation such as a picture of food increases the desire to eat (Lambert & Neal, 1991), thus it might be expected that being presented with a bottle of water would make participants feel thirstier. However, other research suggests that subliminal priming with thirst related cues only increases perceived thirst if the individual is already thirsty (Strahan, Spencer, & Zanna, 2002). In this study, the mean self-rated thirst score, at baseline, in the gift condition was 48.78, with a large standard deviation (SD), compared to 57.40 in the no drink condition, suggesting that a large proportion of the cohort may not have felt particularly thirsty. Furthermore, children went out to play in the playground after being presented with the bottle of water to drink later but before rating their thirst at test. Therefore, any acute increase in thirst rating due to seeing the bottle of water may have subsided. However, these arguments do not explain why the thirst rating for the gift condition should not be similar to the no drink condition. In previous research self-rated thirst change scores are consistently statistically significantly higher in children that have not had a drink than children that have a drink (Edmonds & Burford, 2008; Edmonds, Crombie & Gardner, 2013; Edmonds & Jeffes, 2009). This result is inconsistent with those findings. Future research could look at the priming effect on self-rated thirst of being given a drink but not being able to drink it. Additionally, these results do bring into question whether self-rated thirst is a proxy for dehydration as it would be expected that children would become as dehydrated in the gift group as the no drink group, and their thirst scores would get higher during a period of not having a drink. The relationship between self-rated thirst scores and dehydration will be explored further in Study 3.

In the immediate object recall task there were no significant differences, between conditions in performance at test. This finding is not consistent with Benton and Burgess (2009) study which reported that children who had a drink recalled more objects than those who did not have a drink. The difference in results may be explained by the slightly different study design. Benton and Burgess (2009) study had the children verbally recall objects while due to the group testing in the current study children had to write or draw the objects they remembered. It may be that the modifications to the test procedure in the present study did not allow the effect of water consumption on memory to be tested effectively. Drawing or writing down the names of objects may have taken longer than simple verbal recall and the time limits may have stopped recall prematurely. However, this notion seems unlikely because most of the children in this task were finished before the end of the allocated time. It is possible that Benton and Burgess' (2009) procedure drew more heavily on speed of processing than that used in the present study, because their study had a shorter timeframe in which to recall the objects. In this study the children were given longer to recall the objects. This result clarifies why it is important to be consistent in cross study design when replicating previous research. Further investigation in to the effects of water consumption on object recall task performance will be carried out in study 4 (chapter 6).

In the letter cancellation task, children in the drink condition performed better at test than those children in the gift condition. This result infers that being given a gift had no positive impact on performance, while drinking water improved cognitive performance. However, the children in the no drink condition performed similarly to the drink condition at test and significantly better than the gift condition. In previous literature children have consistently performed better when they have had a drink than when they have not had a drink. Therefore, this study will be used again in studies 2 and 3 to determine whether this result was an idiosyncrasy.

In this study, being given a drink or a gift had no effect on object recall delayed task performance, and it is suggested this may be due to the change in design condition. In this study, recalled objects were written down or drawn because of the group testing rather than verbal recollection which was the design in Benton and Burgess (2009) study. Furthermore, there was no effect of drink condition on spot-the-difference performance. Some previous research has reported positive effects of drinking water on visual memory (Edmonds &

Burford, 2009) thus, further investigation of the effects of water consumption on spot-the-difference performance will be carried out in Study 2 and 3.

In the digit span task, children in the gift condition performed better at test than those in the no drink condition. However, children in the drink condition did not perform significantly better than those in the no drink condition, thus it is suggested that the gift effect did not contribute to the effect of being given a bottle of water to drink, but is an independent effect. Any improvement of being given a bottle of water to drink later, such as additional effort or motivation, would also have improved performance in those children given a bottle of water to drink immediately. Therefore, it is suggested that drinking the water may have had a negative effect on digit span performance thus counteracting any positive effect of being given the bottle of water. Previous results from studies of the effects of hydration on digit span performance are very inconsistent with some studies showing a positive effect of hydration (Bar-David et al., 2005; Cian et al., 2001; Cian et al., 2000; Fadda et al., 2012; Gopinathan et al., 1988) and others who found a negative effect. For example, D’Anci et al. (2009) found that dehydration improved digit span and Edmonds et al. (2013) found that water consumption worsened performance. Other studies have found no effect of dehydration on digit span (Bradley & Higenbottam, 2003; Sharma et al., 1986; Szinnai et al., 2005). More in-depth research will be carried out in study 4 to determine the effect of water consumption on digit span performance.

In the bead threading task, children in the drink condition improved significantly more between baseline and test than children in either the no drink or gift condition. These results show that drinking water improved performance on this task, but being given a bottle of water and being unable to drink it had no beneficial effects. Very few studies have studied the effects of water consumption, or dehydration, on basic fine motor skills and findings are very inconsistent (see 2.2.1). The current finding suggests that fine motor skills, with minimal cognitive components, are sensitive to water consumption or hydration status. Further investigation into the effects of water consumption on fine motor skills will be undertaken in studies 2, 3, 4 and 5.

This study found no direct relationship between self-rated thirst and cognitive performance. Previous research has found that self-rated thirst moderates the effect of water consumption, on the Rapid Visual Information Processing task (RVIP) and simple reaction time task (SRT) task. Both these tasks are tests of attention and reaction time. Therefore, it is suggested that these specific cognitive skills are more sensitive to levels of thirst. Reaction time tasks were not included in the present study due to the group design but the effects of self-rated thirst and water consumption on reaction time and tasks requiring a large attentional component will be investigated in study 2, 3 and 4.

3.4.3 Methodological Issues

It is unfortunate that some procedural aspects of this first study were less than ideal. These aspects will be addressed in future studies. In this study the children were allowed out to the playground for a break between baseline and test, thus they were exposed to fresh air and physical activity, which may have had an independent effect on cognitive performance. There may have been an effect of having a drink, or not, on the amount of energy expended at play, which consequently may have affected cognitive performance at test (Veasey et al., 2013). It is possible that some children may have had a sip of water from the fountain or a snack. In studies in schools it can be difficult to have full control over the scheduling of testing sessions relative to school breaks and so on, but in future studies children will remain in the controlled environment at all times.

In this study, a pragmatic decision was made to allocate each class to a condition in order to reduce any inconvenience to the school, which would have occurred if we had mixed up the classes. When working in schools it is important to work with the teachers, and it can be hard to maintain optimal study design. One advantage of the design in this study was that it reduced the possibility of demand effects because children in one condition could not see children in a different condition, during the intervention, which might have changed their performance at test. However, assigning whole classes may have introduced cluster effects. For example, the class teacher may have been very strict in one class and consequently the children may have learned to be quiet and work quickly and efficiently, whereas in another class the teacher may have been more relaxed allowing the children to talk and take their time. Thus, the teacher may have had some influence on the children's attitude to the tasks in the study and consequently, the results (Field, 2009). Differences in baseline performance between conditions and reduced *p* values may be a consequence of cluster effects (Lauer, Kleinman, & Reich, 2015). Future studies will have a crossover design and test individuals, or more than one cluster will be included in a condition. For example, children from different classes and different schools will participant in the drink condition, and thus reduce any possible cluster effect.

3.4.4 Conclusion

In conclusion, the results of this study suggest that the beneficial effects of drinking water on cognitive performance are due to the drinking of the water, rather than being due to an increase in positive affect after being given a free bottle of water. Children that consumed water had an improved performance in the bead threading task compared with children that were in the No Drink condition and did not consume water. However, this task utilises an array of cognitive domains, for example, motor speed and visual perception and it is difficult to determine with any degree of certainty which domain may be sensitive to water consumption. Therefore, the next study will seek to identify which component parts of cognitive performance are most sensitive to water consumption.

CHAPTER 4

Study 2: Does Volume and Perceived Thirst Moderate the Effects of Water Consumption on Cognitive Performance and Mood?

4.1 Introduction

The primary aim of this study was to investigate:

- Whether children's cognitive and motor performance improved after a drink of water compared to an occasion when they did not have a drink of water.

The secondary aim of this study was to investigate:

- Whether self-rated thirst moderated the effect of water consumption on cognitive performance.
- The effect of the volume of water consumed on cognitive performance.

An exploratory aim was to investigate:

- The effect of estimated volume of fluid ingested at breakfast on ratings of thirst and cognitive performance.

In study 1 it was found that water consumption improved performance in the bead threading task. However, successful performance in this task requires more than one cognitive skill. Furthermore, it is possible that certain specific cognitive skills utilised may be more sensitive to water consumption than others. For example, the beading threading task requires hand/eye coordination which utilises visual processing and coordination of fine motor movement and speed; any one or more of these distinct domains may be sensitive to water consumption. Therefore, an aim of this study was to try and determine which specific component cognitive domains were more responsive to water consumption. The rationale for each task is discussed in 4.1.1.

A further aim of the current study was to consider whether the sensation of thirst is a mechanism that may facilitate the water consumption effect on cognitive performance. There is evidence to suggest that the sensation of thirst moderates the effect of water consumption on cognitive performance. Rogers et al. (2001) study found that participants who had a high rating of thirst at baseline showed improvement in cognitive performance after having a drink, whereas participants who had a low rating of thirst at baseline had a deterioration in performance after a drink. It was suggested that thirst ratings may be a proxy measure of dehydration. The participants, who rated themselves as high on the thirst scale, may have been suffering from dehydration and the underlying physiological mechanisms which occur during dehydration may have had a negative effect on cognitive performance, which were then reversed after a drink.

However, there may be an alternative explanation. The subjective experience of thirst is influenced by habit, feeling, social customs and a dry mouth (Buehrer et al., 2014; McKinley & Johnson, 2004) It is possible to feel thirsty without being dehydrated (Ramsay & Booth, 1991). Therefore, the sensation of thirst may reduce cognitive performance as it is a distraction and diverts attention away from the task in hand rather than occurring as a result of a physiological process. This theory is consistent with findings from a study by Edmonds, Crombie and Gardner (2013). In this study participants were divided into a high thirst and low thirst group at baseline dependent on self-ratings of thirst and on one occasion participants were given 500ml of water to drink and on one occasion they were not given a drink. Results from the SRT task showed that all participants' reaction times speeded up between baseline and test except for those participants in the high thirst group who did not have a drink. These results may be interpreted as meaning that participants that rated themselves as high on the thirst scale were too distracted to perform well on the task. Moreover, if the subjective thirst sensation is removed or reduced cognitive performance may improve as there is no longer a distraction. This topic is elaborated upon further in Chapter 5.

This study will also investigate whether the volume of water drank moderates the effect of water consumption. A dose response relationship between the volume of water drank and cognitive performance has previously been found (Rogers et al., 2001). A positive dose response was found between volume drank and cognitive performance in participants who had a high subjective self-rating of thirst. Conversely, a negative dose response between volume drank and cognitive performance was found in participants who had a low thirst rating. However, this result was not supported in a study by Neave et al. (2001). Results from Booth et al. (2012) showed that ball catching skills, which require hand/eye coordination, improved more in children who had drank more than 200ml of water compared to those who had drank less than 200ml.

The volume of water drank may be a significant factor in improving performance.

4.1.1 Rationale for Mood Scales and Tasks

An aim of this study was to investigate whether thirst moderates the effect of water consumption on cognitive performance or has a dose response relationship with performance or mood. Therefore, a visual analogue scale was included to measure ratings of perceived thirst. This scale was used successfully in study 1. It was also considered that fluid consumed in food and drink before coming to school may have had an effect on thirst ratings and cognitive performance at baseline. Consequently, children were asked to write down what they recalled having to eat and drink that morning, in as much detail as they could remember. An estimation of fluid ingested on the morning of testing was calculated using CompEat Nutrition System software. Although weight of food types was not recorded the CompEat programme contains nutritional analysis for different typical units of food, for example a slice of bread, one large muffin, a small banana, a teaspoon of jam and small, medium and large portions. In this thesis, if another unit was not appropriate, a ‘small’ portion of the food type was typically chosen for analysis.

In this study a rating of perceived hunger was included because results a study by Buehrer et al., (2014) found that ratings of hunger and thirst strongly correlate. Therefore, it was deemed important that ratings of hunger be collected.Subjective ratings of happiness were also measured. Whilst study 1 found no effect of water consumption on ratings of happiness Edmonds and

Jeffes (2009) study did find an effect of water consumption on self-ratings. As ratings of happiness could potentially be an important moderator of cognitive performance (Erez & Isen, 2002) it is important that it be determined through replicable research whether water consumption does have an effect on ratings of happiness. Rationales for the cognitive tasks included in the testing are discussed next.

In study 1 the bead threading task, which requires visual processing and coordination of fine motor movement and speed, was found to be sensitive to water consumption. Participants threaded more beads when they had a drink compared to when they did not. To determine which aspects of the bead threading task were most sensitive to water consumption a simpler task was introduced in the current study which only requires motor control and speed without visual processing (Christianson & Leathem, 2004). The finger tapping task is often used as part of the Halstead-Reitan neuropsychological test battery to assess neurological damage as it is a test of speed which is a precise, specific aspect of motor performance. The aim of the current study was to investigate whether perceived thirst, volume drank or hydration status moderated the effect of water consumption on a measure of motor speed.

In this study the design of the letter cancellation task was changed so that it could be determined whether predominantly perceptual speed or motor skills were sensitive to water consumption. In Study 1 performance in the letter cancellation task was shown to improve in those children that had a drink compared to when they were given a bottle of water but did not drink it; and performance on this task has consistently been improved by water consumption in previous studies (Edmonds et al., 2013; Edmonds & Jeffes, 2009; Edmonds & Burford, 2009). There are many different processes required in the letter cancellation task, including motor speed, control, selective attention and perceptual speed, but a study by O'Connor & Burns, (2003) suggests it mostly requires perceptual speed. Findings by Edmonds & Pirie (unpub) showed that when children were asked to find all the target letters in a grid "as fast as possible" they completed the task more quickly when they had a drink compared to when they did not have a drink. However, when the children were just asked to find all the target letters in a grid, under no time pressure, but were surreptitiously timed, there was no difference in performance between the two conditions. The interpretation of the results by the authors was that perceptual speed was sensitive to water consumption and motor speed was not. The letter cancellation task was used in this study both in a speeded and non-speeded version to assess whether the speeded version performance was more sensitive to water consumption.

The present study will explore the effects of water consumption and thirst on reaction time. Reaction time tasks require motor speed, control, selective attention and perceptual speed. Findings from studies (D'Anci et al., 2009; Ganio et al., 2011; Patel et al., 2007) show that dehydration does not have an effect on SRT performance. Conversely, in the water consumption research literature, a study by Edmonds, Crombie and Gardner (2013) found significant differences in reaction time change scores between the low and high thirst group: the participants with a high thirst rating who did not have a drink had a slower reaction time than participants with a high thirst rating that had a drink or participants who had a low thirst rating regardless of whether they had a drink. Conversely, the choice reaction time task (CRT) has not been found to be sensitive to either dehydration or water consumption in previous studies (Bradley & Higenbottam,2003; Edmonds, Crombie & Gardner, 2013; Ely, Sollaney, Cheuvront, Lieberman & Kenefick, 2013). The choice reaction time task is a dual task requiring both accuracy and speed and an element of decision making and hand eye coordination. Previous studies which have found no effect of hydration status or water consumption on the CRT have tested adults and not children. This is the first time that the effect of water consumption on CRT and SRT task will be tested on children.

To date, the effect of water consumption on the inhibition of motor response has not been investigated. However, Adam et al. (2008) found no effect of dehydration on ‘sentry duty task’ performance. Conversely, a study investigating the effect of dehydration and alcohol consumption on motor inhibition found a negative effect of dehydration on performance (Irwin, Leveritt, Shum, & Desbrow, 2013). In the study by Irwin, et al. (2013), all participants were dehydrated at baseline but then completed the tasks in a variety of conditions. The participants either remained dehydrated and were given alcohol, remained dehydrated and were not given alcohol or were rehydrated and given alcohol. The participants’ Stop Signal Reaction Time (SSRT) was much slower when the participants were dehydrated and given alcohol than when they were not given alcohol or rehydrated and given alcohol, suggesting that the dehydration was a moderating factor in the increase in SSRT. The present study will look in more depth at the sensitivity of SSRT task performance to water consumption and thirst.

The present study will also include a spot-the-difference task in the test battery. No effects of water consumption were found in Study 1 but results from Edmonds & Burford's (2009) study suggest that performance may be sensitive to hydration status. The task parameters were changed for the present study so that a faster speed of information processing was required as it was observed in study 1 that most participants had finished before the end of the time allotted for the task.

Furthermore, the relationship between water volume and cognitive performance, and the moderating effect of self-rated thirst on cognitive performance, were investigated. Several hypotheses were tested:

Hypotheses

1. That having a drink would improve cognitive and motor performance and mood levels compared to not having a drink.

2. Those children in the high thirst group would improve their cognitive performance more, after having a drink, than children in the low thirst group.

3. That there would be a positive dose-related response between volume drank and mood and cognitive performance.

4. The estimated volume of fluid ingested at breakfast would correlate positively cognitive performance at baseline.

4.2 Method

4.2.1 Design

The study was a repeated measures design. On one occasion participants were given a drink (drink condition) and on the other occasion they were not (no drink condition). The interventions were counter balanced. The children completed tasks before and after the intervention on both occasions. Each child was tested individually. While group testing has been used in studies 1 and 5, in the present study individual testing was required as some of the tasks could not be administered in a group setting. For example, the letter cancellation task required timing for individual children.

4.2.2 Participants

Fifty seven children participated in the study. Data were removed for 8 participants as they did not complete all of the cognitive tasks. From this point the description of the sample refers to the 49 children after the exclusions. For details of all the exclusion criteria see section 3.2.2. Data came from 18 males and 31 females and the mean age was 10 years 11 months. Fifteen of the 49 children attended a primary school in Newham. An Ofsted report stated that most pupils from this school were from ethnic minority backgrounds and approximately 75 % of the children came from homes in which English was spoken as a second additional language. The proportion receiving free school meals was above average ("Ofsted Report," 2010). The remaining 34 children attended a primary school in Essex. A high number of pupils attending this school were White British and the percentage of children coming from homes in which English was spoken as an additional language was below average, as was the proportion receiving free school meals ("Ofsted Report," 2010). The post-hoc power analyses showed that the sample size of 49 provided a 92 % chance of detecting a medium effect size (t = 0.5; cf. Cohen, 1977), with an alpha level of .05 (two tailed).

4.2.3 Measures

Children were given a battery of tasks to complete at baseline and test on two different occasions except for the StopSignal (SSRT) task, which was given at test only. Tasks were presented in the order shown in Figure 4.1. Parallel versions of the spot-the-difference tasks and letter cancellation tasks were used and six different versions were developed and pilot tested in order to determine that the four final versions used were very similar in terms of level of difficulty.

Figure 4.1 Cognitive Tasks Included in the Task Battery in the Order That They Were Completed.

4.2.3.1 Mood Scales

Three visual analogue scales (VAS) were used to determine subjective feelings of thirst, hunger and happiness. The scales were each 100mm long and end-anchored with a picture and statement to symbolise ‘not’ thirsty, happy or hungry at 0mm and ‘very’ thirsty, happy and hungry at 100mm. The dependent variable (DV) was the degree of thirst, happiness or hunger measured by the number of millimetres from the left hand side of the line to the child's mark.

4.2.3.2 Cognitive Measures

- Non-Speeded Cancellation Task

  The task consisted of a 20 x 20 grid which measured 18cm x 18cm. The target stimulus was the letter C (n = 38) and distractor stimuli O, V & U (n=362) and parallel versions were developed one for baseline and one for test. For an example of the grid see Appendix VII. The children were told to "Find every letter C and draw a line through them. Do the task as carefully as possible so that you don't make any mistakes. If you make a mistake carry on." The children were told when to start and to tell the researcher when they had finished. The session was surreptitiously timed by the researcher. The DV was the time taken in seconds to complete the task.

- Deary-Liewald Simple Reaction Time Task (SRT)

  The participants sat in front of a computer screen. When the letter 'X' (stimulus) appeared on the screen the children had to tap any key on the keyboard, with a finger on their dominant hand, as quickly as possible. The stimulus remained on the screen until a key was pressed. The task involved eight practice trials and 20 test trials. The DV was the reaction time (ms).

- Deary-Liewald Four Choice Reaction Time Task (CRT)

  Facing the computer screen, the children placed their middle and index finger of their left hand over the 'Z' and 'X' key on the keyboard and their middle and index finger of their right hand over the comma and full stop keys. On the screen were images of four empty boxes. Each box corresponded with one of the four keys identified above. When a cross appeared in a box the participant had to hit the corresponding key as quickly as possible. The stimulus remained on the screen until a key press was registered. The task involved 8 practice trials and 40 test trials. The DVs were reaction time (ms) and accuracy (the number of errors).

- Spot the Difference

  The children were shown a picture, which they could study for 45 seconds. The pictures were simple, cartoon pictures ("UpToTen," 2010). An example of a picture can be seen in Appendix VIII. The picture was then removed and replaced with a blank page for a couple of seconds in order to counter visual pop-out effects. Another picture was then presented to the child that was identical to the first picture apart from 7 items, critical probes, which had been deleted, added or changed. The children had 45 seconds to find and circle the critical probes from memory. The DV was the number of items correctly identified.

- Finger Tapping

The finger tapping task required participants to tap their thumb and index finger together, on their dominant hand, as quickly as possible within a 30 second period. The researcher counted the number of finger taps. The task was repeated twice with a 15 second break between the two trials and the DV was the number of finger taps, averaged over the two trials.

- Speeded Cancellation Task

This task was very similar to the non-speeded letter cancellation task. The children were presented with a sheet of paper with a 20 x 20 grid which measured 18cm x 18cm printed on it. The target stimulus was the letter O (n=38) and the distractor stimuli were C, V & U (n=362). Parallel tasks were provided for baseline and test. The children were told that they were being timed and they had to complete the task as quickly as possible. The researcher told them when to start and the child shouted stop when they had finished. The DVs were the time taken to complete the task to the child's satisfaction.

- The Stop-Signal Task

The Stop-Signal task was presented to the participant on an IBM-compatible computer. The participant sat in front of a computer screen with the index finger of their left hand on the letter 'X' on the keyboard and the index finger of their right hand on the 'O'. In each trial an X or O appeared in the centre of the screen (the Go stimulus) for 1000ms and the participant had to press the matching key on the keyboard as quickly as possible. There were an equal number of X and Os in each test session. The Go stimuli was preceded by a 500 ms blank screen with a fixation point, and followed by a blank screen which was presented for 1000ms. On 25 % of the trials participant heard a loud buzz (the Stop Signal) after the letter had appeared on the screen. The buzz was a 1000-HZ, played for 100 ms at a comfortable volume. On those occasions the participant had to inhibit their response and not press a key on the keyboard. Initially, the Stop-signal delay was set at 250ms and this time adjusted automatically dependent on the participants' performance. If the participants inhibited their response successfully the task was made more difficult by increasing the delay by 50ms, if the participant did not inhibit their response successfully then the delay decreased by 50ms. The task consisted of two shorter practice sessions and then 512 trials which were administered as four test sessions of 128 trials each. One trial was presented every 2.5s giving a total time of 5 minutes 20 seconds per test session and the participant was allowed a rest between each trial. The order in which the trials were presented was random. The DVs were the number of go and stop errors and the stop signal reaction time. These terms are explained below:

- Go Errors – the number of times the incorrect key was pressed
- Stop Errors – the number of times the stimulus key was pressed when the stop audible signal was played.

- Stop Signal Reaction Time– was the mean of the Go Reaction time plus the Stop Signal Delay
- Go Reaction Time – the time taken to react to the visual stimulus
- Stop Signal Delay – times between the go stimulus and stop audible signal were automatically varied so that the participant correctly inhibited their reaction. The time they required between the go stimulus and audible stop signal to successfully inhibit their reaction 50 % of the time was the Stop Reaction Time.

4.2.3.3 Food/Drink Consumption.

After the intervention, the children were asked to fill in a questionnaire which consisted of 4 questions:

- What did you have to eat before you came to school?
- What did you have to drink this morning?
- Have you done any activities this morning?
- How did you get to school?

The children were asked to be as detailed as possible and then this information was entered as either “Yes” (the child had eaten, drank, participated in an activity or walked or cycled to school) or “No” categorical data for each question into SPSS. Additionally, the volume of water consumed in food or drink before coming to school was estimated using the CompEat Nutrition System. Weight or volume of food and beverages were not recorded, therefore the volume of water in a small size portion or typical unit of food or drink, as shown in CompEat, was used.

4.2.4 Intervention

On the occasion that the children were given a drink, they were offered a 500ml bottle of water. The children were given a maximum of 10 minutes in which to drink the water and were able to drink as much or as little as they wished. The amount of water drank was recorded. On the other occasion the children were not offered a drink. During this period the children were asked to read quietly to themselves. The conditions were counter-balanced.

4.2.5 Procedure

Each child was tested individually in a quiet room away from the classroom. Testing began at 9.15am. Before the battery of visual analogue scales and cognitive tasks were administered, the child was asked to go to the toilet by themselves and provide a urine sample. (This chapter will only examine the mood and cognitive outcomes and their association with self-reported thirst scores and volume drank). Analysis and discussion of urine osmolality measures will take place in Chapter 5. After completion of the tasks the child was offered a bottle of water to drink on one occasion and on the other occasion they were not. After the intervention the child was given an interval of 20 minutes to continue to read a book and complete a food and drink questionnaire. After the interval they were asked to provide another urine sample and then complete another battery of visual analogue scales and cognitive tasks.

4.3 Results

4.3.1 Primary Analysis: the Effect of Drinking Water on Cognitive Performance and Mood (Hypothesis 1).

4.3.1.1 Data Analysis.

Change scores from the two conditions were compared using a t-test or Wilcoxon test, to determine if the intervention (DRINK/NO DRINK) had an effect on task performance. However, in the SSRT test children only took part after the intervention, and not before. Therefore, only test scores rather than change scores were compared in the DRINK and NO DRINK conditions.

4.3.1.2 Data Preparation.

Data were prepared in exactly the same way as in study 1 (see 3.3.1). As in study 1 the baseline data were first analysed to assess whether there were any differences between conditions. T tests (or a Wilcoxon test for non-parametric data) determined that there were no significant differences for any cognitive task or mood scale when comparing baseline data from the DRINK and NO DRINK condition.

Change scores were calculated by deducting baseline scores from test scores. The statistics reported here are from the data sets in which outliers were replaced (read section 3.3.1.2 for a rationale). The change score data were checked to confirm they met the assumptions of normality. The spot the difference violated this assumption and so a Wilcoxon test was used to determine if there was a difference between the change scores between the DRINK and NO DRINK conditions.

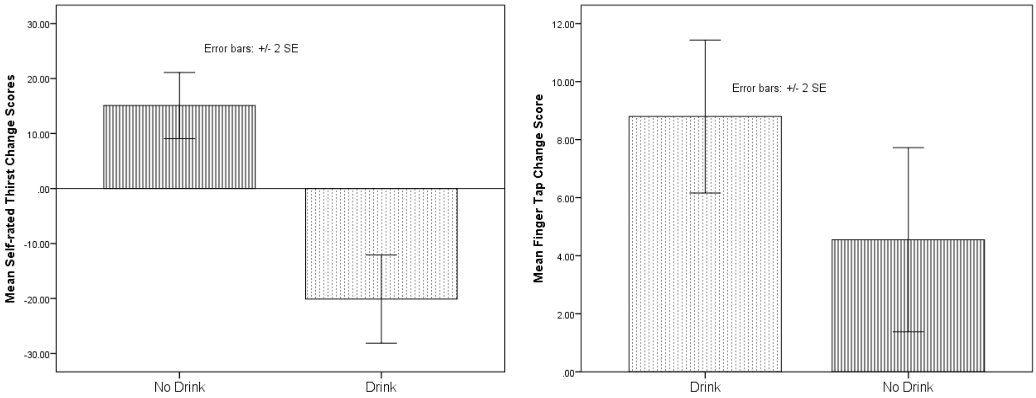


Figure 4.2 a. Self-Rated Thirst Change Scores b. Finger Tap Change Scores

4.3.1.3 Results.

Data presented in Table 4.1 shows the raw scores and SDs for self-reported mood and task outcomes when children had a drink and when children had no drink. Observation of this data and Figure 4.2a show that children rated themselves as statistically significantly less thirsty when they had a DRINK than when they had NO DRINK and there was a large effect size ($t(48)=7.297$, $p<.001$, $r = .72$).

Figure 4.2b shows the change scores for the finger tapping task in the DRINK and NO DRINK condition. Observation of the figure shows that children were statistically significantly faster in the finger tapping task when they had a DRINK than when they had NO DRINK ($t(48)=2.305$, $p=.026$, r =31). There were no other statistically significant effects of the DRINK condition on mood or cognitive performance.

Table 4.1
Means, SDs and Significance Levels for Mood and Cognitive Performance by Drink Condition

	No Drink				Drink				
Mood and Cognitive Tasks	Baseline		Test		Baseline		Test		
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*p*
Thirst	42.14	27.30	58.53	27.67	42.76	26.05	23.57	24.88	**<.001**
Hunger	38.86	27.97	43.82	30.52	36.04	26.05	45.02	33.81	.18
Happiness	78.96	20.61	79.24	19.83	81.92	19.12	83.34	17.66	.70
Non-Speeded Letter Cancellation Time	95.00	24.36	83.93	19.72	95.73	24.87	79.77	17.85	.18
Simple Reaction Time	366.47	34.94	392.11	60.91	366.71	52.11	389.19	55.62	.18
Choice Reaction Time	635.23	83.16	642.38	101.93	639.26	92.65	643.87	105.89	.14
Choice Reaction Time Errors	2.69	1.98	2.62	1.74	2.92	2.44	2.88	1.97	.45
Spot The Difference	4.63	.88	5.17	1.42	4.88	1.05	4.88	1.25	.21
Finger Tap	97.45	22.22	102.0	16.85	98.07	19.93	107.06	14.19	**.02**
Speeded Letter Cancellation Time	68.35	13.23	62.86	14.22	65.43	14.03	60.79	11.76	.13
Stop Signal Go Errors			6.09	5.48			6.13	5.36	.39 [a]
Stop Signal Reaction Time			732.78	104.23			708.58	99.48	.34 [a]
Stop Signal Stop Errors			38.39	13.71			40.63	15.44	.45 [a]

Note.; [a] t-test analysis of test data not change scores

4.3.2 Secondary Analysis: Does Thirst Moderate the Effect of Water Consumption on Cognitive Performance? (Hypothesis 2)

4.3.2.1 Data Analysis

To determine whether thirst at baseline had an effect on task performance, after either a drink or no drink, mixed model Analyses of Variance (ANOVA) were carried out on task and mood change scores. DRINK (DRINK, NO DRINK), was a within subject factor and THIRST (HIGH THIRST/LOW THIRST) was a between subjects factor. Spot the difference change data were not normally distributed in the thirst groups or drink conditions. Therefore, a Wilcoxon signed rank test was used to compare the change scores between the HIGH THIRST and LOW THIRST group. Participants reported being significantly hungrier at baseline in the High Thirst group in both the Drink and No Drink conditions, so change scores were not used for this DV. Instead, a within subject factor of TIME (BASELINE/TEST) was added to the ANOVA and raw scores used.

To determine if there was a difference in the mean volume drank in the HIGH THIRST and LOW THIRST group a t-test was used. Additionally, correlational analyses were carried out to determine whether there was a dose response relationship between levels of perceived thirst and task performance at baseline or change scores in both DRINK conditions.

4.3.2.2 Data Preparation

Based on the analysis by Edmonds, Crombie and Gardner (2013) participants were divided into two groups labelled HIGH THIRST and LOW

THIRST dependent on whether they scored higher or lower than the median score of 44 at baseline. Participants had to be either in the high thirst or low thirst group in both conditions and were excluded if they were in a high thirst group in one condition and a low thirst group in the other condition. Thirty eight participants met the criteria, 19 in each condition. Baseline scores, for both the Drink and No Drink conditions, in the LOW THIRST group were compared with the HIGH THIRST group. There were no significant differences except for self-reported hunger for which children were significantly hungrier in the HIGH THIRST group than the LOW THIRST group so baseline and test scores were used for this DV. For all other outcomes the change score data were used and tested to confirm that they met the assumption of normal distribution. Additionally, the results were interpreted using the Greenhouse-Geisser statistics if data violated assumptions of sphericity.

4.3.2.3 Results.

Data presented in Table 4.2 shows the mean change scores and *SD*s for self-reported mood and task outcomes and the main effect of thirst and the interaction between THIRST and DRINK condition for children in the HIGH THIRST group and LOW THIRST group. Visual inspection of these data show, that between baseline and test, the participants in the HIGH THIRST group who had a drink reduced mean ratings of thirst more than the participants in the LOW THIRST group who had a drink. Interestingly the volume of water drank in the intervention was very similar in both the HIGH THIRST group (*M* = 359.37ml,*SD* = 142.44) and LOW THIRST group (*M* = 336.89ml, *SD* = 143.14).

As expected, there was a main effect of THIRST on self-rated thirst scores (F(1,36)=14.279, p=.001 , r =.53) but no significant interaction between DRINK condition and THIRST (F(1,36)=2.196, p=.147). Figure 4.3 shows a bar chart of the mean self-rated thirst scores at baseline and test in the LOW THIRST and HIGH THIRST group in both DRINK conditions. Observation of the chart show that children that rated themselves highly on the thirst scale when they came to school and then had a drink were still rated as thirstier at test than those children that rated themselves low on the thirst scale when they came to school at baseline. However, self-rated thirst scores had decreased substantially in the DRINK condition between baseline and test.

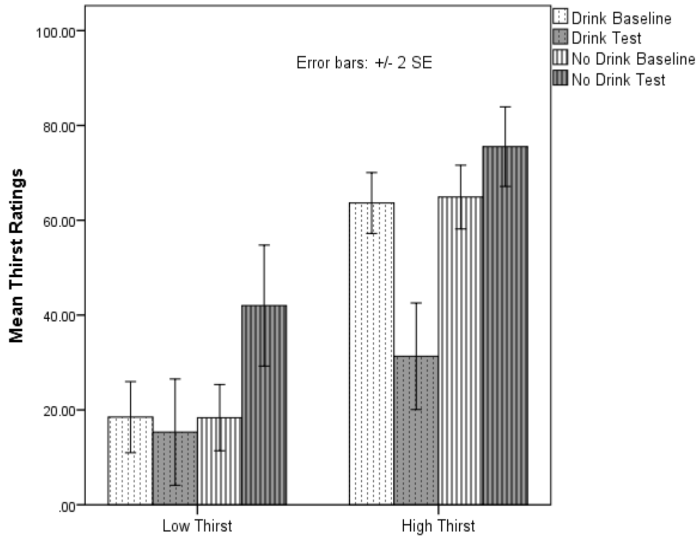


Figure 4.3. Self-Rated Thirst Scores at Baseline and Test in the High Thirst and Low Thirst Groups in Both Conditions.

Table 4.2. *Means, SD and Main and Interaction Effects for Mood and Cognitive Task Change Scores in Thirst Groups.*

	High Thirst Group				Low Thirst Group				
	No Drink Change		Drink Change		No Drink Change		Drink Change		
Task	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Test of main effect and interaction
Thirst	10.63	17.23	-32.32	27.44	21.68	20.94	-5.47	23.35	Thirst x Cond F(1,36)=2.19,*p*=.14 **Thirst F(1,36)=14.27, *p*=.001**
Hunger	10.95	14.82	8.63	19.04	4.42	14.65	15.57	17.22	***Thirst x Cond F(1,36)=6.08,*p*=.01** *Thirst F(1,36)=.04, *p*=.830
Happiness	1.74	15.27	1.42	14.21	-2.47	7.61	.32	14.06	Thirst x Cond F(1,36)=.20,*p*=.65 Thirst F(1,36)=.54,*p*=.467
Non-Speeded Letter Cancellation Time	-12.67	22.87	-10.83	20.82	-11.79	16.87	-22.05	13.59	Thirst x Cond F(1,36)=.20,*p*=.65 Thirst F(1,34)=0.681,*p*=.415
Simple Reaction Time	42.98	47.36	27.17	43.72	11.98	51.65	19.31	15.45	Thirst x Cond F(1,31)=2.22,*p*=.14 Thirst F (1,31)=0.01, *p*=.895
Choice Reaction Time	18.26	43.26	1.83	61.57	14.31	57.71	19.20	88.81	Thirst x Cond F(1,36)=.323*p*=.57 Thirst F(1,32)=.05, *p*=.816
Choice Reaction Time Errors	1.00	2.06	.00	3.05	-.72	2.11	-.33	2.84	Thirst x Cond F(1,32)=1.53,*p*=.22 Thirst F(1,32)=3.77 *p*=.061
Spot The Difference	.22	1.48	.42	1.39	.79	1.81	.32	.83	Thirst DRINK group z=1.928, *p*=.05 Thirst NO DRINK grp z=.52, *p* =.60
Finger Tap	5.58	11.20	4.47	6.00	5.42	10.87	10.21	9.72	Thirst x Cond F(1,36)=.20,*p*=.655 Thirst F(1,36)=.38, *p*=.541
Speeded Letter Cancellation Time	-8.21	6.09	-3.21	6.37	-3.58	7.35	-5.66	6.70	Thirst x CondF(1,36)=1.06*p*=.310 Thirst F(1,35)=.91, *p*=.344
Stop Signal Go Errors	9.43	6.76	7.54	5.88	4.84	4.95	4.57	4.37	Thirst x Cond (1,29)=1.33,*p*=.25 **Thirst F(1,29)=4.22, *p*=.049**
Stop Signal Reaction Time	828.06	20.60	816.52	19.68	819.37	17.66	814.43	15.53	Thirst x CondF(1,29)=1.13,*p*=.29 Thirst F(1,29)=.48, *p*=.494
Stop Signal Stop Errors	10.63	15.66	39.21	14.02	34.45	15.88	41.59	12.74	Thirst x Cond (1,29)=1.34,*p*=.56 Thirst F(1,29)=1.41, *p*=.244

*Note. * = Time included as a within factor in the ANOVA*

As observed in Table 4.2 all the participants became hungrier between baseline and test. There was a significant interaction between THIRST and TIME, (F(1,36)= 5.745, p=.022), with participants who were in the HIGH THIRST group at baseline having a significantly higher perceived hunger score than those that were in the LOW THIRST group. The higher self-rated hunger score in the HIGH THIRST group at baseline can be seen in Figure 4.4, which shows a bar chart of the mean self-rated hunger scores at baseline and test in the LOW and HIGH THIRST groups for both DRINK conditions. Additionally, there was a significant interaction between THIRST and DRINK condition on perceived hunger scores, F(1,36)= 6.079, p=.019, r = .39 but no main effect of THIRST

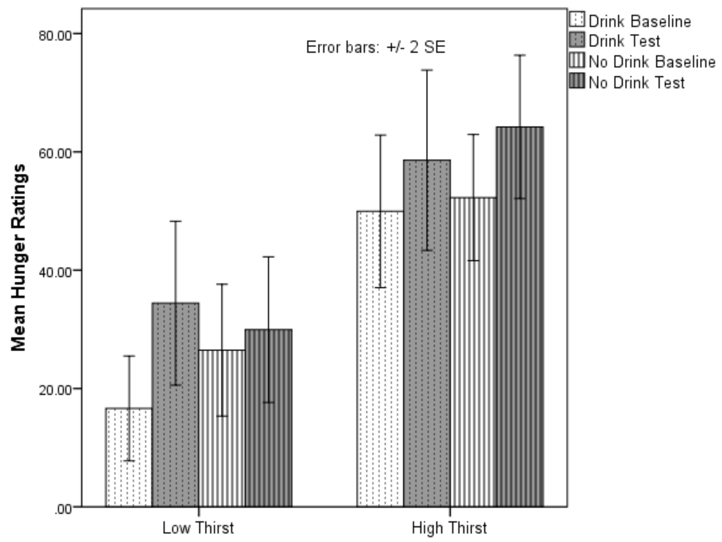


Figure 4.4. Self-Rated Hunger Scores at Baseline and Test in the High Thirst and Low Thirst Groups in Both Conditions.

Observation of Figure 4.5, shows that in the SSRT task participants in the HIGH THIRST group made significantly more errors (F(1,29)=4.222, p=.049 r = .35) than those in the LOW THIRST group (DRINK condition M =4.57; NO DRINK condition M = 4.84) regardless of whether they had a DRINK (M =7.54) or NO DRINK (M =9.43).

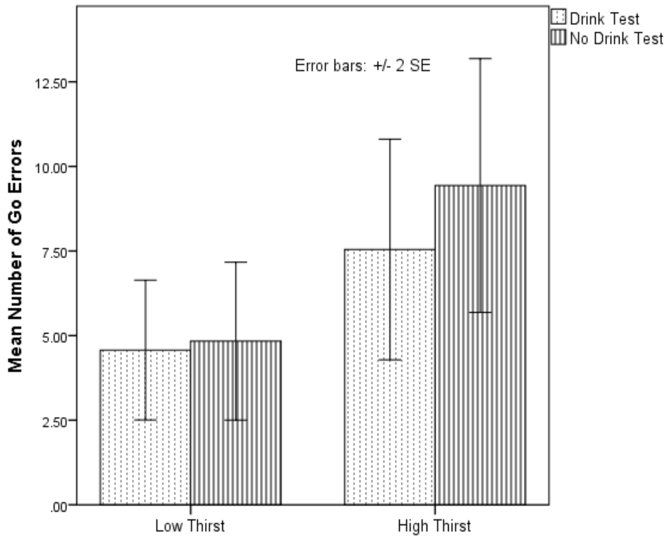


Figure 4.5. The Number of Go Errors in the SSRT Task at Test in the HIGH THIRST and LOW THIRST Groups in Both Conditions.

Additionally, correlational analyses were carried out to determine whether there was a dose response relationship between levels of self-rated thirst and task performance at baseline or change scores in both DRINK conditions. No significant correlations were found between task, mood and self-rated thirst change or baseline scores in either the DRINK or NO DRINK condition.

4.3.3 Secondary Analysis: The Effect of the Volume of Water Consumed on Cognitive Performance (Hypothesis 3).

4.3.3.1 Data Preparation

The data were checked to determine whether it met the assumptions for a correlational analysis. The volume drank data were not normally distributed and hence the correlational coefficients were calculated using Spearmans Rho.

4.3.3.2 Results

Correlational analyses between volume of water consumed and change scores in tasks and mood, and test scores for the stop-signal task, found no statistically significant relationships. Notably, there was no correlation between volume drank and self-rated thirst scores.

4.3.4 Exploratory Analysis: The Effect of Estimated Volume of Fluid Ingested at Breakfast on Baseline Ratings of Thirst and Cognitive Performance (Hypothesis 4)

4.3.4.1 Data Analysis.

The estimated total volume of fluid, consumed before coming to school, was correlated with mood and baseline task scores.

4.3.4.2 Data Preparation.

The volume of fluid consumed in either food or drink before coming to school was estimated, using CompEat Nutrition System software, based on small portion sizes. The data was assessed to ensure it met the assumptions for the analysis. As the data were not normally distributed the correlational coefficients were calculated using Spearmans Rho.

4.3.4.3 Descriptive Analysis.

Data presented in Table 4.3 shows the number of children that ate breakfast and had a drink before coming to school on the water and control condition test days. As observed very few children did not eat breakfast or have a drink before coming to school. The mean volume consumed before coming to school was 188.6ml on the DRINK condition day and 201.0ml on the NO DRINK condition day.

The descriptive statistics showed that there was very little difference in ratings of thirst in those children that had a drink before coming to school (DRINK mean = 43.5, NO DRINK mean = 42.8) in comparison with children that did not have a drink (DRINK condition mean = 43.2, NO DRINK condition mean = 49.1). Inferential stats were not used to analyse this difference as so few children did not have a drink or breakfast before coming to school. These statistics will be referred back to when discussing osmolality at baseline in chapter 5.

Table 4.3.
Frequencies of Eating Breakfast and Having a Drink before Testing on the Water Condition Day

		School	
		St. Mary's	Carpenters
Breakfast	Yes	25	12
	No	0	3 (1 child no breakfast or drink)
Drink	Yes	23	12
	No	2	3
Total Estimated Fluid Volume Consumed		202.68ml	158.53ml

4.3.4.4 Inferential Exploratory Analysis

There was no correlation between estimated amount of fluid consumed before school and baseline thirst (*$r(47) = -.101$, $p = .501$*). Furthermore, there were no correlations between estimated amount of fluid consumed before school and baseline cognitive performance scores.

4.4 Discussion.

4.4.1 Summary of Findings

The primary aim of this chapter was to determine if children performed better when they had a drink than when they did not and to identify whether specific cognitive domains were sensitive to water consumption. The results showed that when children had a drink of water they increased the number of finger taps, between baseline and test, compared to when they did not have a drink. This finding suggests that fine motor skills are enhanced by water consumption and supports the hypothesis that consuming water would improve motor performance compared to not consuming water. However, the hypothesis that there would be a dose-related response between ratings of thirst or volume drank and motor or cognitive performance was not supported. Furthermore, self-rated thirst scores did not correlate with volume drank.

Nevertheless, the results showed that ratings of thirst did impact on cognitive performance, independent of water consumption. Scores for the StopSignal task showed that the number of ‘go errors’ were higher in the high thirst group at test, than those in the low thirst group regardless of whether the children had a drink or not. Additionally, participants in the high thirst group were much hungrier at both baseline and test than those in the low thirst group, again regardless of whether they had a drink or not.

These results show foremost that the effects of water consumption and ratings of thirst differ subject to each cognitive domain, but also that they may have an effect on specific cognitive and motor skills that are not dependent on each other. The results and the possible mechanisms involved will be discussed in more detail in the section below.

4.4.2 Examination and Implications of the Findings

Ratings of thirst are often used as a proxy measure of hydration (Rogers et al., 2001) ,but the current study found no correlation between volume drank in the intervention and changes in thirst ratings. Indeed, children that were in the high thirst group had a mean rating of thirst at test, after having a drink, which was higher than the baseline ratings for those in the low thirst group. Moreover, descriptive analysis showed that subjective thirst scores were very similar for children who consumed fluid before coming to school compared to those who did not. The results from the current study are consistent with other findings (McKiernan, Houchins, & Mattes, 2008) which show that ratings of thirst tend to be relatively level throughout the day with very little fluctuation in ratings.

In a study by Buehrer et al., (2014), in which children fasted overnight and the following morning were either given a light milk based breakfast or a fruit syrup to drink, results showed that there were no correlations between gastric residual volumes and thirst ratings. Furthermore, there were both inter-individual and intra-individual variations in the thirst rating after the fast and at different time intervals after the breakfast food or drink were consumed the following morning.

One explanation for the lack of relationship between volume drank and perceived thirst scores may be that children are not particularly aware of and unable to rate their feeling of thirst (Mattes, 2010; McKinley & Johnson, 2004). In a study (Bar-Or et al., 1978) 10-12 year old boys were deliberately dehydrated by means of exercising in the heat, but given the opportunity to drink as much as they wished so that they could replace fluid lost in sweat. The results showed that the children did not drink enough voluntarily to replace lost body fluid suggesting that the boys were not able to recognise and act on sensations of thirst. The second explanation is that the sensation of thirst is not only a physiological reaction triggered by dehydration or having a dry mouth (Ramsay & Booth, 1991) but can also be a product of desire, habit or motivation unrelated to fluid balance (Mattes, 2010; McKinley & Johnson, 2004). Further investigation in the next chapter will determine whether urine osmolality and the subjective sensation of thirst are related, in order to assess more fully why the sensation of thirst influences cognitive performance.

In the current study, the sensation of thirst was related to self-rated hunger. Participants in the high thirst group had much higher ratings of hunger at baseline and test, regardless of whether they had a drink or not, than participants in the low thirst group. It may be that as the participants in the current study were children they were unable to recognise or discriminate between sensations of thirst and hunger, and may have been misattributing the sensation of thirst to hunger or vice versa; these results are consistent with previous research literature. In Buehrer et al. (2014), children were unable to differentiate between thirst and hunger and the scores were strongly correlated. This result is in contrast to the findings by Booth, O'Leary, Li and Higgs (2011) in which adult participants were asked to rate sensations after eating a bowl of soup and a yogurt. When factor analysing the descriptions, it was noted that ratings of thirst were loaded on a different factor to ratings of "full", "bloated" and "empty" which would be associated with feelings of hunger. These results suggest that adults may be more easily able to differentiate between the feelings of hunger and thirst than children. Further more detailed investigation is required into the relationship between feelings of thirst and hunger.

Results from the present study suggest that motor control and speed are sensitive to water consumption because the number of finger taps increased when children had a drink, compared with when they did not have a drink. These findings are consistent with findings from study 1 in which the number of beads threaded increased after children had a drink. The finger tapping task in this study showed no effect of thirst ratings suggesting that fine motor control and speed are not attenuated by the subjective sensation of thirst. Additionally, volume drank had no effect on the number of finger taps. Study 3 will examine the relationship between volume drank and hydration status and whether hydration status moderates the effect of water consumption on the number of finger taps.

In this study, no effects of water consumption were found on performance on any of the other cognitive tasks. This result was unexpected, particularly for the letter cancellation task, as previous studies have consistently shown beneficial effects of water consumption (Booth et al., 2012; Edmonds & Burford, 2009; Edmonds et al., 2013; Edmonds & Jeffes, 2009) and the reasons for this result are difficult to delineate. Further investigation into the effects of water consumption on performance in the letter cancellation task is required.

In the SSRT task it was the rating of thirst rather than water consumption that had a statistically significant effect on performance. Participants in the high thirst group had more go errors at test than those in the low thirst group. Whether the participant had a drink or not made very little difference when the participant was in the low thirst group at baseline. When the participant was in the high thirst group at baseline and had a drink they make fewer errors than if they did not have a drink, but still considerably more errors than those that were in the low thirst group at baseline. This is consistent with the results of the analysis of the subjective thirst scores which showed that participants who were in the high thirst group and had a drink rated, themselves as less thirsty over time, but still had higher thirst ratings than those in the low thirst group at baseline. Errors are likely to occur because the participant is not paying attention. As more errors occurred in participants that had a high rating of thirst it suggests that the sensation of thirst itself may be attenuating attention away from the task. This effect is consistent with Kahneman's (1973) model of attention which theorises that there is only a limited amount of cognitive resources, thus performance will deteriorate once capacity is reached.

Alternatively, the high level of thirst may be an indication of underlying dehydration. A study by Kempton et al. (2011) suggests that dehydrated participants require more neurological resources to produce the same level of performance than euhydrated participants. In that study participants had to complete a task requiring a high level of executive functioning in both a dehydrated and a euhydrated state. Despite there being no difference in task performance between the two conditions there was an increase in fronto-parietal blood oxygen-level-dependent (BOLD) response when the participants were in the dehydrated condition compared to the euhydrated condition. It was theorised that had the task continued over a longer period when the participants were dehydrated they would have been unable to sustain their performance for as long as when they were euhydrated as they would have exhausted their metabolic resources more quickly. The results from the SSRT task support the argument that participants who were in the high thirst group were less able to sustain performance. As the SSRT task was the last task of the testing session, and was itself a lengthy task taking 16 minutes to complete, it is likely that the participants were beginning to suffer from mental fatigue, and the dehydrated participants were unable to sustain performance . Study 3 will assess whether ratings of thirst are a proxy measure of hydration by correlating ratings with a biomarker of hydration. Therefore, it can be assessed whether the high thirst group were more likely to have been unable to sustain performance due to dehydration or from the subjective thirst sensation attenuating attention away from the task.

4.4.3 Methodological Issues

A limitation in the current study was that the Low Thirst and High Thirst groups were independent, thus any findings from the analyses may have been due to another factor other than thirst, for example hunger, exerting an effect. To counter this problem future research could consider manipulation of thirst within each individual so the measures could be compared in a within subjects analysis.

In the current study, a more robust analysis investigating the relationship between fluid intake and thirst ratings could have been undertaken had weight and portion sizes of food and drink consumed at breakfast been recorded rather than estimated. A more in depth study of the relationship between fluid intake, thirst and hydration status will be undertaken in study 4.

Additionally, children were not screened for vitamin or mineral intake which evidence suggests may have an acute effect on cognitive performance (Haskell, Kennedy, Milne, Wesnes, & Scholey, 2008) and breakfast food intake was not regulated. However, as the study was a repeated measures design it is considered that those children regularly taking a vitamin/mineral supplement would have taken a dose on both days of testing. Observation of breakfast foods consumed suggested that breakfast content is often habitual and very similar food types were eaten on both days of testing. However, it should be noted that breakfast foods were recalled from memory and thus may have been subject to impairments of recall. This issue is particularly pertinent as dehydration may have had negative effects on memory, although the results did not reflect this. Immediate food and beverage recall measures will be used in study 4.

4.4.4 Conclusion

In conclusion, in the present study, it was found that motor control and speed improves when participants had consumed water compared to when they have not. This is an important finding because school children spend a large percentage of their time in the classroom involved in tasks utilising fine motor skills (McHale & Cermak, 1992). The next study will assess whether water consumption may improve performance due to a physiological change in hydration status.

Furthermore, in the present study, participants with high ratings of thirst had high numbers of errors in a reaction time type task compared with participants with low thirst ratings, with no significant effects of water consumption. This finding suggests that the subjective sensation of thirst may have effects on cognitive performance; either because the sensation has occurred as a result of dehydration and it is the underlying physiological mechanisms and processes necessary to maintain water balance which are having an effect on cognition or because the sensation itself, regardless of water balance, attenuates attention away from the task in hand. The next study will investigate the relationship between hydration status and thirst ratings.

CHAPTER 5

Study 3: The Relationship and Effects of Volume Drank, Hydration Status and Self-Rated Thirst and on Cognitive Performance and Fine Motor Skills

5.1 Introduction

The aim of this chapter is to carry out investigations on the effects and relationship of urine osmolality with self-reported thirst, mood scores, cognitive task scores and volume drank. These variables have already been introduced and discussed in study 2. Study 3 is a continuation of that study using the same data with the addition of urine osmolality data.

The primary aim of this study was to investigate:

- The relationship between thirst ratings, volume drank and hydration level

Two exploratory aims of this study were to investigate:

  - Whether the high thirst group had higher urine osmolality readings than the low thirst group
  - The effect of estimated volume of fluid ingested at breakfast on hydration levels at baseline

A secondary aim of this study was to investigate:

- Whether hydration level scores moderated the effect of water consumption on mood, fine motor skills and cognitive performance

A supplementary aim was to investigate:

- Whether there was a high correlation between urine osmolality readings and urine colour scores.

In study 1 and 2 it was found that consuming water had a positive effect on cognitive performance, which is consistent with findings from the previous research literature (see section 2.2 for a review). To date, no previous studies have looked in detail at how self-reported thirst, volume drank and an individuals' hydration status (as indexed by a biomarker of hydration) might moderate this effect. Some studies have looked at the effect of one or two of these variables, but not all three, when examining the relationship between water consumption and cognitive performance (Edmonds, Crombie and Gardner, 2013; Fadda et al., 2012; Rogers et al., 2001). However, it is difficult to speculate on the mechanism that might underlie their findings when there is uncertainty as to whether the hydrated state of each individual at baseline is a moderating factor, whether perception of thirst can be used as a proxy measure for dehydration in children or whether cognitive performance levels are dose-related to volume of water drank.

In a study by Fadda et al., (2012), a physiological measure of hydration status (urine osmolality) was collected, but this data was not used to examine how it might moderate the effects of volume drank and self-reported thirst on cognitive performance. In their study the urine osmolality change scores, from morning arrival at school to mid-afternoon, were correlated with cognitive performance change scores to assess if cognitive performance was sensitive to hydration status. The results showed that the lower the urine osmolality change score the more the participants had improved in the digit span task but the worse their performance had got in the verbal analogies task. These results are difficult to interpret as a high osmolality change score would mean that the child would have had a high score in the morning and a low score at the end of the school day, or vice versa. A low osmolality change score could mean that the child had a relatively stable osmolality score throughout the day which could have been quite low, indicating that the child was well hydrated, or equally quite high, indicating that the child was dehydrated, or anywhere in between.

In Rogers et al. (2001) study it was suggested that self-reported thirst was a good measure of hydration status. Participants who reported high levels of thirst had a beneficial effect from drinking water so it was inferred that high thirst indicated that they were more likely to be dehydrated. However, biological measures of hydration status were not taken, so this theory was not explicitly assessed. Additionally, in Edmonds, Crombie and Gardner's (2013) study participants who had higher rates of thirst had slower response times in a reaction time task in the no drink condition. The inference was that the sensation of thirst and slowing of response time was possibly due to a state of dehydration but again this was not formally tested.

In this study a biological measure of hydration status will be collected and the relationship between the hydration biomarker and perceived thirst and volume drank will be investigated. Study 2 has already shown that self-reported thirst does not correlate with volume drank and the reviewed research literature suggests little relationship between self-reported thirst and fluid consumption (McKiernan et al., 2008). Moreover, a study by Denton et al., (1999) found no correlation between blood plasma osmolality (a further biomarker of hydration status) and self-rated thirst.

Previous research has found no relationship between urine osmolality and self-rated thirst (McDermott et al., 2009). However, a relationship between urine osmolality and volume drank has been reported. Findings from Perrier et al., (2012) show that low drinkers, those who habitually drank less than 1.2 litres per day (L/d), had significantly higher first morning Uosm and 24 hour Uosm than high drinkers, those who habitually drank 2–4 L/d. The current study will determine whether there are correlations between Uosm and self-rated thirst and volume drank, as well as consider whether hydration status moderates the effect of water consumption on cognitive performance.

In particular, it will be determined whether the effect of water consumption or self-rated thirst on finger tapping and the SSRT task is moderated by hydration status. In study 2, finger tapping became faster on the occasion that children had a drink of water but performance was not sensitive to self-reported thirst or volume drank. It can now be considered whether hydration status at baseline moderated the effect of water consumption on finger tapping performance. Furthermore, the number of go errors in the SSRT was higher in the children that were in the high thirst group but it was unknown whether this was due to underlying dehydration in that group. This study will assess if there are differences in hydration status between the low and high thirst groups.

The current study will also determine whether children who arrive at school in a dehydrated state perform more poorly in any cognitive task or rate themselves as having a more negative mood at baseline than those who are hydrated. Results from the previous research literature of deliberately dehydrated adults have shown that their performance is worse on a range of tasks and that they have a more negative mood than those who are not dehydrated (see section 2.2 for a review). However, Bar-David et al. (2005) reported that children that arrived at school voluntarily dehydrated did not perform any worse at baseline than children who were euhydrated. Differences in performance between the two groups only occurred when tested at lunchtime, suggesting that the children who were dehydrated did not have the resources to maintain performance over time. If this finding is replicable it will have implications as to the mechanism involved in deficits in cognitive performance.

5.1.1 Rationale for Assessments

As the aims of this chapter were to determine the moderating effect of a biomarker of hydration on cognitive performance and to investigate the relationship between a biomarker of hydration status and self-rated thirst and volume it was essential to choose an appropriate biomarker of hydration status. There are many to choose from and a description of each, a review and a rationale for the methods adopted in this study can be read in section 1.4.

For a variety of reasons, urine osmolality seemed to be the most appropriate biomarker of hydration status for this study. Urine samples are relatively easy and quick to collect. Whilst other methods such as plasma osmolality analysis which require blood samples are invasive and understandably some parents would be cautious about giving permission for their children’s blood to be collected, which could result in low participant numbers. Furthermore, when assessing voluntary dehydration some methods, such as body weight loss, are not viable as the participant’s baseline bodyweight when euhydrated is not able to be determined in this acute study design.

An additional measure of dehydration, the assessment of urine colour, was measured as it has been recommended (Armstrong, 2007) that a single technique is not sufficient to effectively measure hydration status and that two or more different methods should be used. Findings from Armstrong et al., (2012) showed that 77 % of the variance in urine colour scores could be explained by Uosm readings. However, Eberman, Minton and Cleary’s study (2009) found only 29 % of the variance in urine colour was accounted for by Uosm. Therefore, as a supplementary aim it was decided to determine whether Uosm and urine colour scores in this study correlate. If the results showed that measurement of urine colour correlated highly with Uosm, this would indicate that assessment of urine colour is a very effective way of assessing hydration status. Thus, this might suggest it could be used in future studies, as an alternative to Uosm, as it is an extremely quick and cheap method of assessing hydration status. This chapter is a continuation of study 2, thus the cognitive tasks and mood scales administered remain the same as detailed in section 4.2.3.

Several hypotheses were tested:

Hypotheses

1. That there would be a positive correlation between ratings of thirst and Uosm levels

2. That there would be a negative correlation between volume drank and ratings of thirst and Uosm levels

3. That Uosm readings reduced and self-rated thirst scores decreased, between baseline and test, when participants had a drink compared to when they did not.

4. That the high thirst group would have a higher Uosm reading than the low thirst group

5. That estimated fluid volume consumed in food and drink before coming to school would correlate negatively with Uosm readings

6. That, after consuming water, participants in the dehydrated group would improve cognitive performance compared to participants in the hydrated group.

7. That there would be a medium to strong positive correlation between urine colour and Uosm readings

5.2 Method

5.2.1 Design

The study had a repeated measures design with each child being tested individually, pre and post intervention, on two occasions. On one occasion the child was offered a 500ml bottle of water to drink and on the other occasion the child was not offered a drink. This chapter is a continuation of study 2 (Chapter 4) and the design is described in more detail in section 4.2.1.

5.2.2 Participants

Data from 49 participants were originally included in the study. The children attended the schools described in section 4.2.2 However, data from an additional eight participants were excluded from this analysis as they did not provide a urine sample at either the no drink baseline, drink baseline or drink test ($n = 41$). Participants that were only missing their no drink test sample had the data replaced (see data preparation, section 5.3.1.2). The mean age of the participants was 9 years 11 months and there were 28 females and 21 males. The post-hoc power analyses showed, that with an alpha level of .05 (two tailed), the sample size of 41 provided an 88 % chance of detecting a medium effect size ($t = 0.5$; cf. Cohen, 1977).

5.2.3 Measures

- Urine Colour

To assess urine colour, one urine sample was collected from each child at baseline and test stages. The entire void of urine was initially collected in a portable bidet which was placed under the toilet seat. A maximum of 30ml of urine from the void in the bidet was then poured into an individual 30ml Sterilin clear sample tube. The colour of the urine in the tube was compared to a card (Armstrong & Pumerantz, 2010) that had 8 bars of colour printed on it, ranging from very, very pale yellow, equivalent to euhydration (number 1), to a brown colour, equivalent to high levels of dehydration (number 8), which was supplied by Hydration for Health. The researcher and an independent third party compared the urine samples to the urine colour card separately. The number of the colour on the card that most matched the urine colour was recorded. Intraclass correlation coefficients were calculated to assess intra-rater reliability. The DV was the colour score average from the two raters.

- Urine Osmolality

The urine samples in each sample tube were analysed using an Advanced Multi Sample Micro Osmometer. Three 20µl samples were taken from each urine sample tube and analysed individually. The number on each sample tube was written on a print out of the scores from the osmometer and again separately in a log book with the scores. If two of the three samples did not have a range of 10 Uosm or less between them then more 20µl samples were taken from the sample tube and analysis continued until two scores had a range of less than 10 Uosm. The DV was the mean score of the two samples that were closest in value. All specimens and samples were then disposed of appropriately.

5.2.4 Procedure

The details of the procedure can be read in chapter 4.2.5. Additionally, the participant was asked to provide two urine samples at each testing session. At the start of the session the participant visited the toilet alone to provide a urine sample in a numbered sample tube just before administration of the visual analogue scales and cognitive tasks at baseline. They repeated this procedure again after the interval and just before administration of the tasks at test (see section 4.2.1 for a description of the tasks). The urine samples were stored immediately after collection in a food storage container filled with ice. Immediately after completion of the testing session the sample tubes were transported to a freezer, where they were stored, for a maximum period of 2 months, until analysis. The evening before analysis the sample tubes were removed from the freezer and put into the fridge to thaw overnight. Analysis of the samples commenced the next morning. This method of freezing and thawing the samples replicates the procedure employed by others. In Phillip, Chaimovitz, Singer and Golinsky's (1993) study, urine samples were immediately analysed and then frozen for two months, thawed and reanalysed. Results showed no significant differences between the osmolality readings of the samples before and after freezing.

5.3 Results

5.3.1 Primary Analysis: The Relationship between Self-Rated Thirst Scores, Volume Drank and Hydration Status (Hypothesis 1, 2 and 3).

5.3.1.1 Data Analysis.

A t-test was carried out to determine if there was a difference in the Uosm and self-rated thirst change score between the DRINK and NO DRINK condition. Correlational analyses were used to determine if Uosm scores correlated significantly with thirst ratings at baseline, change and test. Additionally, volume drank scores were correlated with Uosm change scores. Data were not normally distributed so the correlational coefficients were calculated using Spearmans Rho.

5.3.1.2 Data Preparation

The same data as those analysed in study 2 were used in the current study. Additionally, readings for Uosm were added to the data collection. However, data from from eight of the original 49 participants were excluded as they were missing either baseline Uosm data or test data from the drink condition. There was a large percentage of Uosm data missing from test in the no drink condition (12 of the remaining 41 participants). The reason for the large volume of missing data was that participants had not had a drink since leaving home to attend school, having given a urine sample at baseline 9.15am and not been given a drink in the intervention, they were unable to produce urine to give another sample at 10.30am. To enable the analysis of data, missing test Uosm readings in the no drink condition were replaced in the following way. Analysis showed that the mean change from baseline to test in the no drink condition was Uosm +77.20 mOsm/kg and so missing test data were replaced with the baseline Uosm score plus 77.20 mOsm/kg. Baseline NO DRINK and DRINK condition scores were compared using a Wilcoxon test, as the data was not normally distributed, which showed that they were not significantly different. Change scores were calculated by deducting the baseline from test Uosm readings. The variation in the change scores was reduced in the dataset in which missing test data had been replaced (*SD* 96.20) compared to the original dataset (*SD* 114.98). However the change no drink data were normally distributed. Data were then screened and outliers replaced with a value that was one unit higher than the next highest score (or lower than the next lowest score if applicable) within the normal distribution of scores (Dancey and Reidy, 2004). In this way the outliers were removed but replaced with scores from the far end of the distribution curve so as to avoid changes to the mean.

5.3.1.3 Results

At baseline, the mean Uosm for children in the DRINK condition was 874 mOsm/kg (*SD* = 189.45) and in the NO DRINK condition was 838 mOsm/kg (*SD* = 195.99). Data presented in Table 5.1 show the mean change scores and *SD*s for self-reported thirst and Uosm and the *p* values for the analysis comparing outcomes when participants had a drink to when they did not have a drink. Observation of Table 5.1 also show that both the Uosm change score ($t(40) = 6.311$, $p<.001$) and the self-rated thirst score ($t(40) = 8.46$, $p<.001$)

became significantly lower in the DRINK condition compared to the NO DRINK condition. Both had high effect sizes (r = .70 and r =.80 respectively). Mean volume drank was 345.39 ml with an SD of 157.10. The volume drank ranged between 80ml and 500ml.

Table 5.1

The Mean Change Scores, SDs and Significance Levels for Self-Reported Thirst and Uosm

Scores	No Drink Change Score		Drink Change Score		Significance	
	Mean	*SD*	Mean	*SD*	*T* (*n = 41*)	*p*
Uosm	70.05	57.02	-133.13	104.50	00.31	**<.001**
Thirst	15.98	3.30	-25.23	25.22	00.46	**<.001**

To investigate further the relationship between self-reported thirst and Uosm correlational analyses were carried out. Data presented in Table 5.2 show the Spearman Rho correlations between reported thirst and Uosm baseline, test and change scores in the DRINK and NO DRINK condition and the *p* values. Additionally, the table shows the Spearman Rho correlations between volume drank and Uosm change and test scores in the DRINK condition and the *p* values. All the correlational coefficients were very weak and were not statistically significant. Observation of Figure 5.1 shows that a large number of the participants drank 500ml of water in the intervention but that there is a large range in Uosm change scores (Minimum Uosm= -589.50

mOsm/kg, maximum Uosm = 308.50 mOsm/kg). Therefore, these results show there is not a strong relationship between reported thirst rating and Uosm scores or volume drank and Uosm scores.

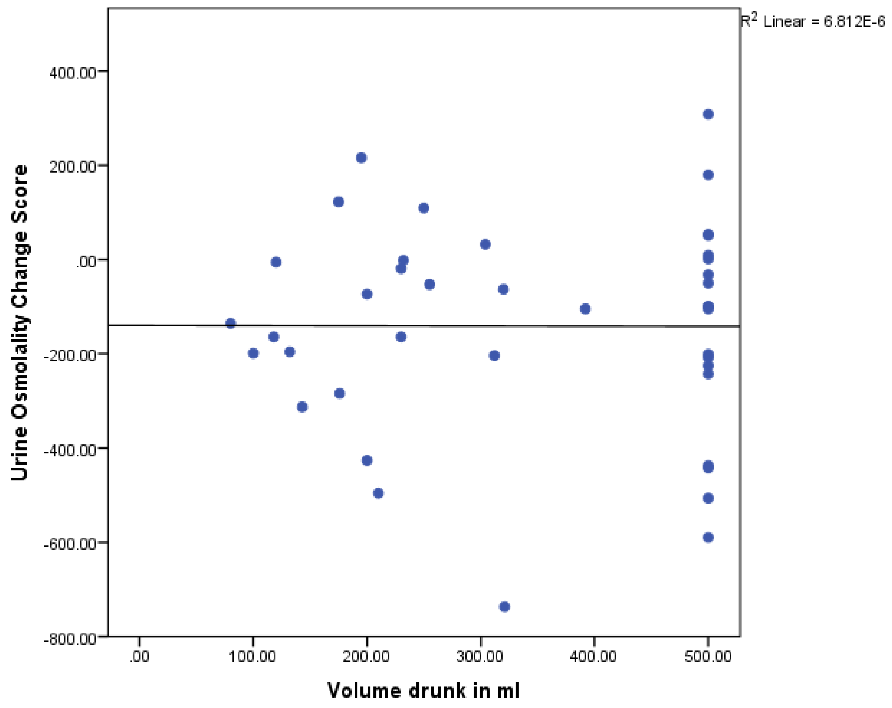


Figure 5.1 Scatter Plot Showing Correlation Between Change Scores in Uosm and Volume Drank.

Table 5.2

Spearmans Rho and Significance Levels for Correlations of Self-Rated Thirst and Urine Osmolality.

n=41	No Drink						Drink					
	Baseline		Test		Change		Baseline		Test		Change	
	r_s	p	r_s	p	r_s	p	r_s	p	r_s	p	r_s	P
Thirst Ratings	.17	.25		.69	.08	.60	-.17	.24	.06	.66	.15	.31
Volume Drank	Na	Na	Na	Na	Na	Na	Na	Na	.03	.86	.01	.94

Note r_s = Spearmans Rho; Na = not applicable

5.3.2 Exploratory Analysis: Whether the High Thirst Group had a Higher Uosm Reading than the Low Thirst Group

In Study 2 (4.3.2.1) participants were divided into those that had a high or low self-reported thirst score at baseline, by means of a median split (Mdn=44) in both the DRINK and NO DRINK condition. A 2x2 split plot ANOVA was carried out with the factors DRINK (DRINK, NO DRINK) and THIRST (HIGH THIRST, LOW THIRST) to determine whether there was a main effect of THIRST on cognitive performance or an interaction between the THIRST and DRINK condition. Results showed that participants in the high thirst group rated themselves as significantly hungrier than those in the low thirst group at baseline. Furthermore, participants made significantly more go errors in the SSRT task if they were in the HIGH THIRST group at baseline than if they were in the LOW THIRST group, regardless of whether they had a drink. To try and determine if the participants in the HIGH THIRST group were more dehydrated than those in the LOW THIRST group, the Uosm scores in the predetermined thirst groups were compared to each other. Hypothesis 4 predicted that the high thirst group would have a higher urine osmolality reading than the low thirst group.

5.3.2.1 Data Analysis

As a follow up from study 2, to determine whether Uosm scores differed in the high thirst and low thirst groups a mixed model Analyses of Variance (ANOVA) was carried out on Uosm baseline and test scores to determine if there was a main effect of THIRST. DRINK (DRINK, NO DRINK) was a within subject factor and THIRST (HIGH THIRST, LOW THIRST) was a between subjects factor.

5.3.2.2 Data Preparation

For the ANOVA analysis, participants were divided into HIGH THIRST and LOW THIRST groups using the criteria set in study 2 (4.3.2.1). In the original groups there were 19 participants in each group but due to missing data there were 17 participants in the LOW THIRST group and 14 participants in the HIGH THIRST group in this analysis. Mean and SD scores in the high and low thirst groups, at baseline and test, in both drink conditions can be observed in Table 5.3.

5.3.2.3 Results

The ANOVAs showed that there was no main effect of THIRST, *F*(1,29)=.468, *p*=.500 or DRINK *F*(1,29)=.1.266, *p*=.270 on Uosm scores. These results suggest that self-rated thirst scores are independent of Uosm scores in the children in this sample.

Table 5.3

Mean Uosm Scores for Participants in Each Thirst Group at Baseline and Test.

		High Thirst				Low Thirst			
		Baseline		Test		Baseline		Test	
Condition	Measure	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Drink	Uosm	848.14	201.12	785.32	284.34	910.67	186.89	680.38	286.47
	Thirst	63.63	13.97	31.32	24.47	18.47	16.35	15.32	24.45
No Drink	Uosm	844.71	190.69	928.43	141.59	796.91	211.76	868.82	193.54
	Thirst	64.89	14.66	75.53	18.30	18.36	15.20	42.00	27.80

5.3.3 Exploratory Analyses: The Effect of Estimated Volume of Fluid Ingested at Breakfast on Uosm Readings at Baseline (Hypothesis 5)

5.3.3.1 *Data Analysis.*

The estimated total volume of fluid ingested was correlated with Uosm baseline readings using Spearman’s Rho.

5.3.3.2 Data Preparation.

Estimated fluid volume data from study 2 were used (4.3.4.1) and baseline Uosm data.

5.3.3.3 Inferential Results.

Correlations between the estimated amount of fluid consumed before school and baseline Uosm readings were very weak and not statistically significant in both the DRINK (*r(44) = -.069, p = .658*) and NO DRINK (*r(45) = .201, p = .196*) conditions.

5.3.4 Secondary Analysis: Do Uosm Levels Moderate the Effect of Water Consumption on Cognitive Performance? (Hypothesis 6)

5.3.4.1 Data Analysis

To determine if dehydrated participant's mood and cognitive performance change scores differed significantly, when they were in the DRINK condition compared to when they were in the NO DRINK condition, data that were not normally distributed were analysed using the Wilcoxon test and parametric data were analysed with a t-test. Only test scores, rather than change scores, were used for the SSRT task, as this task was only administered after the intervention and not before.

5.3.4.2 Data Preparation

In each condition, participants were divided into two groups; those that had a Uosm level of above 800mOsm/kg at baseline, were allocated to the DEHYDRATED group, and those that had a Uosm below 800 mOsm/kg at baseline, were allocated to the HYDRATED group. Twenty-five children consistently had a Uosm above 800 mOsm/kg at baseline on both the DRINK condition day and the NO DRINK condition day. Only these participant's data were included in the DEHYDRATION group in the statistical analysis. Only 5 of the 9 children that were in the HYDRATED group at baseline in the NO DRINK condition were also in the HYDRATED group at baseline in the DRINK condition.

In the DEHYDRATED group, there were no significant differences between the DRINK and NO DRINK condition cognitive performance and mood baseline scores. Therefore, change scores, deducting the baseline scores from test scores, were used when comparing the differences in cognitive performance between the DRINK and NO DRINK conditions.

5.3.4.3 Descriptive Results

The mean Uosm in the DRINK condition at baseline in the HYDRATED group was 716 mOsm/kg (*SD* =75) and 964 mOsm/kg (*SD*=82) in the DEHYDRATED group. Observation of Table 5.4 shows that at baseline, 25 % of the children in the NO DRINK condition and 28 % in the DRINK condition were in the HYDRATED group. The remaining 75 % and 72 % respectively were in the DEHYDRATED group. At test, in the No DRINK condition the percentage of children defined as 'hydrated' reduced to 21 % from 25 % whereas in the DRINK condition the percentage of children that were 'hydrated' rose to 44 % from 28 %. The percentage of children defined as dehydrated increased to 79 % from 75 % in the NO DRINK condition, and decreased to 56 % from 72 % in the DRINK condition.

Table 5.4.

Number of Children that were in the Hydration Groups at Baseline and Test in Both Drink Conditions.

	No Drink		Drink	
	BL	Test	BL	Test
Hydration Group	9	H 6 D 3	12	H 9 D 3
Dehydration Group	32	H 1 D 31	29	H 10 D 19

Note. BL = Baseline; H = Hydrated group; D = Dehydrated group;

5.3.4.4 Inferential Results.

These statistics only refer to analysis of the DRINK condition data. There was no significant difference, in the volume of water drank, between the HYDRATED (*M* = 323.58ml) and DEHYDRATED group (*M* = 352.21ml). Furthermore, there were no significant differences between the HYDRATED and DEHYDRATED groups in reported thirst baseline, test or change scores. However, the comparisons between the hydrated and dehydrated groups are only exploratory as the hydration group had a very low number of participants (n=5).

Data presented in Table 5.5 show mood and cognitive change mean scores and *SD*s for participants in the DEHYDRATED group who had a DRINK and NO DRINK. Change scores were compared using a t-test and the *p* values shown. Observation of the data show that, Uosm scores increased ($t(24)=5.085$, $p<.001$) on the occasion that children had NO DRINK (*M* = Uosm 50.12mosm/kg, *SD*=51.77), with a large effect size (r =.72) compared to when they did have a DRINK (*M* = Uosm-172.06mosm/kg, *SD*=227.16).Moreover, children reported becoming significantly thirstier between baseline and test ($t(24)=3.974$, $p<.001$) when they were in the NO DRINK condition (*M* = 11.69, *SD*=18.57), with a large effect size (r =.62) compared to when they were in the DRINK condition (M = -16.92,SD = 28.25). However, a bivariate correlation between Uosm and self-rated thirst scores showed there was no statistically significant relationship between these two variables.

Observation of the data in Table 5.5 show that, in the DEHYDRATED group there was no statistically significant difference in change scores between the DRINK and NO DRINK condition for either mood scores or cognitive performance other than for the finger tap task. In the finger tap task the participants change scores increased significantly more when participants had a DRINK compared to when they had NO DRINK ($t(24)=2.595$, $p=.016$), with a medium to large effect size (r =.47)

Table 5.5

Change Scores for Children in the Dehydrated Group in the Drink Condition Compared to the No Drink Condition (n=25)

	No Drink		Drink		
Task/Mood	Change Scores	*S.D*	Change Scores	*S.D*	*p*
Uosm	50.12	51.77	-172.06	227.16	**<.001**
Thirst	11.69	18.57	-16.92	28.25	**<.001**
Hunger	6.42	13.43	9.62	16.56	.394
Happiness	1.65	9.57	.62	9.58	.714
Non Speeded Letter Cancellation	7.28	17.35	-11.12	17.71	.373
Simple Reaction Time	12.63	9.64	22.65	5.81	*.201*
Choice Reaction Time	11.45	35.54	4.02	65.46	.530
Choice Reaction Time Errors	-.29	1.81	.02	2.44	*.589*
SPOT	.38	1.58	-.23	1.58	.203
Finger Tap	.85	8.83	7.52	8.27	**.016**
Speeded Letter Cancellation	-4.56	5.13	-3.00	6.50	.372
Stop Signal Go Errors	5.42	5.34	5.50	5.13	*.824*
Stop Signal ReactionTime	720.02	94.56	713.04	96.16	*.676*
Stop Signal Stop Errors	36.63	12.26	37.67	14.03	*.764*

Note. Wilcoxon test *p* value in italics.

As a post hoc analysis, the scores between baseline and test were compared in both the HYDRATED and DEHYDRATED group in the DRINK and NO DRINK condition, with a bonferonni adjusted level of .0125 (.05/4). A larger data set was able to be used for this analysis as baseline was being compared to test, so participants did not need to be consistently hydrated/dehydrated in both the DRINK and NO DRINK condition. Numbers, however, were still very low so these analyses are only exploratory. The HYDRATED group significantly improved the number of finger taps between baseline and test in the DRINK condition ($t(8)=-4.361$, $p=.002$) (M change score = 11.25) and approached significance in the NO DRINK condition ($t(8)=-2.755$, $p=.028$) (M change score = 9.5). In the DEHYDRATED group only those in the DRINK condition improved the number of finger taps significantly between baseline and test ($t(20)=-3.89$, $p=.001$) (M = 7.62) .Those in the DEHYDRATED group who did not have a drink did not significantly improve their performance between baseline and test ($t(30)=-1.317$, $p=.198$) (M change score = 1.85). These results infer that it is being dehydrated and not having the resources to improve finger tapping performance over time that causes a significant difference between the drink and no drink group rather than it being exclusively a positive effect of drinking water.

5.3.5 Supplementary Analysis: The Relationship between Osmolality Levels and Urine Colour Scores (Hypothesis 7).

5.3.5.1 Data Analysis

Correlational analysis was used to determine if there was a relationship between urine colour and Uosm.

5.3.5.2 Data Preparation

There was a large proportion of missing data in the NO DRINK condition at test as participants had not been able to produce a urine sample. Therefore, urine colour and Uosm data were only available for 29 participants in the NO DRINK condition at test. Histograms showed that the urine colour and Uosm data were not normally distributed so the correlational coefficients were calculated using Spearmans Rho. Intraclass correlation coefficients were calculated which showed there was a substantial agreement between raters ranging from 0.62 to 0.71 for the baseline and test, DRINK and NO DRINK conditions (Landis and Koch,1977).

5.3.5.3 Results.

Table 5.6 shows descriptive statistics for urine colour for the NO DRINK and DRINK condition at baseline and test and Uosm scores. The urine colour score is an interval scale from 1 to 8. Table 5.7 shows the Spearmans Rho correlation coefficients for urine colour and Uosm and the shared variance. The scores correlated moderately to strongly and three of the four analyses were statistically significant. At test in the drink condition the squared correlation coefficients showed that 61 % of the variance in urine colour was accounted for by urine osmolality but at baseline only 9 % of the variance in urine colour was accounted for by urine osmolality and this was not a statistically significant relationship.

Table 5.6

Means, SD and Confidence Intervals for Uosm and Urine Colour for Both Drink Conditions at Baseline and Test

		Uosm	Urine colour			
					95 % CI	
Condition	Score	Mean mOsm/kg	Mean	*SD*	*LL*	*UL*
No Drink	Baseline	858	3.96	.62	3.35	4.56
	Test	935	4.47	.49	3.90	5.02
	Change	77	.31	.27	-.16	.78
Drink	Baseline	878	4.25	.45	3.71	4.79
	Test	722	3.68	.49	3.13	4.24
	Change	-155.5	-.66	.35	-1.17	-.16

Note: CI= confidence intervals; LL = lower level; UL = upper level

Table 5.7

Results for Correlational Analyses between Uosm and Urine Colour Scores by Drink Condition at Baseline, Test and Change.

Condition	Score	*rho*	% shared variance	*p*
No Drink	Baseline	.629	39 %	**<.001**
	Test	.528	28 %	**.003**
Drink	Baseline	.305	9 %	.053
	Test	.779	61 %	**<.001**

Note. Rho= Spearmans Rho

5.4 Discussion

5.4.1 Summary of Findings

A primary aim of this study was to investigate whether there was a relationship between hydration levels and thirst ratings. Results showed that there were no significant correlations between hydration levels and self-rated thirst change scores or scores at baseline and test and thus the hypothesis was not supported. Furthermore, an exploratory analysis showed that the high thirst group did not have a statistically higher Uosm score than the low thirst group, hence rejecting the hypothesis and suggesting that self-rated thirst is not dose dependent on hydration status in this sample of children.

However, self-rated thirst scores and hydration levels were significantly lower when children had a drink than when they did not have a drink, although correlational analyses showed no relationships between Uosm and self-rated thirst change or test scores or volume drank in the intervention. Moreover, exploratory analysis showed no relationship between estimated fluid ingested before coming to school in either food or drink and hydration scores at baseline. Thus, the hypotheses were rejected that predicted there would be a dose response relationship between self-rated thirst or volume drank to hydration levels.

Another aim of this study was to look at the relationship between hydration status and cognitive performance and mood. There were no statistically significant differences found in mood or cognitive performance in the dehydration group between the children when they had drink compared to when they did not have a drink other than in the finger tap task. Children in the dehydration group increased the number of finger taps between baseline and test significantly more on the occasion when they had a drink compared to when they did not; increasing the number of finger taps to the same level at test as those in the hydrated group. However, these results need to be interpreted with caution as the number of participants in the hydrated group was very low. These results supported the hypothesis that participants in the dehydration group would improve cognitive performance after consuming water compared to participants in the hydration group.

It was also hypothesised that there would be a medium to strong positive correlation between urine colour and Uosm which was supported. Scoring urine colour is a cheaper alternative to measuring Uosm as a method of assessing urine concentration and the effectiveness of this method will be considered in the main discussion.

5.4.2 Examination and Implications of the Findings

An important finding in the present study was that baseline urine osmolality readings moderated the effect of water consumption on the finger tapping task. Exploratory analysis showed that performance improved in both the hydration and dehydration risk groups when participants had a drink and also in children in the hydration group when they did not have a drink. Only the performance of children in the dehydration group when they did not have a drink did not improve over time. These results suggest that there may be more of a detrimental effect of dehydration on performance, rather than a beneficial effect of water consumption. In addition, the results showed that there were no significant differences in finger tapping performance between the hydration and dehydration group at baseline. This finding is consistent with the results from

Bar-David et al. (2005). The results from the present study suggest that most participants improved with practice but those participants that were dehydrated and were not given a drink did not have the resources to increase speed.

It is speculated that participants' motor performance may have deteriorated over time due to the effect of dehydration on acetylcholine levels, which are dependent on the level of dehydration, and may impair synaptic neuromuscular transmission (Adan, 2012). Alternatively, it has been shown that dehydration reduces brain volume which may have a negative effect on cognitive performance (Duning et al., 2005; Kempton et al., 2009). In support of this theory, functional magnetic resonance imaging (fMRI) analysis of adolescents whilst engaged in a cognitive task showed that when adolescents were dehydrated they had increased brain ventricular enlargement, which is associated with lower brain volume. The adolescents also had a much stronger increase in fronto-parietal blood oxygen-level-dependent (BOLD) response whilst performing the task when they were dehydrated than when they were hydrated (Kempton et al., 2011). This relationship, between decreased brain volume and increased BOLD response when performing a task, could suggest that completing a task requires more resources when dehydrated than when hydrated. It could also be speculated that performance when dehydrated might reduce or plateau over time as it becomes harder to devote more resources to performance.

Conversely, Cheuvront and Kenefick (2014) argue that studies show inconsistent effects of dehydration on brain volume. They suggest that effects of dehydration on cognitive performance are unlikely to have a physiological basis and more likely to be due to distraction from negative mood states and discomfort due to the dehydration. Some studies have found dehydration has a negative effect on mood in adults (Armstrong et al., 2012; Ely et al., 2013; Ganio et al., 2011; Pross et al., 2013) but to date, there is little evidence that mild, voluntary dehydration in schoolchildren has a negative effect on mood. In this study children that were in the dehydration risk group did not rate themselves as less happy than those in the hydration group. Furthermore, in study 1 there were no differences in changes of ratings of happiness or fatigue on the occasion that children had a drink than when they did not have a drink. Results from Booth et al., (2012) showed no evidence of an effect of water consumption on positive affect. However, Edmonds and Jeffes (2009) study did report that children that did not have a drink of water had lower happiness ratings than those that did have a drink, although this result may be due to the 'no drink' group having a higher rating at baseline. It, therefore, seems unlikely that differences in finger tapping performance might be due to negative mood states.

The evidence from this study also shows that ratings of thirst did not moderate or have a causal effect on finger tapping performance. However, Cheuvront and Kenefick's (2014) theory is consistent with the results from study 2 which showed that the number of go errors in the SSRT task were higher in children in the high thirst group at test than those in the low thirst group. Moreover, the results from the present study show there was no effect of urine osmolality readings on the number of go errors, suggesting that the effects on cognitive performance were due to the sensation of thirst rather than an effect of hydration status. The implications of the results from the two different tasks, finger tapping and SSRT task, suggest that performance in different cognitive domains may be sensitive to different psychophysiological mechanisms. It is speculated that performance in tasks predominantly requiring fine motor skills may be more sensitive to hydration status whereas performance in tasks requiring attention may be more sensitive to the sensation of thirst. Supporting this argument, in Edmonds, Crombie and Gardner's (2013) study participants that had higher rates of thirst had slower response times in a simple reaction time task. More research is required to investigate these theories further.

Results from the present study support the theory that subjective thirst ratings are not strongly related to Uosm scores in children. Furthermore, the high and low thirst groups did not have significantly different Uosm scores in each group at baseline. Moreover, there was no significant difference in ratings of thirst between the hydration and dehydration risk group at baseline; suggesting that ratings of thirst may be independent of hydration status. Indeed, Ramsay & Booth, (1991) theorise that the causal factors for thirst can be divided into three categories: somatic influences which include physiological signals, for example a specific interindividual level of plasma osmolality; sensory influences such as the palatability of the fluid, or the feel of the fluid in the mouth; and social factors such as social rituals and cultural norms for example coffee breaks. Alternatively, the lack of relationship between Uosm and thirst may be a time lag between the sensation of thirst and hydration status. Denton et al., (1999) theorises that when people are thirsty they will drink until they are satiated which is detected by oral, pharangoesophageal, and gastric neural feedback and the sensation of thirst is diminished. Changes will occur to plasma, saliva or urine osmolality and water balance but there is a variable time period before these occur. This theory could explain why we observed no dose response relationship between ratings of thirst or volume drank and urine osmolality in the short time frame of the study. In study 4 self-rated thirst, volume drank and Uosm will be recorded and their relationship observed, over a longer period of time in a more natural environment.

Another finding of the present study was that changes in hydration status did not have a strong relationship to volume drank. As well as no relation between fluid drank and Uosm, the exploratory analysis found no correlation between volume of fluid ingested in food and drink at breakfast and baseline hydration status. However, Uosm readings became significantly lower when children had a drink compared to when they did not have a drink. This result was consistent with the study by Perrier et al. (2012) who found a significant drop in Uosm readings in participants when supplemented with additional water. The lack of correlations between volume drank and urine osmolality may be in part due to the time lag between drinking fluid and measurement of urine osmolality, which may not be sufficient for changes to occur. In a study (Péronnet et al., 2012) in which water was labelled with deuterium oxide (D2O) before ingestion so that it could be traced, the tracer was detected in plasma 2 to 2 ½ minutes after the water had been drank. The highest level of D2O in blood plasma peaked between 15 and 60 minutes after the water had been ingested and it took approximately 75 to 90 minutes for 300ml of plain water to be absorbed into blood plasma or blood cells. As organs such as the brain and the kidneys have a large network of blood vessels supplying them with blood they are likely to start receiving labelled water within 2 to 10 minutes of consumption. Dependent on the water balance of the individual some of the labelled water may be excreted in urine. Consequently, although ingested water will initially get into the bloodstream very quickly, it could take a considerable time for the whole quantity of water to be absorbed and dependent on the hydration status of the individual, even longer for it to be excreted in urine. Furthermore, the results show there was a large inter-individual variation in absorption rates of ingested water. Additionally, solute load due to diet and exercise will have an effect on urine osmolality levels (Cheuvront & Kenefick, 2014). Therefore, the study by Perrier et al. (2012) and the results from the present study suggest that urine osmolality may reflect habitual hydration habits and indicate when fluid has been drank, but perhaps not be a sensitive enough measure to reflect volume of fluid drank or ingested in the short term. The relationship between volume of fluid consumed and urine osmolality in individuals will be investigated in more depth in the next chapter.

A final and supplementary aim of this study was to determine if ratings of urine colour correlated highly with urine osmolality readings. Results showed that correlations between the two variables were moderate to strong, however, the percentage of variance in urine colour accounted for by urine osmolality varied greatly for each data set analysed, despite there being high intra-rater reliability. This was not dependent on whether the data set was from the drink or no drink condition or from a particular time point but appeared to be random. These results are similar to previous studies in which the outcomes have been inconsistent (Armstrong et al., 2012; Eberman, Minton & Cleary, 2009). Therefore, the reliability of this measure as an alternative to urine osmolality is in question.

5.4.3 Methodological Issues

A consideration in this study was whether to use Uosm 800 mOsm/kg as the threshold of dehydration. Previous studies of voluntary dehydration in children (Bar-David et al., 2005; Barker et al., 2012; Bonnet et al., 2012; Fadda et al., 2012) have all used this threshold, but other literature have published other Uosm readings as the threshold of dehydration (see Baron et al., 2015, for a review). Indeed, as Uosm has a highly significant inter and intra-individual variability one threshold can never be generalisable. However, in their review Baron et al., (2015) states that due to a conclusion drawn by EFSA, a threshold of Uosm 800 mOsm/kg may be a “relevant cut-off” (pg 153) to define the threshold between euhydrated and ‘slightly dehydrated.’ Therefore, despite reservations as to the authenticity of a dehydration threshold, this study used Uosm 800 mOsm/kg to confer some consistency and uniformity to research in this area.

A threshold is also only of any use if it is of functional significance, so for this study the Uosm cut-off is only of value if cognitive performance is shown to deteriorate or improve on either side of the threshold. Another implication of using a threshold of Uosm 800 mOsm/kg is that a large proportion of children arrive at school with a Uosm above this threshold. In this study 72-75 % of the children had a baseline Uosm above 800 mOsm/kg. In the studies by Bar-David et al. (2005) and Fadda et al., (2012) 63 % and 84 % respectively were defined as dehydrated. Having such a large proportion of children arriving at school defined as ‘slightly dehydrated’ merits the question as to whether Uosm is a useful measure to collect in future studies when weighed against the negative aspects of urine collection. Requiring schoolchildren to provide a urine sample in a study makes identifying schools that are willing to participate more difficult and participant numbers much lower. As a large proportion of children can be assumed to be ‘slightly dehydrated’ at baseline, it may make the assessment of hydration status at baseline unnecessary. The next chapter reports a case study that investigates, in more depth, the pattern of Uosm scores and the relationship between volume drank and cognitive performance in individual children, to further consider the merit of measuring hydration status, before designing the next large scale study.

5.4.4 Conclusion

In conclusion, in the present study it was found that in a reaction time task the number of errors were higher in participants with a high self-rating of thirst compared with those who had a low self-rating of thirst. Hydration status had no effect on cognitive performance. It is speculated that the increased number of errors is due to the sensation of thirst which causes a distraction (see section 4.4.2) rather than an underlying biophysiological mechanism. In contrast, participants that were dehydrated and did not have a drink did not improve motor speed or control in a fine motor skills task, over time, whereas those that were hydrated or who had a drink improved their performance over time. Self-rated thirst had no effect on fine motor skills performance. It is suggested that children at risk of dehydration are unable to sustain their performance due to an underlying psychophysiological mechanism such as a loss of brain volume (Kempton et al., 2011). As fine motor skills are so important to children in a classroom setting (McHale & Cermak, 1992) further investigation will be carried out, and reported in study 5, to determine which specific motor skills components can be improved by water consumption.

CHAPTER 6

Study 4: A Case Study of Fluid Intake, Urine Osmolality, Self-Rated Thirst and Cognitive Performance of Three Children Over Five Days

6.1 Introduction

Primary aim

- To observe, interpret and discuss descriptive statistics and data patterns in the volume of fluid consumed and urine osmolality (Uosm) scores over a 5 day period, in three individuals.

Secondary Aim

- To observe, interpret and discuss descriptive statistics and data patterns of self-rated thirst, self-rated fatigue and cognitive task performance and how they relate to volume of fluid consumed and Uosm scores, in 3 individuals, over the final 3 days of the study.

Guidelines from the European Food Safety Authority (EFSA, 2010) recommend that an Adequate Intake (AI) for girls between the age of 4-8 years is 1.6 litres per day (L/d) of fluid (fluid intake from beverages and food) and girls of between 9-13 years consume 1.9 L/d per day. Yet a recent survey shows that only between 30 % to 55 % of children in the UK adhere to these guidelines and that a large proportion of children globally are not drinking enough (Iglesia et al., 2015).Furthermore, results from study 3 and previous research literature (Barker et al., 2012; Bonnet et al., 2012; Stookey et al., 2012) show that a large proportion of children arrive at school with a high Uosm reading. The inference is that these children are not drinking enough fluid which generates the high Uosm reading and indicates dehydration. Evidence from previous research (Perrier et al., 2013) supports the inference that high Uosm is a result of not drinking enough fluid. The findings from Perrier et al. (2013) showed that participants who habitually drank a higher volume of fluid had a significantly lower morning Uosm reading than participants that habitually drank a low volume of fluid, which is consistent with the theory that a child with a high morning Uosm reading consumes lower volumes of fluid. There is evidence that low fluid intake can lead to a higher risk of chronic kidney disease and hyperglycaemia in adults and high levels of Uosm also increase the risk of chronic kidney disease (see review by Bankir, Bouby, & Ritz, 2013). Extrapolating from the review (Bankir et al., 2013) it could be suggested that a high proportion of schoolchildren may be at risk of these conditions in later life.

As an intervention in a study by Perrier et al. (2013), adults with a habitually low water intake were supplemented with an additional 1.5 litres of water per day (L/d) for the last 3 days of the 5 day experiment and their Uosm scores were recorded. Results showed that 24 hour Uosm scores had reduced significantly the day following the water supplementation, although it was noted with interest that there was a large interindividual variation in Uosm scores. Uosm at baseline in the low water intake group ranged between 435 and 1,123 mOsm/kg, despite participants being on a strict standardised diet and beverage intake.

Of further interest was the detection of a definite circadian rhythm in Uosm scores (Perrier et al., 2013). Urine was collected between 7am and midday (AM), midday and 16:00 (PM-1), 16:00 and 20:00 (PM-2) and 20:00

until sleep (EVE) and results showed that AM Uosm scores were high and gradually dropped during the day to the lowest level at PM-2 before rising again for the EVE collection. These fluctuations occurred despite fluid intake being strictly regulated with a 250ml bottle of water provided at 4 hourly intervals. Afternoon Uosm scores were the most indicative of 24 hour Uosm. These results suggest that previous research literature (Barker et al., 2012; Bonnet et al., 2012; Stookey et al., 2012) that has used morning Uosm as an indicator of hydration status may be prematurely defining children with a morning Uosm of above 800 mOsm/kg as being dehydrated, as 24 hour Uosm or PM Uosm is liable to be much lower.

The primary aim of this study was to record and observe fluid intake and Uosm scores over a longer period than that used thus far in this thesis. Rather than assessing pre and post-intervention in the present study, measurements were taken over five days. A very small number of children were assessed in order that very detailed, individual observation of data could be conducted in preference to gathering a larger cohort and using inferential statistics. Therefore, individual differences are commented upon.

Thus, the daily volume of fluid consumed in both food and beverages for each child can be scrutinised and discussed and compared to the current EFSA guidelines. Moreover, the relationship between volume of fluid consumed in both food and beverages and Uosm scores can be explored in depth in each individual case. In study 3, results showed that drinking fluid reduced Uosm scores but there did not appear to be a dose response effect. It was speculated that the lack of a correlational finding may have been as a result of a time lag between consuming fluid, and the effect on hydration status (Denton et al., 1999). Data patterns observed in the present study will be explored to determine whether there is a noticeable time lag between fluid consumed and a reduction in Uosm in this small group of children.

Moreover, it will be possible to determine whether a circadian rhythm emerges in the Uosm scores over the course of 5 days and whether morning Uosm scores are much higher than Uosm scores from later in the day. As an additional 1000ml of fluid will be supplemented on day 4 and 5 it will also be possible to observe whether this has a distinguishable effect on reducing Uosm scores both in the morning, on the day following water supplementation and throughout the day.

On days 3 to 5 self-rated thirst and fatigue scores will be collected. An aim will be to investigate whether self-rated thirst scores appear to relate to fluid consumed, fatigue and Uosm scores. Results from study 1 and 2 showed that having a drink significantly reduced self-rated thirst scores compared to not having a drink, but that volume drank did not correlate with ratings of thirst. Furthermore, the mean volume drank did not differ in the high thirst group compared to the low thirst group and Uosm scores were not related to self-rated thirst scores. This study will allow detailed exploration of the timeline between self-rated thirst scores and fatigue, volume of fluid consumed and Uosm in each individual to assess whether a consistent pattern emerges in each individual.

Cognitive task performance data will be collected on days 3 to 5 and visually explored and compared to the Uosm, self-rated thirst scores and fluid volume data to ascertain if there are any interpretable patterns that emerge. A rationale for the cognitive tasks and mood scales will be included below.

6.1.1 Rationale for Mood Scales and Cognitive Tasks

An aim of this study is to observe the patterns of self-rated thirst scores and examine how or if they interact with Uosm, volume drank and cognitive performance. Therefore, a visual analogue scale (VAS) will be used to measure self-rated thirst in order to be consistent with the method of measurement used in studies 1, 2 and 3. Additionally, because dehydration has a negative effect on ratings of fatigue (see chapter 2 for review) and ratings of fatigue have an effect on cognitive performance (Kahol et al., 2008), self-rated fatigue will be measured using a VAS. This measure was used in study 1 but measures of hydration status were not then collected to determine if hydration and fatigue were related. In this study the data of self-rated fatigue scores will be visually presented and examined alongside the self-rated thirst data and Uosm score data to determine if any distinguishable patterns can be observed.

These patterns will also be inspected alongside graphs of cognitive performance scores. The cognitive tasks chosen for this study consisted of those that have been shown in the studies in this thesis to be sensitive to hydration status such as the finger tapping task as well as tasks not yet tested for the effect of water consumption or thirst such as the Stroop test. The letter cancellation task will be included in the task battery as in study 1, performance improved in children that had a drink, compared to those that did not have a drink, and performance has been shown to consistently improve in children that have consumed water in previous research literature (Edmonds & Burford, 2009: Edmonds & Jeffes, 2009). Therefore, despite there being no effect of a drink on performance in study 2 the effects of water consumption on this task merits further investigation.

In study 3, the number of finger taps increased over time in participants unless they were dehydrated and did not have a drink of water. Thus, finger tapping performance will also be measured. This study will examine performance in more detail over three days to explore whether the pattern of scores are consistent with the findings from study 3 over a longer time period. Additionally, a fast tapping task will be included which requires manual dexterity, speed and reaction time skills. These skills have all been shown to be sensitive to self-rated thirst or hydration status in previous studies or research literature (study 1; study 3; Edmonds, Crombie & Gardner, 2013). This study will assess whether fast tap performance shows the same improvement when the children are hydrated as the simple finger tap task.

In study 2 and 3 the StopSignal task (SSRT) was used to assess the effect of drinking on water on inhibitory control. Results from study 3 showed that children with a high thirst rating made more errors. There has been some previous research literature which shows that experiencing uncomfortable sensations such as urination urgency (Tuk, Trampe, & Warlop, 2010) has an effect on Stroop performance. Thus, it is speculated that a when a child has higher thirst scores their performance in the Stroop task may deteriorate. The Stroop task is a similar task to the SSRT but in the Stroop task an alternative response to a stimulus is required whereas in the SSRT participants are required to withhold their response to a stimulus. For example, in the Stroop task participants are shown colour names (for example red, green and yellow) displayed in incongruent colours (for example, the word blue is presented in the colour yellow). The participant has to inhibit the response to identify the stimulus as the name of the colour that the word identifies and instead choose an alternative response, which is the colour in which the word is presented. This is the first study to explore the effects of water consumption and self-rated thirst on Stroop performance in children.

In study 1 an object recall task was administered but no significant difference was found in performance between children that had a drink compared to those who did not have a drink. These findings were not consistent with results from Benton and Burgess' (2009) study. However, some aspects of the object recall task had been changed and it was considered that the task in study 1 assessed memory and attention rather than speed of processing as in Benton and Burgess' (2009) study. In this study the object recall task will be administered in exactly the same way as in Benton and Burgess' (2009) study. It will be observed if any patterns of performance, along with the self-rated thirst, Uosm scores and fluid consumed scores, emerge in the data.

The forward digit span task has been used in previous research studies and results have been inconsistent (see chapter 2). When a reverse digit span task, which requires different cognitive processes to forward digit span, was used in a study by Edmonds et al. (2013) the results showed that participants that had no drink improved over time more than the participants that had a drink. Reverse digit span requires more executive control than forward digit span due to the extra attentional demands. Therefore, reverse digit span is often used in studies of children with attentional deficits (Karatekin & Asarnow, 1998). In study 2, it was found that children with high self-ratings of thirst made more go errors in the SSRT. Based on the study 2 findings it would be expected that performance on the reverse digit span task, in which executive control demands are already high, might deteriorate if self-rated thirst levels were high thus requiring more attentional resources from a finite capacity (Kahneman, 1973).

The purpose of the present study was to explore and discuss the data for each of the three individual cases to discover how the variables; fluid consumed, Uosm, self-rated thirst, self-rated fatigue and cognitive performance may relate. In particular, the study was to assess whether consistent, interpretable patterns of data emerged daily and across all participants or if there were inter-individual and intra-individual variation in data patterns.

6.2 Method

The research for this study has a different approach to the method for studies 1, 2, 3 and 5. The practices for the other studies are firmly rooted in a positivist paradigm whereas this study uses mixed methods. The methodology for this study was inspired by the graphical techniques used in exploratory data analyses (EDA) rather than the confirmatory data analyses used in my other studies. EDA has more of a focus on graphical representation of data and was developed to explore data rather than test hypotheses (Behrens, 1997). My interpretation of the data patterns were offered rather than models of analysis being developed and inferential statistics used, and so the ontology differs from the ‘realist’ view held in my other studies. Instead, it is acknowledged that my individual beliefs may have influenced my interpretations. The observations and discussion from this study are not intended to be construed as empirical evidence but as a complimentary addition to broaden an understanding of the data in this area of research.

6.2.1 Design

Three participant's actual water intake from food and beverages in a natural environment were recorded in detail over a five day period. Additionally, scores from periodic cognitive tests, a self-rated thirst scale and Uosm testing were collected, as shown in Figure 6.1 over the final three days of the study.

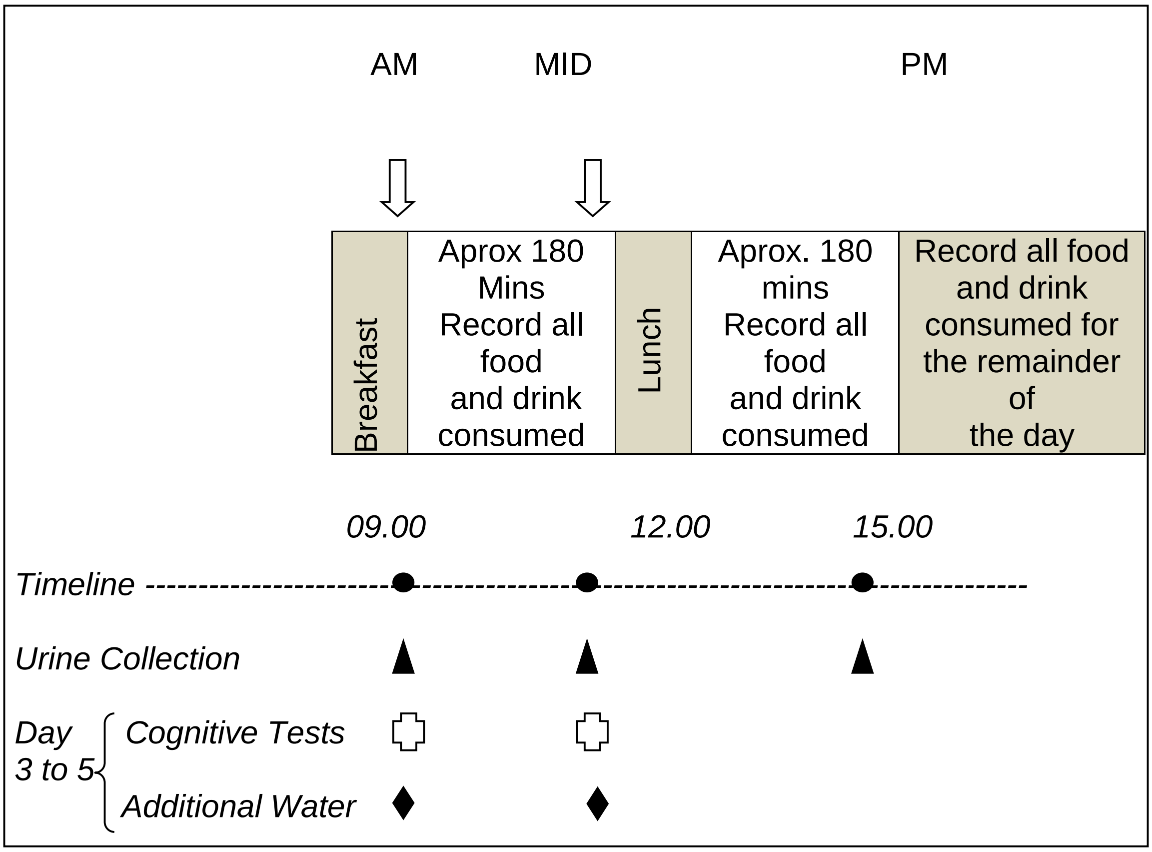


Figure 6.1. Daily Procedure.

6.2.2 Participants

Participants were recruited from the children of friends and colleagues of the researcher. Children were excluded if they were regularly taking any prescription drugs for a medical condition or had a medical condition or learning disorder which might interfere with participation in the study.

Initially seven females and one male participated in the study but only the data for three of the children, all of which were females, were included as four of the children had lots of missing data. One female suffered from a stomach bug on the final day and so did not complete any of the day 5 assessments and the male opted out of the study at the beginning of day 4. Two other females forgot to record some of the food and drink consumed. These difficulties with data collection are discussed later in section 6.3.6. The study took place in the school Lent Half Term and Summer holidays. The children did not take part in any routine activities or sporting events during the testing period. Generally the children were fairly sedentary but did varying amounts of walking during each day.

Two females, Case 1 and 2, were monozygotic twins and were aged 7 years and 5 months during the testing period. Case 3 was aged 10 years 9 months. All three females were White British, with English as a first language and were attending primary schools in Essex. All three children came from families with parents educated to at least first degree level or equivalent.

6.2.3 Measures

The children were given a battery of mood scales and cognitive tasks to complete on days 3, 4, and 5 of the study at period AM (15 minutes after breakfast) and MID (3 hours after breakfast), see Figure 6.1. The tasks were completed in the order presented below. Some of the tasks were carried out on an iPad and an Apple iPad Version 6, 58GB, was used.

6.2.3.1 Mood Scales

Four printed visual analogue scales (VAS) were presented to the children to assess subjective feelings of thirst, hunger, happiness and fatigue. Each analogue scale was anchored with a picture and a statement at each end of the 100mm scale. The child put a mark to depict their subjective rating of that particular mood or sensation. The happiness VAS had sad printed on the left hand side of the scale and happy on the right hand side, with appropriate pictures. For an example, see Appendix III. The hunger and thirst scales had 'not hungry or thirsty' printed on the left hand side and 'very hungry or thirsty' on the right hand side. Measurement was taken from the left hand side of the VAS to the child's mark. The fatigue VAS had the statement 'very tired' at the left hand end of the scale and 'not tired' at the right hand end of the scale with appropriate pictures. Measurement was taken from the right hand side of the VAS to the child's mark. A low score showed that the child had put a mark at the 'not' end of the scale, a high score showed that the child had put a mark at the 'very' end of the scale.

6.2.3.2 Cognitive Measures.

- Object Recall

  The children were shown an A4 sheet of paper with pictures of 15 everyday objects on it. For an example of a sheet see Appendix IV. The sheets were developed by finding names of objects that appeared in the high frequency words list (MRC Psycholinguistic database, 2010) and matching pictures to these words. The children were given 30 seconds to view the pictures and then one minute to recall them verbally. The score was the number of correctly recalled objects.

- Letter Cancellation Task

This task was printed on paper and presented to the child. The task consisted of a 20 x 20 grid which was 18cm x 18cm. In each case the target stimulus was the letter U (n = 38) and the distractor stimuli O, V and C (n = 362). Six parallel versions were developed for the six time points over the study. The children were told to find and draw a line through the letter U as quickly as possible and they were given 45 seconds. The score was the number of target stimuli identified.

- Reverse Digit Span

This task was adapted from the Wechsler Intelligence Scale for Children III. The researcher presented orally a sequence of digits and the child had to repeat the digits back to the researcher in reverse order. The trial began with a two digit number. The number of digits in the sequence increased by one digit every second sequence. The trials were stopped when the child got two consecutive sequences incorrect, with the same number of digits in the sequence. The score was the number of correctly remembered sequences.

- Finger Tap Task

The children completed the finger tap task on the iPad. The finger tap task is a free application found at https://itunes.apple.com/gb/app/digital-finger-tapping-test/id439751108?mt=8. The iPad was placed flat on a table and the children lay their own hand on a hand shape on the iPad screen. The palm of the hand had to stay in contact with the screen while the index finger tapped the screen as quickly as possible and the number of taps was recorded. A point was given for each finger tap. The task duration was 10 seconds and the task was repeated three times. The score was the average number of finger taps over the three trials.

- Fast Tap Task

This task is carried out on an iPad and was a free application. In this task the participant was able to see a grid of 3 by 4 white squares. One or more red lights appeared simultaneously in the squares and they had to be tapped out with a finger as quickly as possible, using one or more fingers. The participant was initially given a time of 30 seconds but ‘bonus’ seconds were added on for hitting the red lights quickly. For each light tapped out 15 points were given and for each square without a light that was tapped incorrectly 50 points were deducted from the score. The participant was instructed to choose the medium difficulty level to play and the 30 seconds begins as soon as this level was chosen.

- Stroop Task

The participants completed a Stroop test on the iPad. This task can be found at https://itunes.apple.com/gb/app/the-Stroop- effect/id472707 380?mt=8. In this task, five different coloured squares were visible at the bottom of the screen. In the centre of the screen a word appeared naming a colour and presented in a contrasting colour. The participant was required to choose one of the squares at the bottom of the screen which was the same colour as the ink in which the word was presented rather than the colour that the word described. The participant was given 30 seconds to tap the coloured squares as quickly as possible. One point was added for each correct answer and one point deducted for each incorrect answer. The total number of points was the final score.

6.2.3.3 Food/drink consumption.

Separate food and beverage diaries were provided for each child. Each diary consisted of a front page and one A4 page for each day. This method of measuring dietary intake in children has been validated by Rocket and Colditz (1997).

- Food Diary

On each page a table was printed with columns for the time, the type of food and the amount or weight of the food. The children and parents had to record what was eaten in these columns and they were asked to be very specific in recording the type of food, for example a cheese sandwich would consist of 2 slices of white bread, 2 slices of cheese and margarine. The amount or weight could consist of weight in any unit or amount, for example 1 teaspoon. An example of the food diary can be seen in Appendix IX. The amount of water in the food was analysed using CompEat Nutritional Analysis Software. Weight of food was converted into grams before it was input into the software, if weight was not provided the CompEat software provided analysis for a small, medium or large portion and for teaspoon and tablespoon measures. The output was the number of millilitres (ml) of water in each food item. The amount of water consumed before AM, between AM and MID, between MID and PM and after PM was calculated.

- Beverage Diary

  The beverage diary had the same design as the food diary but with volume required rather than weight. The CompEat Nutritional Analysis Software was used to analyse how much water was contained in beverages such as smoothies or orange juice, which may contain solutes and solids as well as water. The output was the number of ml of water contained in each beverage item. The amount of water consumed before AM, between AM and MID, between MID and PM and after PM was calculated.

6.2.3.4 Exercise.

The first two children that participated in the study were provided with a pedometer to record the number of steps taken per day. The pedometer was clipped to a waistband at the waist. However, the pedometers both continuously fell off during day 1 and 2 and so this aspect of the study was discontinued.

6.2.3.5 Urine Osmolality

The urine samples were analysed using an Advanced Multi Sample Micro Osmometer. The same protocol as that used in study 3 was used. The score was the average Uosm reading for each urine sample.

6.2.4 Intervention

One 500ml bottle of water was provided to each child in the morning after breakfast, and after lunch, on day 4 and 5 of the study, see Figure 6.1.

6.2.5 Procedure

Initially a meeting was arranged so that the researcher could inform the primary caregiver and children about the study, give them an information sheet, answer any questions and obtain written consent from both the parent and the children.

Once consent was given, the researcher visited the child and the primary caregiver, which in each case was the mother, two days before the start of the study. The visit was to explain carefully the procedure to both mother and child, to drop off the necessary materials and equipment and to familiarise the child with the cognitive tasks. From day 1 the child and mother followed the procedure which can be seen in Appendix XII. The child was asked to record all the beverages that they consumed and the mother recorded all the food eaten. It was suggested that they stick the diaries onto the fridge door and that they would both regularly check that all food and drink had been recorded. The researcher routinely texted the mother throughout the study to check that urine had been collected and that all food and drink was being recorded. All three children that completed the experiment started the study on a Monday.

On day 3 of the study cognitive tasks were introduced. The researcher administered the cognitive battery immediately after urine collection at AM and MID. This was repeated on day 4 and day 5. Additionally on day 4 and day 5 a water supplement was given. A 500ml bottle of water was given to the child in the morning after the first battery of tasks and again after the second battery of tasks. On day 6 the researcher visited the house to collect the completed food and beverage diaries and the frozen urine samples (which were transferred to a storage freezer).

6.3 Observations and Discussion

As this study is an observation of three cases no inferential statistics are included. Instead, descriptive results and patterns of data shall be commented upon.

6.3.1 Volume of Fluid Consumed

This study aimed to record the volume of fluid consumed over a five day period and discuss the descriptive statistics and interpretations of observational findings. Figure 6.2 shows the volume of fluid (ml per day) consumed in beverages only and in both beverages and food (Actual Intake). On days 1 to 3 the children drank between 570ml and 985ml per day from beverages only. Mean daily fluid intake over the 3 day period was 822ml for Case 1, 772ml for Case 2 and 825ml for Case 3. This intake is below 1560 L/d which was the reported average daily fluid intake consumed in beverages by 4 to 9 year old children in the UK (Iglesia et al., 2015). Therefore, these figures indicate that the children in this case study drink less than an 'average' child in the UK. This is surprising as it was considered that the children may have consumed more fluid as it was a school holiday, rather than a school day. As the children were at home, they were able to provide themselves with a drink, ask a parent or caregiver for a drink, or were likely to be offered a drink whereas at school there may be less access to drinks. However, this remains an empirical question as, to date, there is no research literature available, which has compared volume of fluid consumed at home to volume consumed at school.

When the children were offered a 500ml bottle of water in the morning and the afternoon on day 4 and 5, the consumption of fluid increased to between 1120ml and 1500ml per day. The mean daily fluid intake from beverages over this 2 day period was 1,225ml for Case 1, 1,400ml for Case 2 and 1,185ml for Case 3. It is interesting to note that total daily beverage intake did not increase by 1000ml so the children were reducing fluid intake from other beverages.

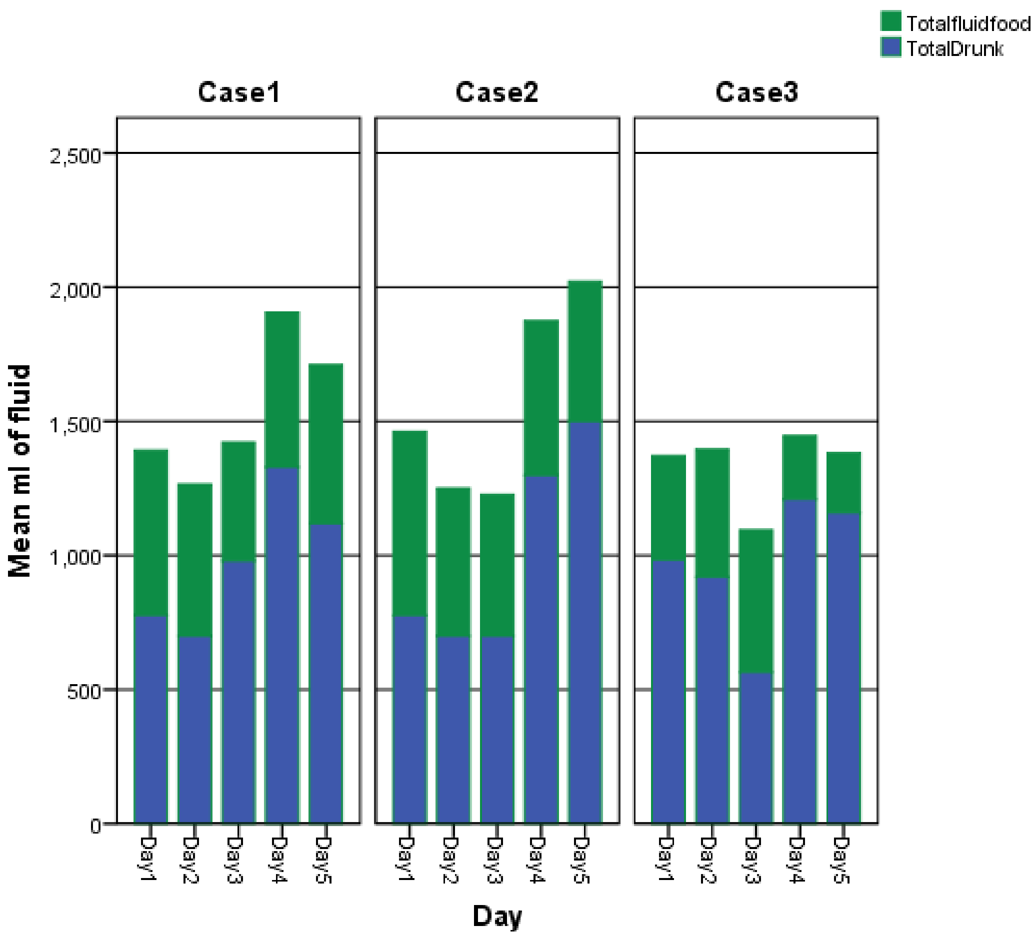


Figure 6.2. Mean Volume of Fluid Consumed in Beverages and in Food on Day 1 to 5 for Each Case.

The mean Actual Intake, in food and beverages, for the children on day 1 to 3, was 1,360mL/d for Case 1, 1,313mL/d for Case 2 and 1,287mL/d for Case 3. This is below the EFSA (2010) guidelines of 1,600mL/d for girls between 4 to 8 years and 1,900mL/d for girls between 9 to 13 years. It is interesting to note that the EFSA (2010) guidelines state that only approximately 20 % of fluid is likely to be consumed from food and the remaining 80 % consumed in beverages, whereas the children in this study consumed an average volume of between 36 %-41 % of their daily Actual Intake on day 1 to 3 from food, which is substantially higher. However, these figures are very similar to those published by Stahl, Kroke, Bolzenius & Manz, (2007) as part of the DONALD study (Dortmund Nutritional and Anthropometric Longitudinal Designed Study). The DONALD study showed that the mean percentage of fluid intake per day in food, in 174 girls living in Germany between the ages of 7 and 10 years old, was 33.5 %. Additionally, Average Intake (AI) in 7 to 10 year old girls in the DONALD study was 1,483ml per day, which although higher than the three cases in the current study, is not as high as the EFSA guidelines (2010). Furthermore, results from Gandy (2012) study, in which 1,456 men, women and children from the UK recorded fluid intake over 7 days, showed that less than 50 % of children in the UK consumed the EFSA AI and in the 7 to 10 year old age group only 44 % achieved the EFSA AI.

These figures from previous literature research (Gandy, 2012; Iglesia et al., 2015; Stahl et al., 2007) suggest that AI is not a reliable indicator of average fluid consumption by children in the UK and there has been criticism of methodological problems with calculation of AI (Vergne, 2012). The AI is a recommendation based on a collection of data from 13 countries in Europe and there are big cultural and national differences in fluid consumption within those 13 countries. Furthermore, there have been different results from different surveys carried out in the same country due to differences in data collection methods (Vergne,2012). It, therefore, does not seem reasonable to assume that the children in this case study ought to be consuming the volume suggested in EFSA guidelines. Instead, Uosm scores will be studied to explore whether the current volume of fluid consumed by each case is sufficient to maintain euhydration.

When additional water was supplemented on day 4 and 5 Actual Intake increased to 1,807mL/d for Case 1, 1,948mL/d for Case 2 and 1,414mL/d for Case 3. Despite reducing fluid intake in other beverages, the Actual Intake for Case 1 and 2 is within the EFSA (2010) guidelines for 7 year old girls. However, Case 3 consumed far less fluid in foods on day 4 and 5, therefore Actual Intake did not increase substantially and the consumption of fluid was still below EFSA (2010) guidelines for a 10 year old girl. It is not known whether this reduction of fluid in food was due to deliberate food choice in response to the increase of fluid in beverages: the results from previous literature on the effects of fluid intake on diet is inconsistent (Ballauff, Kersting, & Manz, 1988; Montenegro-Bethancourt, Johner, & Remer, 2013). Alternatively, the food and beverages may have been provided by the parent and not selected by the child.

In summary, the cases in this study drank less than the reported daily average in a recent study (Iglesia et al., 2015) and consumed less than the AI recommended by EFSA (2010). An additional 1000ml of fluid supplemented on day 4 and 5 increased Actual Intake for Case 1 and 2, but not by 1000ml because the children reduced fluid intake from other beverages. Case 3 did not increase Actual Intake due do a decrease in fluid consumption from both other beverages and food. The following section will discuss Uosm scores and observations can be made about the relationship between fluid consumed and Uosm.

6.3.2 Uosm Scores

Table 6.1 shows AM Uosm every day for each case. The mean score was shown for days 1 to 4 as this was before the additional 1000ml of water was supplemented. Supplementation began after AM urine collection on day 4 and, therefore, changes in Uosm are not reflected in the AM Uosm score. Mean AM Uosm for days 1 to 4 for Case 1 was 701 mOsm/kg, Case two was 739 mOsm/kg and Case three was 807 mOsm/kg, but there was a large intraindividual variation across days. These scores are lower than the morning mean Uosm scores (838 mOsm/kg water condition and 874 mOsm/kg no water condition) for the participants in study 3. These results are surprising, particularly as descriptive statistics show that the children in the study were consuming less fluid than the guidelines recommended by EFSA.

Furthermore, only 33.3 % of the daily AM scores in this study for days 1 to 4 are defined as being above the threshold of dehydration (Uosm 800 mOsm/kg), which is a much lower proportion than the 75 % of children arriving at school in a dehydrated state in study 3 and the percentage in the previous research literature (Barker et al., 2012; Bonnet et al., 2012; Stookey et al., 2012). It is suggested that the low percentage of dehydrated scores were a result of the study taking place in the school holidays when there was more time for the children to eat and drink in the morning without time restraints.

Table 6.1
AM Uosm Scores for Days 1 to 5

	Day 1	Day 2	Day 3	Day 4	Mean score days 1 to 4	Day 5
Case1	455	668	943	738	701	659
Case 2	720	696	737	803	739	731
Case 3	625	864	741	998	807	949

Children were supplemented with an extra 1000ml of water per day after the morning Uosm collection on day 4 so it was expected that Uosm would substantially drop on day 5 AM. However, observation of table 6.1 shows that the average score for Case 1 and 2 for days 1 to 4 do not greatly differ from day 5 and indeed Case 3 has an average score for day 1 to 4 that is considerably lower than day 5. These findings are inconsistent with the results from Perrier et al. (2013) which showed a significant drop in morning Uosm following water supplementation. However, in Perrier et al. (2013) fluid volume was strictly controlled and participants supplemented with 1,500ml of fluid drank the entire additional volume which the participants in the current study did not.

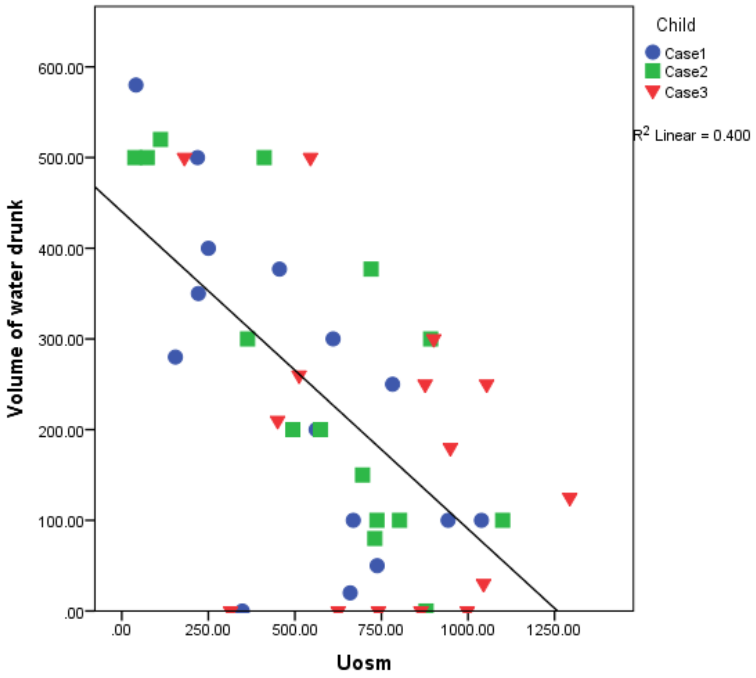


Figure 6.3. Total Fluid Drank and Uosm from Day 1 to 5***.***

Figure 6.3, which shows a scatterplot of Uosm scores plotted against volume drank in the period immediately before urine collection, shows that there is a dose response relationship between the two, as volume increases Uosm decreases. This evidence is not consistent with data presented in table 6.1, as day 5 shows no reduction in Uosm, or the results from study 3, which showed no dose response relationship between Uosm and volume drank. A plausible explanation is that study 3 was carried out over too short a timeframe for volume drank to be reflected in Uosm readings (see 5.4.2 explanation). This explanation is also relevant to the AM Uosm reading because this was collected immediately after breakfast and so there would only be a fairly short timeframe between consuming fluid and collecting the urine specimen. The midday and afternoon urine collections were spaced further apart with potentially longer timeframes for fluid to be consumed and absorbed and, therefore, volume of fluid could be reflected in Uosm readings. Furthermore, the AM Uosm score on day 5 for Case 1 and 2 in Table 6.1 may not reflect the increase in fluid intake due to circadian rhythm. Results from Perrier et al. (2013) suggest that first morning or even later morning Uosm scores are not representative of 24 hour Uosm, and that scores obtained in the morning are generally much higher than Uosm scores from urine collected later in the day. Figure 6.4 shows Uosm scores at all three time periods over the 5 days for each child. Observation of the figure does show that morning Uosm scores are generally higher than midday scores. On day 4 and 5 at the MID time point Case 1 and 2 have very low Uosm scores, suggesting that these children are well hydrated after drinking the supplemented water.

Between MID and PM there is no consistency as to whether scores decrease or increase. Indeed, the direction and range scores vary greatly across days and individuals. This variability was to be expected when comparing Case1 and 2 with Case 3, as Case 3 had a very different diet to the twins. However, Case 1 and 2 had very similar diets and fluid intakes and were tested at similar times, are genetically identical and yet there is still a large degree of variability at some time points. For example, at MID on Day 3 Case 2 had a Uosm of 574 mOsm/kg compared to 155 mOsm/kg for Case1 despite both having eaten and drank the same foods and beverages at approximately the same time before urine collection. These observations are consistent with other research literature which have shown Uosm to be very variable both intra and interindividually (Cheuvront et al., 2010; Perrier et al., 2013).

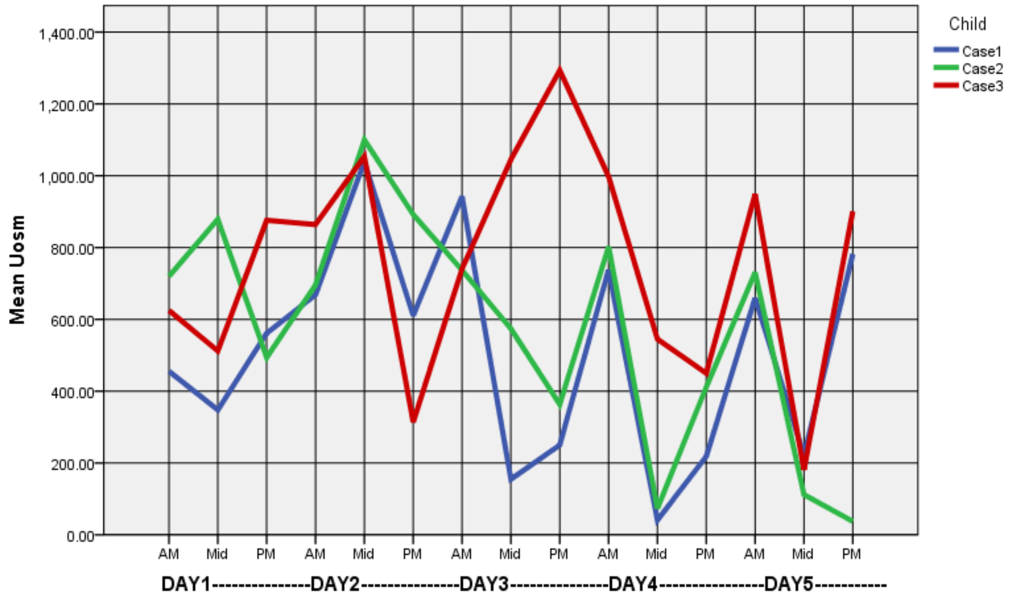


Figure 6.4. Uosm Scores at 3 Time Points on 5 Days for All Cases.

Results from Perrier et al. (2013) suggests that afternoon collections are indicative of 24 hour scores and so table 6.2 gives the MID afternoon (PM) Uosm scores for each case. Observations of the cases show that intraindividual variation is at a high at this time point. For example, scores for Case 3 range from Uosm 314 mOsm/kg to 1294 mOsm/kg over the 5 days. Case 3 has scores above Uosm 800 mOsm/kg on three occasions and a particularly high score on day three which suggests that actual intake is not adequate to maintain euhydration for this child. On the contrary, Case 1 has no scores above Uosm 800 mOsm/kg and Case 2 has a score above Uosm 800 mOsm/kg on only one occasion suggesting that their actual intake was sufficient to maintain euhydration despite not meeting EFSA guidelines.

Table 6.2
PM Uosm Scores for Days 1 to 5

mOsm/kg	Day 1	Day 2	Day 3	Day 4	Day 5
Case1	561	610	250	218	782
Case 2	494	892	363	411	37
Case 3	876	314	1294	450	901

The supplementation of an additional 1000ml of water on day 4 and 5 did not seem to have a beneficial effect on Uosm. Indeed, Case 1 had the highest Uosm reading of the 5 days (Uosm 782 mOsm/kg) on day 5, conversely Case 2 had an extremely low reading on day 5 (Uosm 37 mOsm/kg) which suggests that the water intake maybe exceeding the dilution capacity of the kidney (EFSA,2010). As mentioned above, it is paradoxical that the PM Uosm readings for the twins vary so much when the diet and fluid intake are so similar. In summary, observation of the Uosm scores at the MID time point appear to show that generally the actual intake of Case 1 and 2 is sufficient to maintain euhydration, thereby putting into doubt the validity of the EFSA AI guidelines. Conversely, Case 3 appears to be at a high risk of dehydration, but water supplementation did not appear to reduce this risk. Uosm scores have a large intraindividual and interindividual variation and the findings from this case study and previous research literature (Armstrong et al., 2010; Perrier et al., 2013) suggest that morning single urine collection is not a good indicator of hydration status. Furthermore, Uosm scores do not reflect the volume of fluid drank if consumed recently. Therefore, it is considered that measuring Uosm in study 5 in which testing will begin in the morning and be carried out over a short time frame, to be consistent with the previous studies, will not be a useful exercise.

6.3.3 Relationship of Self-Rated Thirst Scores with Fluid Volume and Uosm Scores

A further aim of this study was to record self-rated thirst scores and investigate whether there was a relationship with fluid intake or Uosm scores. Figure 6.5 shows the timeline of all 3 cases between 08:00 and 13:00 on days 3 to 5, the volume of fluid consumed in food and beverages and the self-rated thirst scores and Uosm scores at the time of testing. Careful observation of the self-rated thirst scores and fluid consumed does not show a consistent pattern of high thirst scores being followed by fluid consumption as would be expected. For example, Case 3 gives herself a score of ‘67’ , indicating moderate thirst, at 9:30 on the thirst scale on day 3 but does not have anything to eat or drink until 11:46 when she only has 3 sips of milk and a doughnut and scores herself as ‘69’ on the thirst scale’ immediately afterwards. Case 2 gives herself a score of ‘52’ at 9:40 but does not have anything to eat or drink until 11:15 when she has 200ml of apple squash and an apple at 12:15 which has a fluid content of approximately 56 ml. At 12:25 she rates herself as ‘74’ on the thirst scale. These observations are consistent with the previous literature research that suggest that children are not very sensitive to feelings of thirst (Bar-Or et al., 1978) and that adults rarely drink in response to the subjective sensation of thirst (McKiernan et al., 2008).

However, on occasion the children did drink after rating themselves as high on the thirst scale. For example, Case 1 rated herself at ‘97’ on the thirst scale’ at 10:15 on Day 4 and then had a 500ml bottle of water at 10:30.

Paradoxically, Case 2 drank a 500ml bottle of water at 10:30 on Day 4 but only rated herself as a ‘7’ on the thirst scale at 10:30am immediately beforehand. Both girls drinking a 500ml bottle of water at the same time suggest that this drink was offered by a parent/caregiver (they are twins) rather than the children being motivated to drink due to the sensation of thirst. Alternatively, the measure used to assess subjective thirst may not be effective in children. Although previous research studies (Edmonds & Burford, 2009) have used Visual Analogue Scales to measure self-rated thirst it has been suggested that the continuum style of the VAS shows too broad a range of sensitivity and is confusing (Miller, 1994). A different method of assessing thirst will be used in study 5, which requires less self-awareness and ability to ‘grade’ the thirst sensation.

Figure 6.5 was also observed to assess whether self-rated thirst scores reduced in response to volume of fluid drank. No obvious relationship was apparent between self-rated thirst and volume drank when looking at the volume of fluid consumed in the hours before the self-rated thirst score was collected. This observation is consistent with results from study 2, in which self-rated thirst did not change in a dose response manner to volume of fluid consumed, and with Buehrer et al.’s (2014) study which investigated children’s subjective thirst rating in response to fluid and food.

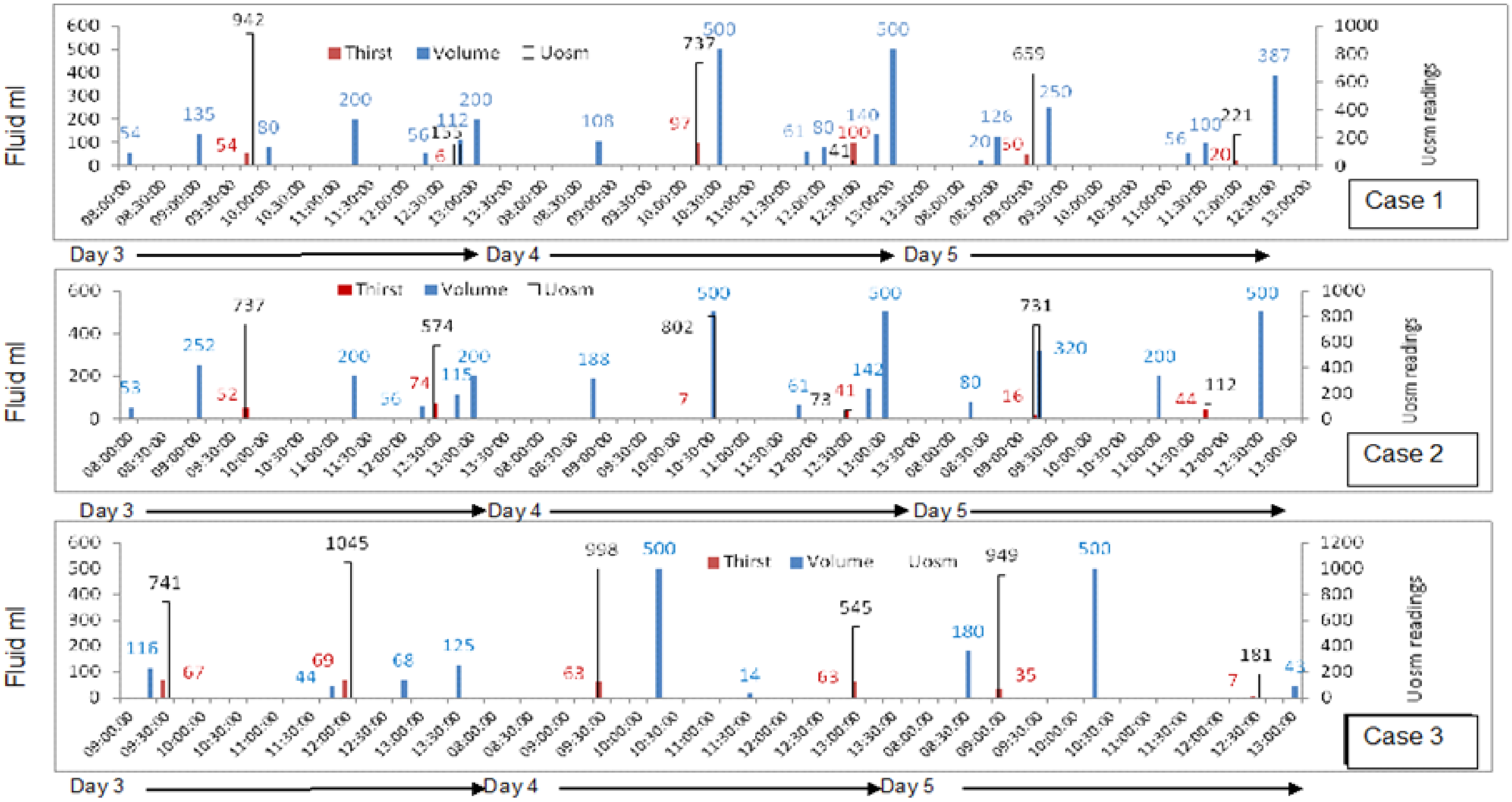


Figure 6.5 Timeline of Case 1,2 and 3 on Day 3-5 Showing Time and Volume of Fluid Ingestion, Uosm and Self-Rated Thirst Scores.

Furthermore, observation of Figure 6.5 shows no consistent pattern between self-rated thirst scores and Uosm. For example, it can be observed that on day 4 at 12:30, Case 2 had a Uosm of 41 mOsm/kg, which is extremely low, but a self-rated thirst score of 100 and Case 3 had a thirst rating of 35 but a Uosm of 949 mOsm/kg. Figure 6.6 shows a scatterplot with self-rated thirst scores plotted against Uosm scores for all three cases. Consistent with results from study 3, no pattern or relationship can be observed between Uosm and subjective thirst ratings. Scatterplots were also produced of self-rated thirst scores plotted against Uosm scores from the next testing session (for example, thirst scores from AM plotted against Uosm scores from MID) to determine if there was a time lag between the two variables as suggested by Denton et al. (1999). However, no relationship could be observed. The lack of an observable relationship between self-rated thirst and Uosm scores is consistent with study 3 and suggests that the sensation of thirst is a complex psychophysiological phenomenon which is influenced by more than just hydration status (Ramsay & Booth, 1991).

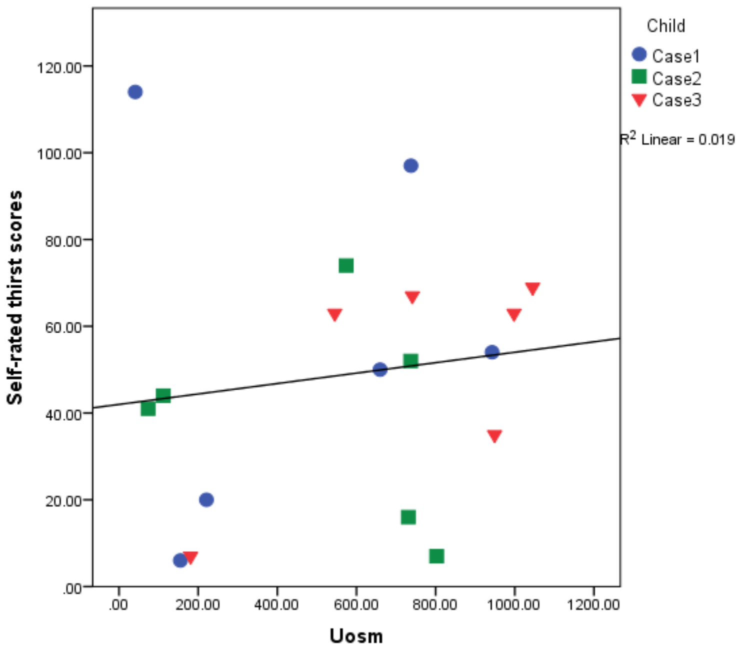
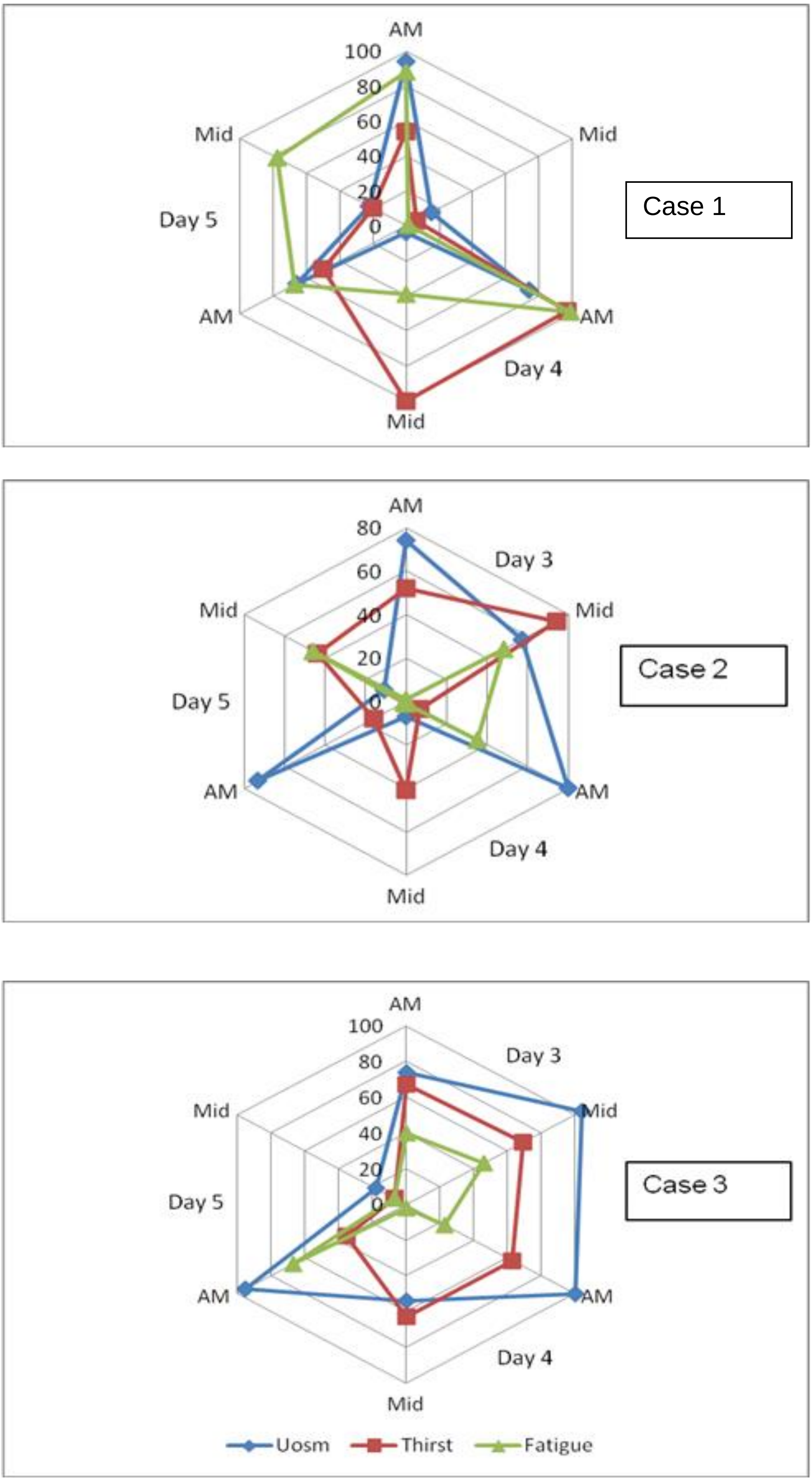


Figure 6.6 Self-Rated Thirst and Uosm from Day 3 to 5.

6.3.4 Relationship of Self-Rated Fatigue Scores with Self-Rated Thirst and Uosm Scores

This section discusses the relationship between self-rated fatigue, thirst and Uosm scores. Figure 6.7 shows radar plots of self-rated fatigue, thirst and Uosm. Each case has a separate radar plot which shows the variables scores plotted on a shared axis (self-rated thirst and fatigue scale =1:1, Uosm scale = 1: 10 mOsm/kg) at AM and MID on day 3, 4 and 5. These plots allow for ease of comparison of multivariate data patterns. Observation of the plot for Case 1 shows some degree of relationship between Uosm and self-rated fatigue and thirst, particularly at AM on each day. When Uosm levels are high so are self-rated fatigue and thirst scores. However, there is very little indication of an emerging pattern in the data for Case 2 and 3. Case 3, in particular, had very high Uosm readings at specific time points (MID of day 3 = 1045 mOsm/kg and AM of day 4 = 998 mOsm/kg) and Figure 6.4 shows that at PM of day 3 this reading is even higher (1294 mOsm/kg). It would be expected that fatigue ratings would be high at these time points, as previous research literature shows an effect of dehydration on fatigue (see Chapter 2 for review). However, self-rated fatigue scores are not particularly high (46 and 23 respectively).These observations suggest that self-rated fatigue scores are not related to Uosm scores in this sample of children. Alternatively, children may find it difficult to assess their level of fatigue using a Visual Analogue Scale and an alternative measure may be required; this will be explored in study 5.



Note: Scale shows Uosm as 1:10 mOsm/kg. Self-rated thirst and fatigue scores are 1:1

Figure 6.7 Self-Rated Fatigue and Thirst scores and Uosm Scores

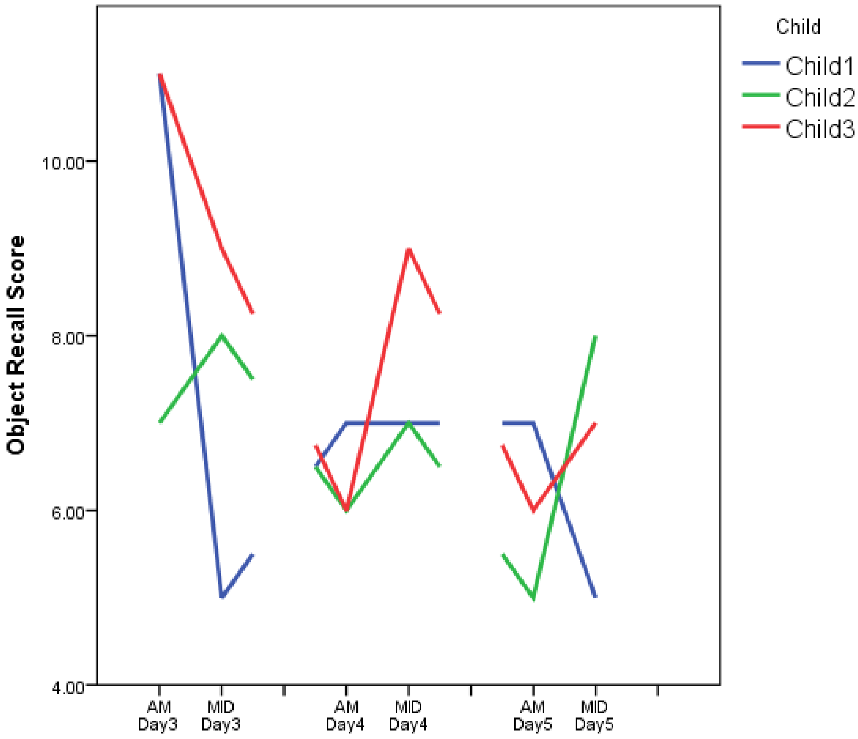
6.3.5 Relationship of Cognitive Performance with Self-Rated Thirst and Uosm Scores

The next section discusses the children's cognitive performance at two time points, AM and MID, on day 3, 4 and 5. The data was plotted and notable patterns of performance that may relate to fluid intake, Uosm or self-rated thirst are described here. Figures 6.8 to 6.10 shows the cognitive performance scores at AM and MID on days 3 to 5 for all three cases. Reference is made to Figure 6.5 to assess whether any relationship or interaction could be observed between cognitive performance and Uosm, self-rated thirst or fluid volume.

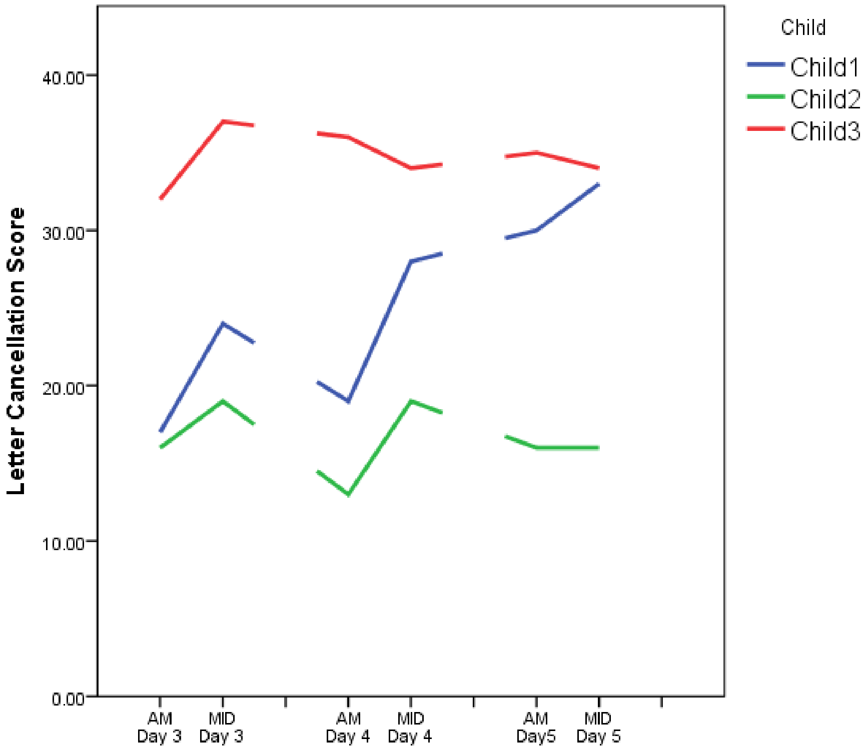
Figure 6.8a shows the scores on the object recall task over 3 days. Performance on the object recall task and the reverse digit span task, seen in Figure 6.9a, seem to be random with no distinguishable pattern of results or relationship with self-rated thirst scores, volume of fluid consumed or Uosm. Observation of Figure 6.8b, which displays the scores for the letter cancellation task, show that on day 3 all three cases improved between AM and MID, which is likely to be due to practice effects. On days 4 and 5, Cases 1 and 2 continue to improve or plateau between AM and MID but Case 3's performance deteriorated over time. There is no obvious explanation for this deterioration related to self-rated thirst scores, fluid drank or Uosm and it may be due to chance fluctuations in performance.

Conversely, the scores for the finger tap task, shown in Figure 6.9b, showed no regular effects of practice. These observations are not consistent with results from study 3. In study 3 it was found that participants that were hydrated or had a drink of water improved with practice. Only on the occasion that children were dehydrated and did not have a drink did performance not improve. In this case study all three cases were either hydrated or they had a drink in the period before testing.

Observation of Figure 6.10a show that, in the fast tap task, performance generally improved between AM on day 3 to day 5 for all three cases, although Case 2's performance deteriorated between AM and MID on day 4 and all three cases performance deteriorated between AM and MID on day 5. There is some indication that performance may have deteriorated when ratings of thirst were low at AM, followed by moderate fluid intake (fluid intake of 406ml, 520ml, 500ml by Cases 1, 2 and 3 respectively) before testing at MID. This theory is consistent with Rogers et al. (2001) study which found that when participants were not thirsty and had a drink, performance in the RVIP task deteriorated. Rogers, et al., suggested that the sensation of thirst was a proxy for hydration status and in this case it would suggest that 'not thirsty' children that were hydrated and then had a drink of water, had a reduction in performance, which was comparable to a "post lunch dip" (pg 57). Study 3 shows that self-rated thirst scores are not a proxy measure of hydration. However, drinking fluid when not thirsty may be an unpleasant experience and may lead to feeling uncomfortable and attention being diverted away from the task (see study 3). Supporting this interpretation is the fact that both the RVIP task and the fast tap task have a large attentional component.

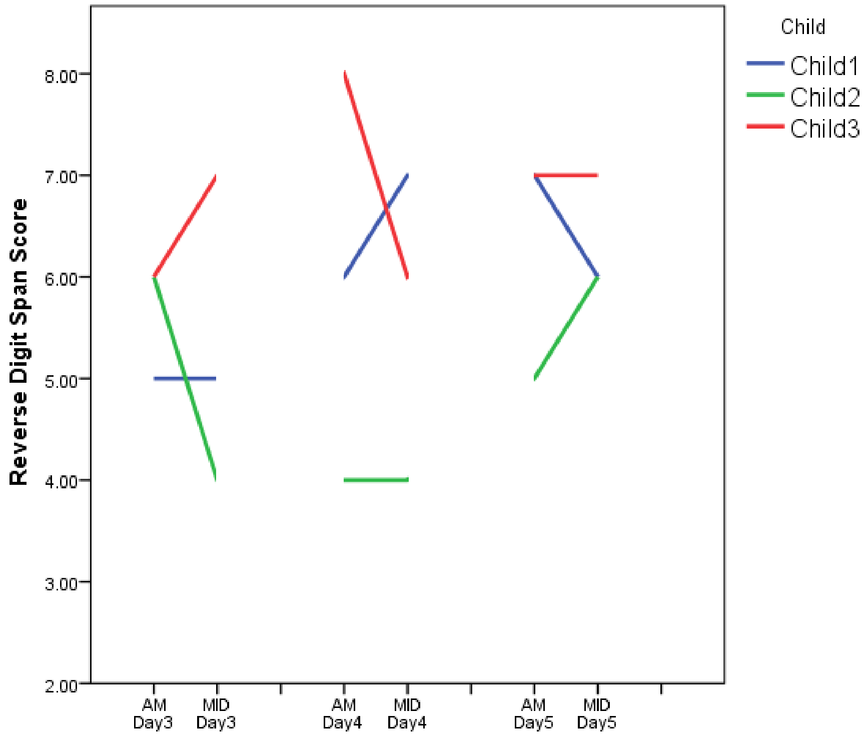


6.8a. Object Recall

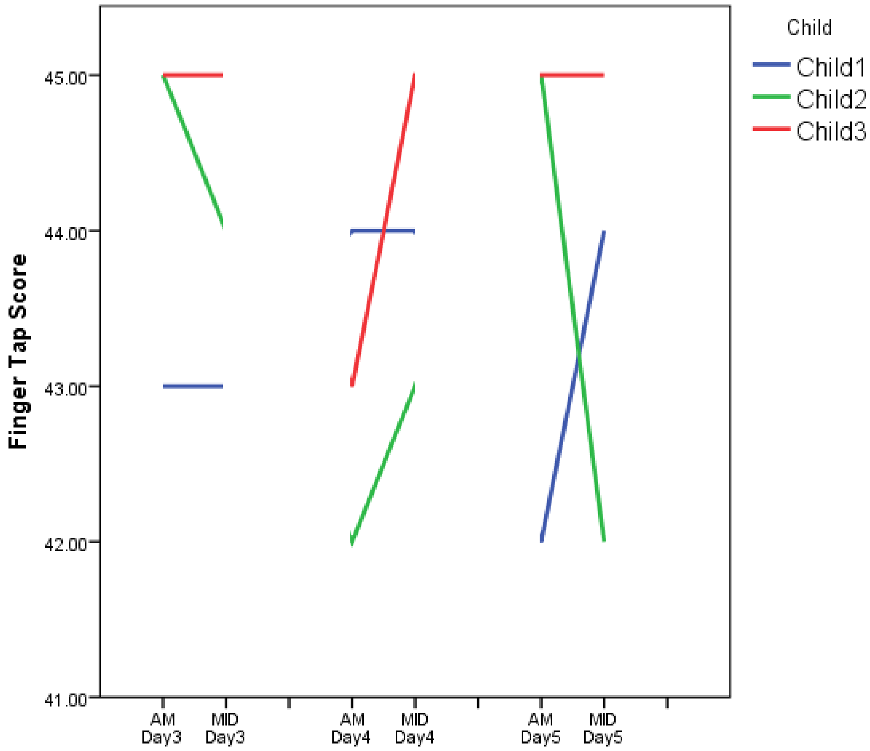


6.8b. Letter Cancellation

Figure 6.8. Plots of Object Recall and Letter Cancellation Task Scores on Days 3 to 5

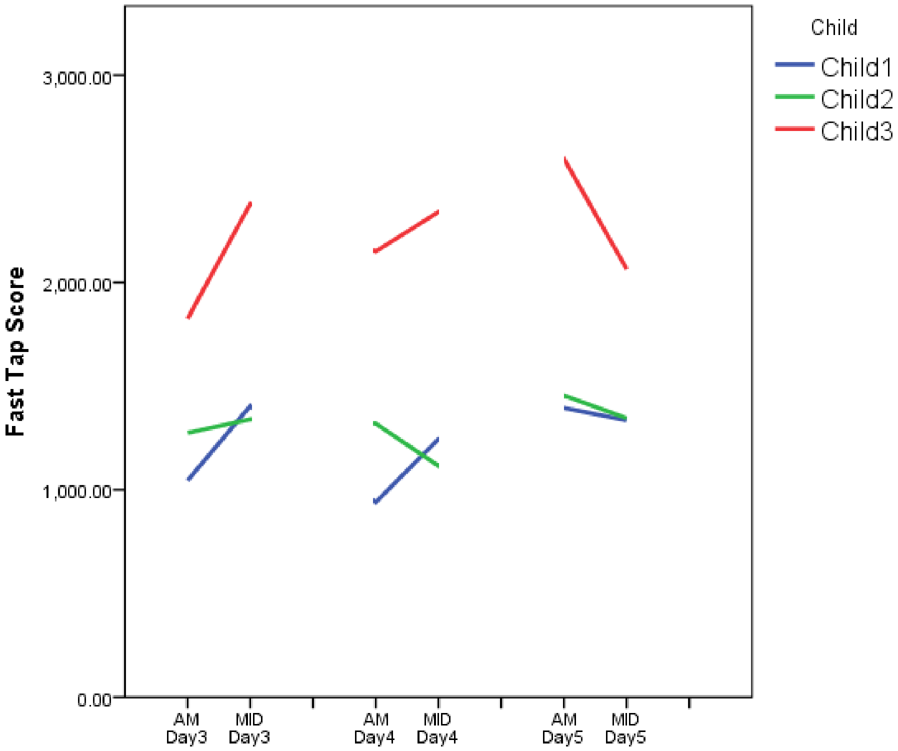


6.9a. Reverse Digit Span

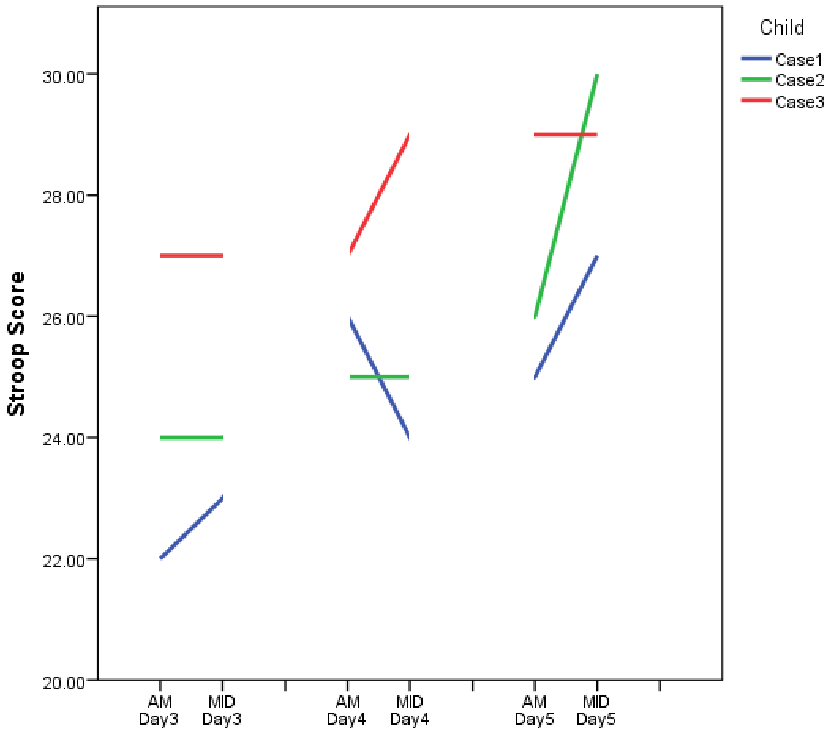


6.9b. Finger Tap

Figure 6.9. Plots of Reverse Digit Span and Finger Tap Scores on Days 3 to 5



6.10a. Fast Tap



6.10b. Stroop

Figure 6.10. Plots of Fast Tap and Stroop Scores on Days 3 to 5.

Figure 6.10b displays the Stroop task scores. Observation of Figure 6.10b show that in the Stroop task scores consistently improved on a daily basis, so all three cases got a higher score at AM on day 5 than on day 3. It is suggested that this improvement is due to practice effects. However, Case 1 did show a marked deterioration on day 4 between AM and MID. Observation of Figure 6.5 show that at MID, the self-rated thirst score was the maximum score of 100. It is speculated that the deterioration on that one occasion may have been due to a lack of attention due to the distraction of the thirst sensation. This theory is consistent with results from study 2 which suggests that tasks that require an attentional component may be compromised by high self-rated thirst scores. However, these results are not consistent with results from Tuk et al. (2010) which found that as bladder pressure increased so did speed. However, Tuk et al. hypothesized that bladder urgency, rather than being a distraction such as thirst, does itself require inhibition and self-control and this spills over to enhance the inhibitory control required in the Stroop task.

In summary, observation of the plots of cognitive performance data in tandem with exploration of the self-rated thirst, Uosm and fluid consumed data, show some suggestion of an effect of self-rated thirst and fluid consumption on Stroop and fast tap performance. These observations suggest that tasks with an attentional component may be particularly sensitive to sensations which may divert attention away from the task. These sensations may be high self-rated thirst scores or unpleasant sensations brought about by drinking fluid when not feeling thirsty. However, due to the nature of this study these data patterns may be idiosyncrasies and the theories are purely suppositional. However, it would be interesting to explore the relationship between performance in tasks requiring attention and self-rated sensations in the future.

6.3.6 Issues with Methodology

A difficulty experienced in this study was getting the parents and children involved in the study to adhere to the protocol. A large proportion of the cohort was excluded from the study because the children and parents, despite text reminders, did not remember to collect urine samples at the appropriate times and to record all the food and beverages that they consumed. Of the final three children whose data were included in the study, case 3 (the non-twin) was very reluctant to drink the additional water supplemented on day 4 and 5. Due to the high drop-out rate it became necessary to recruit children that were younger than the 9 to 10 age category originally sought. Thus case 1 and 2 were 7 years old and case 3 was 10 years old. All children were pre-pubescent and there was little difference in cognitive performance. The older child did not perform at a noticeably higher level than the younger children and generally comparison of data was intra-individual rather than inter-individual. However, future research should endeavour to recruit children of a similar age. A large scale prospective study may be considered for future research to counter the high dropout and variability in adherence.

The present study focussed on the fluid intake, hydration status and thirst of children in a natural setting; therefore, diet was parentally controlled or self-selected. However, diet and exercise may have had an effect on cognitive performance (Veasey et al., 2013), but given that the effects of diet were not the focus of the study and as this study was observational in nature, neither a full analysis of all food eaten or a controlled and standardised diet were considered.

6.3.7 Conclusion

This case study is unique as it has looked in such detail at fluid intake and Uosm over 5 days as well as introduced mood and cognitive task testing. Observation of cognitive score data showed that there was a lot of individual differences in performance over the three days and a suggestion that high self-rated thirst scores or uncomfortable sensations may divert attention away tasks with an attentional component.

Additionally, observation of the data has shown that Uosm is extremely variable both within and between individuals and there was no obvious relationship between Uosm and volume of fluid consumed or self-rated thirst scores. Previous research literature has used morning Uosm as an indication of the proportion of children coming to school in a dehydrated state (Barker et al., 2012; Bonnet et al., 2012; Stookey et al., 2012). However, as previous research literature (Perrier et al., 2013) have shown that morning Uosm does not seem indicative of 24 hour Uosm and this study has shown it does not reflect the volume of fluid consumed the day before, or the morning before urine collection, in this small group of children, it is suggested that it may not be best suited as a measure of children's general hydration status.

Furthermore, data from Case 1 and 2 has shown that it is not necessary to consume the amount of fluid recommended by EFSA (2010) in order to be hydrated. Moreover, as Gandy's (2012) study has shown that less than 50 % of UK children achieve this guideline, it is suggested that one recommendation for the whole of Europe may not be fit for purpose. It seems that recommending a volume of fluid to consume in food and beverages when diet is so variable is going to be confusing for the general public and generally not very effective when water balance is dependent on so many individual factors such as body weight, temperature and activity. Rather than recommending daily intake, another method of helping to keep the public hydrated may be more successful. Educating the public to check that they are hydrated by looking for signs such as pale urine colour, and recommending that they increase fluid intake if urine colour is too dark, would seem to be a much more pragmatic and useful guideline designed to help each individual (Armstrong, 2005). Although, how effective the general public, and in particular children, are at assessing the colour of their urine has yet to be empirically tested.

To conclude, more in depth observation of the data in this study suggests that self-rated thirst is independent of the volume of fluid consumed and Uosm, in this small sample of children, which is consistent with findings from study 2 and 3. Furthermore, the data show that the single collections of Uosm at any time point are liable to large fluctuations that are not obviously related to volume of fluid consumed, and hence 24 hour collections may be a more reliable method of assessing general hydration status. However, as study 5 takes place within a short timeframe 24 hour urine collection is not a possibility. Therefore, urine will not be collected in study 5 as a single Uosm score is not considered a useful measure.

CHAPTER 7

Study 5: the Effects of Drinking Water and Thirst on Fine Motor Skills in Children

7.1 Introduction

The primary aims of this study were to investigate:

- Whether fine motor and visual perception skills improved in children that had a drink compared to children that did not.
- Whether self-rated thirst scores had an effect on visual perception and fine motor skills.

A supplementary aim was to investigate:

- Whether there was a correlation between self-rated thirst scores when measured by Visual Analogue Scales and Likert Scales.

Consistently, throughout this thesis a positive effect of water consumption has been found on task performance requiring fine motor skills. In study 1, the number of beads threaded increased in those children that had a drink compared to those who did not, and in study 2 the number of finger taps increased when children had a drink. Furthermore, exploratory analysis, in study 3, suggested that the water consumption effect, on finger tapping performance, was a reversal of negative effects due to dehydration.

To date, there is very little research literature published on the effect of dehydration or water consumption purely on fine motor skills. Some research has looked at the effects of dehydration or water consumption on psychomotor tasks such as manual tracking tasks (Edmonds & Jeffes, 2009; Szinnai et al., 2005) but the results are inconsistent. The inconsistent results may be in part due to the different cognitive domains utilised by the different psychomotor tasks. For example, in the tracking task (Edmonds & Burford, 2009) the children were asked to draw a line with a pencil in between two printed lines as quickly as possible. The measures for this task were the distance drawn and the number of times the children drew outside the printed lines. This task as well as requiring fine motor speed also requires attention, visual perception, and goal directed movement. Other tasks such as the trail making task (Gopinathan et al., 1988) require participants to draw a line through consecutive numbers and letters, so this task requires the skills listed above as well as quick speed of processing.

Additionally, Flatters et al. (2014) suggests that fine motor tasks requiring manual dexterity, are dependent on postural control, requiring larger muscle groups, for level of performance. For example, Naider-Steinhart and Katz-Leurer's (2007) study, of 8 to 10 year old children, found that individuals with less variability in postural muscle activity (the trapezius) and thumb activity had faster handwriting speeds than those with greater variability. Therefore, an effect of hydration status on the larger muscle groups required for postural control may have a consequential effect on fine motor skills. The results on the effects of hydration on postural stability are inconsistent. Erkmen, Taskin, Kaplan and Sanioglu's (2010) study and Gauchard, Gangloff, Vouriot, Mallie and Perrin's (2002) study showed a negative effect of exercising without a drink on posture whilst Ely, Sollanek, Cheuvront, Lieberman and Kenefick's (2013) study found no effects of dehydration on posture.

This study aims to investigate the effects of water consumption on fine motor skills. However, fine motor skills are a collection of different activities. For example, fine motor speed is the ability to perform rapid movements of the fingers (Henderson and Pehoski, 2006) whereas manual dexterity is much more complex. Manual dexterity requires guided motor action of the fingers using sensory feedback, for example, tactile information is required when manipulating objects, as the friction, between the fingertip and the object, needs to be correct when handling objects. Sometimes visual feedback will be required for tasks requiring manual dexterity (Henderson & Pehoski, 2006). Another fine motor skill is visual-motor integration (VMI) which requires both coordination of finger movement and visual perception (Sortor & Kulp, 2003) and the majority of tasks carried out in the classroom will require visual-motor integration skills (McHale & Cermak, 1992).

This study will investigate the effects of water consumption on separate tasks which test fine motor speed, manual dexterity and visual motor integration skills, to determine whether specific aspects of fine motor performance are more sensitive to water consumption. Therefore, a finger tapping task will be included as this is a measure of motor speed without a requirement for visual processing (Christianson & Leathem, 2004). The bead threading task is a test of manual dexterity (Ramus et al., 2003) and so shall be included in the test battery. Both finger tapping and bead threading have been shown to be sensitive to water consumption in previous studies in this thesis.

As a test of visual-motor integration (VMI) skills, a handwriting test was chosen. Handwriting development in children requires coordination of many processes; motor speed, manual dexterity (Smits-Engelsman, Niemeijer, & van

Galen, 2001), postural stability (Naider-Steinhart & Katz-Leurer, 2007), perceptual skills such as visual perception (Tseng & Chow, 2000), visual – motor integration, memory and sustained attention (Feder & Majnemer, 2007). However, in typically developing children handwriting becomes an automatic process between the age of 8 to 9 years old (Feder & Majnemer, 2007) so should require less cognitive resources. The rationale for choosing a handwriting test in preference to traditional VMI tasks was the need for a task that could be applied to a classroom scenario and would be meaningful to pupils and teachers. The English version of the Dutch SOS screening tool was chosen as the method of assessment because it is a short test that enables measurement of both quality of handwriting and speed in a group setting (Van Waelvelde, Hellinckx, Peersman, & Smits-Engelsman, 2012).

Optimum fine motor skills are an important requirement for children. Previous research literature (McHale & Cermak, 1992) showed that junior-school children spent between 31 % and 60 % of the school day engaged in tasks requiring fine motor skills; of these tasks 85 % of the time was spent doing paper and pencil tasks such as writing or drawing and 15 % was spent on manipulation tasks such as cutting or sticking. Furthermore, Grissmer, Grimm, Aiyer, Murray and Steele’s (2010) study showed that the levels of fine motor skills of pre-school children were predictive of academic achievement in reading, maths and science in children aged 10 years old.

Indeed, handwriting skills, in particular, are linked to academic performance (see Dinehart for a review, 2015). McHale and Cermak (1992) suggest that there may be a link between academic achievement and fine motor skills because children that are quicker to copy information from the board or out of a book will have more time to devote to working out the answers and thinking about the task at hand. In children or adults in whom the handwriting process is not fully automatic memory and attention are required (Jones & Christensen, 1999), and the use of memory and attentional resources leave fewer resources available for task demands such as composition or maths processes. Conversely, poor sustained attention or memory can lead to difficulty in developing handwriting, as an automatic process, and a reduced level of handwriting quality and speed (Feder & Majnemer, 2007). Jones and Christensen's (1999) study found that 53 % of the variance in the score on a story-writing test was due to speed and quality of handwriting.

The limitations of reduced handwriting skill on higher cognitive processes can also be applied in further and higher education. For example, a study of undergraduates showed that handwriting fluency had a significant effect on exam results (Connelly, Dockrell, & Barnett, 2005). Therefore, it was considered that a study to investigate the effects of water consumption and self-rated thirst on handwriting was a unique and important addition to the literature.

It was also decided that a task should be included that could test visual perception skills, without need of motor skills. Tasks such as handwriting have a visual perception aspect and it may be that this domain is improved by water consumption. Alternatively, it may be that that visual perception is sensitive to the self-rated sensation of thirst. Visual processing has a large attentional element (Luck & Ford, 1998) and results from this thesis and previous research literature (Edmonds, Crombie and Gardner, 2013) suggest that task performances with an attentional component are likely to be negatively affected by high levels of thirst. In study 2, children in the high thirst group made more go errors, in the StopSignal task, than children in the low thirst group, regardless of whether they had a drink of water or not.

Testing of visual perception as a process pure will allow assessment of whether this cognitive domain is more sensitive to self-rated thirst, hydration status or neither. Therefore, it was important to find a task in which visual processing was tested, in isolation from tests of motor abilities. The Figure-Ground task was chosen and adapted from the Development Test of Visual Perception Third Edition (DTVP3; Hammill, Pearson, & Voress, 1993) so that it could be administered in a group setting. In the Figure-Ground task children are required to find target shapes or figures that are hidden amongst non-target shapes, figures or a more complex background. As the children carried out this task in a group rather than individually they did have to draw a line from the stimulus figure at the top of the page to the figure embedded in the background. However, the children were not timed so line drawing did not have to be done quickly, the lines drawn had no criteria other than they had to begin at the stimulus figure and end at the embedded figure, and there were no children that had sufficient motor deficits for the drawing of the lines to be of any challenge or difficulty.

In the current study it was considered how best to measure subjective thirst. In the previous studies, analysis of self-rated thirst scores have shown that participants rated themselves as getting less thirsty after drinking water and thirstier when they did not have a drink of water. However, no correlations were found between thirst scores and volume of water drank or urine osmolality levels. It was suggested that the lack of correlation may be because the sensation of thirst is not just related to hydration status but may be influenced by psychological factors such as habit and desire (Ramsay & Booth, 1991). Alternatively, previous research has suggested that children are not very sensitive to the sensation of thirst (Bar-Or et al., 1978) and, therefore, a Visual Analogue Scale (VAS) may not be a good choice of measurement. To be able to assess a level of thirst an individual must be able to perceive, recognise and quantify the sensation which is a complex task (Millard-Stafford, Wendland, O'Dea, & Norman, 2012). To do this with a rating that ranges from 1 to 100, which is the range on a VAS, gives a vast array of choice which may be confusing and overwhelming. Indeed, Miller (1994) decreed that adults are only able to detect 7 different magnitudes in stimuli. Therefore, a thirst scale with a smaller range of choices may make it more effective. To date there has been no comparison of thirst measurement using different methods (Millard-Stafford et al., 2012). This study used both a VAS and a 7 point Likert Scale to measure self-rated thirst. Accuracy of the method could not be assessed as thirst is subjective but the two methods were correlated to assess if scores on both were similar.

In the present study a Likert Scale will be used to measure level of fatigue. In contrast to previous research literature (Chapter 2 review) studies 1 and 4 found no effect of water consumption or hydration status on levels of fatigue, however, these results may be due to a VAS being used to measure fatigue. The large scale may have been too confusing for the children.

This last study is focussing on the effects of water consumption and self-rated thirst on visual perception and fine motor skills. It is replicating the design used in previous studies in which the effects of being given a drink are compared to not being given a drink. However, one aspect of the design has been changed. In study 2 the participants were divided into a high thirst and low thirst group at baseline, based on the design from Edmonds, Crombie and Gardner's (2013) study. Hence, it could be investigated if thirst moderated the effect of water consumption on cognitive performance. Based on the results of study 2 and 3, it is now suggested that the thirst sensation may affect cognitive or motor performance due to the distracting influence that the sensation has on performance, rather than due to an interaction with water consumption or hydration status. Thus, if the effects of thirst are due to the sensation attenuating attention away from the task at hand the acute, immediate effects of self-rated thirst on cognitive task performance require observation rather than the sensation of thirst at baseline. Consequently, unlike the previous studies in which children were divided into thirst groups at baseline, in this study the children will be divided into thirst groups dependent on their level of thirst at test.

Several hypotheses were tested:

Hypotheses

1. That having a drink of water would improve mood, fine motor and visual perception skills compared to not having a drink of water.

2. That high self-rated thirst scores (at test) would have a negative effect on visual perception performance, fine motor integration skills and mood compared to low self-rated thirst scores.

3. That perceived thirst measured using a Visual Analogue Scale would correlate with a measure using a Likert Scale

7.2 Method

7.2.1 Design

The study had an independent measures design. Children were tested in groups and the tests were administered by the researcher from the front of the classroom. The classes were randomly assigned to a drink or no drink condition. In the drink condition, the children were supplemented with a 500ml bottle of water and they chose to consume as much as they wished and in the no drink condition the children were not offered a drink. The children were tested pre-intervention and post-intervention. Children were tested in groups so that more children could be tested in less time than if they were tested individually.

7.2.2 Participants

Data were collected from 86 children, 37 males and 49 females*. All participants met the inclusion criteria described in study 1. One female's data were removed as she had not drank any water although she was in the drink condition. From the remaining 85 children, the mean age was 10 years and 1 month. There were 40 children (19 males) randomly assigned to the drink condition and 45 children (18 males) to the no drink condition (See Table 7.1).

Fifty seven children attended Maryland Primary School, Newham. This is a larger than average primary school with a high proportion of pupils that are 'looked after' and eligible for free school meals. There is a high proportion of children that have learning difficulties and the proportion from ethnic minorities and with English as a second language is much higher than the average. Twenty eight children attended St. Mary's Primary School in Essex which has a very low proportion of children from of ethnic minorities, who speak English as a second language and are eligible for free school meals.*

The number of children participating in the study was considered adequate because a similar study by Edmonds and Burford (2009) found statistically significant results (*p = .014*) with an effect size of r =.36 in a cohort of 57. Significant results have also been found in other similarly designed nutrition intervention studies with comparative numbers of participants (Haskell et al., 2008).

* *No statistically significant differences in baseline scores were found between the two schools. Gender added as a covariate did not moderate results.*

Table 7.*1*

Demographic Details of the Participants

		Newham Primary		Essex Primary	
Conditions		**Drink**	**No Drink**	**Drink**	**No Drink**
Number of Participants		26	31	14	14
Mean Age		9y 11m	10y	10y 3m	10y 4m
Gender	**Female**	14	18	7	9
	Male	12	13	7	5

7.2.3 Intervention

The children in the drink condition were each given a 500ml bottle of water. The children were told to drink as much or as little as they wished, and the volume drank was recorded. A period of 5 minutes was given for the children to drink the water. During this period children were able to read quietly to themselves. In the no drink condition children were not given a bottle of water. On day one of the testing the class was randomly allocated to a testing condition by flipping a coin, thereafter each testing day was alternately allocated drink or no drink.

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7.2.4 Measures

The children were given a set of mood scales and cognitive tasks to complete both before and after the intervention. They were completed in the order shown in Figure 7.1 and described below.

Figure 7.1 Tasks Included in The Task Battery in the Order That They Were Completed.

7.2.4.1 Mood Scales

- Visual Analogue Scales (VAS)

The children were presented with three VAS's, and asked to draw a cross along the line to represent how thirsty, how hungry and how happy they felt. The scales were 100mm long with a question along the top, for example 'how thirsty are you?', and a pictorial representation anchoring each end. The thirsty and hungry VAS represented a continuum with 'not' on the left hand side and 'very' printed on the right hand side. The happy scale represented a bi-polar item with 'sad' on the left hand side and 'happy' on the right hand side. Distance in mm was measured from the left hand side of the line to the cross.

- Likert Scales

The children were presented with a 7 point Likert Scale to rate their feelings of fatigue and thirst. Figure 7.2 shows the scale for fatigue. The scale ranged from 1 ‘not at all’ to 7 ‘very, very’, and had an image at each end of the line representing the extremes of the continuum. An explanation of the term ‘neutral’ was given and the children were asked to circle the number that applied to them at that moment.

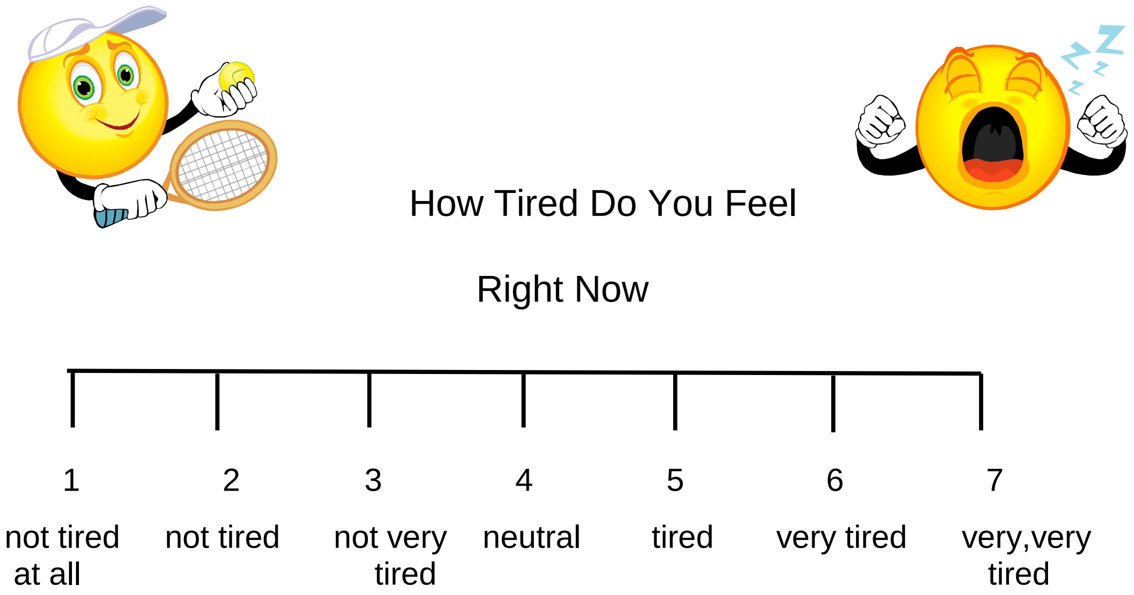

Figure 7.2 Likert Scale for Fatigue

7.2.4.2 Cognitive Measures

- Handwriting Test

The children were given a handwriting speed and quality test which was adapted for this study from the Systemic Detection of Writing Problems Manual SOS-2-EN (Smits-Engelsman,Bommel-Rutgets & Waelvelde, 2014). In this test the children are presented with a sheet of A4 paper with some text printed on it. The text consists of five short sentences, for example 'the sun is warm,' and four longer paragraphs. For an example see Appendix X. The children were given a blank sheet of unlined A4 paper and were asked to copy as much of the text as they were able to in three minutes, in their own handwriting, at their own speed and without erasing any mistakes. The children could use their normal writing instrument whether that be a pencil or pen. The DVs were speed and quality of handwriting. Speed of handwriting was scored by counting how many letters the children had copied in the three minutes, irrespective of whether words were copied correctly and including letters that were crossed out. Quality of handwriting was scored by assessing the handwriting for a variety of measures. The measures are described in Table 7.2.

Table 7.*2*

The Measures Used to Assess Handwriting Quality.

Name of Measure	Description
Deviating Letterform	If the letter strokes do not form the letter correctly
Irregular Writing Fluency	If the letter is not formed fluently due to sudden changes in direction and sharp edges rather than curves
Average Handwriting Size	Height of letter measured. Score 0 = <4millimetres (mm) ; score 1 = 5,6 or 7 mm ; score 2 = >8mm
Irregularity of Letter Size	Variance between smallest and largest letter assessed using a template to determine irregularity.
Irregular Word Spacing	If a space larger than the letter 'o' occurs between words an irregularity has occurred.
Irregular Straight Line	A template is used to determine if the sentence is written in a straight line or an irregularity occurs.

One measure from the original Systemic Detection of Writing Problems was not included, as this was used to assess the quality of cursive writing and a high proportion of the children in this study did not use cursive writing. For each measure, the first five lines of the child's handwriting were assessed. Scoring of each measure can be seen in Table 7.3. The total handwriting quality score was a composite score from all 6 measures.

Table 7.3
Scoring Method for Each Measure of Handwriting Quality Assessment.

Score 0	In 0 or 1 line, an example of the measure being assessed is present
Score 1	In 2 or 3 lines, an example of the measure being assessed is present
Score 2	In 4 or 5 lines, an example of the measure being assessed is present

- Finger Tapping

A hand held, push down, button tally, number counter was used to record the number of finger taps. The children had to hold the tapping device with their index finger placed on the counting button and their thumb supporting the base. They were advised to put their elbow, of the arm holding the tapping device, on to the desk, to give their arm some stability. Participants completed three trials of 10 seconds both on the right hand and then the left hand (Spreen & Strauss, 1998). After each trial the participant recorded the number of taps from the number counter window into their task booklet and reset the tapping device to 0000, ready for the next trial. The score was calculated by finding the averages of the two trials with the smallest range. The average scores for the left hand and the right hand were added together and an average was calculated to give one total score.

- Bead Threading

Each child was supplied with a small Tupperware box containing approximately 150 small, coloured, plastic, barrel beads and a piece of string, approximately 15cm in length, with a knot in one end. The children were told to thread as many beads, as quickly as possible onto the string but not to make a pattern or choose any particular colour bead. The allotted time for the task was 30 seconds. At the end of the task the children were asked to count carefully how many beads they had threaded and write the number in their task pack; then to take the beads off of the string and put them back into the box. The DV was the number of beads threaded.

- Figure-Ground Test

The children were given a four page booklet. On each page either one or two pictures were printed in the centre of the page and along the bottom a row of shapes were printed. These images were adapted from the DTVP3 Figure-Ground task. Examples of some pages from the Figure-Ground task can be seen in Appendix XI. The children had to observe the stimulus pictures to determine if one or more shapes could be seen in the picture that matched exactly to the shapes in the row at the bottom of the page. They then had to draw a line between the shape in the stimulus picture and the matching shape in the row. There was no time limit. The pictures became more gradually more complex on each page. Parallel forms of the baseline Figure-Ground packs were used at test to avoid practice effects. The scoring was based on scoring in the DTVP3. Each picture was scored separately. The child scored 1 point for each shape correctly identified in the stimulus picture. However, if the child identified a shape that was not in the stimulus picture then a score of 0 was given for that picture, regardless of whether they correctly identified any other shapes in that picture. The DV was the level of visual perception measured by the cumulative score for the seven pictures in each pack. The higher the score, the better the visual perception.

7.2.4 Procedure

Testing was administered to a whole class group on each occasion. The testing began at the beginning of the school day, immediately after registration at approximately 9.15am. The baseline tasks took approximately 20 minutes. The children were asked to get out their reading books and begin quiet reading when they had finished the final task, which was the Figure-Ground task. When it was observed that all the children had finished the task the intervention was administered. After the intervention, in the drink condition the water bottles were labelled with the participant number and collected. The children in both conditions were given a further 25 minute period in which they quietly read their books. At the end of this 25 minute session testing began again, approximately 50 minutes after baseline testing had begun. Children were asked to continue with a school work task when they had completed the last task which was the Figure-Ground task. When it was observed that all the children had finished the task the testing booklets, equipment and materials were collected.

7.3 Results

7.3.1 Primary Analysis: the Effect of Drinking Water on Mood and Fine Motor Skills (Hypothesis 1)

7.3.1.1 Analysis.

The data from each of the mood VAS scales and cognitive tests were analysed using a one way independent measures analysis of covariance (ANCOVA). DRINK (DRINK/NO DRINK) was the independent measure and test scores the dependent measure. To control for baseline differences between conditions the baseline score was included as a covariate. A t-test was used to analyse the change data for the finger tapping test because the data broke the assumption of homogeneity of variance

7.3.1.2 Data Preparation

The data were checked to determine whether they meet the assumptions for an ANCOVA. Outliers were checked and replaced with a score 1 unit higher than the next highest score, so that the outlier was removed but the mean score not influenced too severely (Field, 2009). Scatterplots were visually observed and it was confirmed that the baseline and test data had a linear relationship. The assumptions of homogeneity of regression slopes were met as the interaction term was not statistically significant for all tasks other than self-rated thirst measured using a Likert scale. These data were not analysed using ANCOVA and the preparation of the data is described below. For the remaining cognitive task and mood test scores, standardized residuals, were produced and were analysed with a Shapiro-Wilk test which showed that group residuals were normally distributed. The assumption of homoscedasticity was checked, by producing and observing a scatterplot of standardized residuals against predicted values, which showed the values were randomly distributed. Homogeneity of variance was tested using Levene’s test and Hartley’s F max test (Field, 2009).The data for the finger tapping task did not meet the assumption of homogeneity of variance and the distribution did not change after transformation. Preparation of these data is described below.

Data that broke the assumptions for ANCOVA were prepared separately. Baseline data for self-rated thirst measured by Likert scale, and the finger tapping task, were distributed normally, and were not significantly different in the DRINK and NO DRINK conditions (self-rated thirst measured by Likert scale $t(83)= .352$, $p =.725$; finger tapping $t(77)= .098$, $p =.922$). Therefore, change scores were computed by subtracting baseline data scores from test data scores and the difference between the change scores in the DRINK and NO DRINK condition analysed using a t-test. The t-test is more robust than the ANCOVA and if the assumptions of homogeneity of variance are broken a Welch t test can be used, as this determines the probable difference in the two conditions when the distributions of data is not equal.

A reduced number of participants were included in the Figure-Ground data analyses (n=52) as some children were not given adequate time to finish the task. Only work from 30 participants were scored for handwriting quality and analysed (randomly selected) due to the long length of time required to score each sample.

7.3.1.3 Inferential Results

Data presented in Table 7.4 shows the unadjusted baseline and test scores, *SD*s and ANCOVA results, as well as t-test results for the finger tapping task and self-rated thirst measured by Likert scale. Observation of Table 7.4 shows that children in the DRINK condition rated themselves as significantly less thirsty at test, when measured by Visual Analogue scale, than the children in the NO DRINK condition (F (1,81)=24.76, p <.001, partial η^2=.234). These results are consistent with studies 1,2, 3 and 4.These findings mirror the results when self-rated thirst is measured by Likert scale (t(62.242)=- 3.793,p<.001, r =.43). There were no statistically significant differences in conditions for scores of self-rated happiness, fatigue or hunger. There was a statistically significant difference in handwriting speed at test (F(1,79)=5.299, p =.024, partial η^2 =.06). Handwriting speed was significantly faster in those children in the DRINK condition compared to those in the NO DRINK condition. Observation of Table 7.4 shows that scores for the finger tapping and bead threading task increased between baseline and test in both the DRINK and NO DRINK conditions, suggesting the children improved due to practice, conversely, in the Figure-Ground task performance in the task deteriorated over time for children in both conditions. In the finger tapping task the difference in change scores (*M* difference = 2.47) between the DRINK and NO DRINK conditions was approaching significance (t (56.903) = 1.742, p=.087, r =.22), with children in the DRINK condition (*M* = 4.84, *SD* = 7.52) increasing the number of finger taps more than the children in the NO DRINK (*M* = 2.38, *SD* = 4.41) condition. No statistically significant differences were found for the Figure-Ground task, handwriting quality or bead threading.

7.3.2 Primary Analysis: the Effect of Self-Rated Thirst Scores on Mood Scores and Cognitive Performance Scores (Hypothesis 2).

7.3.2.1 Data Analysis

To determine whether self-rated thirst at test had an effect on task performance at test, t-tests were carried out on task and mood scores with a between subjects factor of THIRST (HIGH THIRST/LOW THIRST).

7.3.2.2 Data Preparation

To investigate whether there was an effect of self-rated thirst on mood and cognitive task performance the cohort was divided into a HIGH THIRST and LOW THIRST group, at test, by way of a median split. The VAS scores were used rather than the Likert Scale scores to make the split process easier, as a large proportion of the participants had rated themselves with the median score (*Mdn*=4) when measuring thirst using the Likert scale (see *7.3.3.2* for correlational analysis between Likert scale and VAS). Data were checked to confirm that they met the assumptions for t-tests.

Separate data sets were used when analysing the Figure-Ground task and writing quality task scores because of the reduced number of score sheets. Therefore, these data sets used different medians to separate participants into LOW and HIGH THIRST groups to determine that the groups had equal numbers of participants.

Table 7.4

Unadjusted Means, SD, and Significance Levels (ANCOVA) for Mood and Cognitive Task Scores by Drink Condition.

	Drink				No Drink					
	Baseline		Test		Baseline		Test			
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Sig	*partial* r^2
Self-Rated Thirst (VAS)	43.55	27.54	28.55	35.17	44.67	24.01	61.73	27.89	**$F(1,81)=24.76$, $p<.001$**	.23
Self-Rated Hunger (VAS)	33.80	27.62	48.77	36.52	41.76	34.92	49.25	32.31	$F(1,81)=.727$, $p=.397$	<.01
Fatigue (Likert Scale)	4.25	1.73	3.89	1.92	3.40	1.77	3.20	1.91	$F(1,81)=.033$, $p=.856$	<.01
Self-Rated Thirst (Likert)	4.05	1.53	2.85	1.96	3.90	1.52	4.32	1.72	**$t(62.242)=-3.793$, $p<.001$***	.43
Happiness	60.75	30.45	64.49	33.11	76.13	24.51	72.86	27.79	$F(1,79)=.027$, $p=.871$	<.01
Handwriting Speed	156.90	45.27	208.82	51.46	155.98	49.90	191.95	57.07	**$F(1,79)=5.299$, $p=.024$**	.06
Handwriting Quality	2.47	1.90	3.23	2.19	2.15	2.07	2.23	2.00	$F(1,27)=1.558$, $p=.223$	.05
Finger Tapping	46.80	9.97	51.09	11.21	46.19	7.52	48.11	*6.66*	*$t(56.903)=1.742$, $p=.087$**	.22
Bead Threading	7.16	2.20	8.51	3.06	7.33	2.50	8.59	2.49	$F(1,76)=.009$, $p=.931$	<.01
Figure-Ground	17.17	2.37	15.10	2.34	18.46	1.47	16.37	2.86	$F(1,50)=1.266$, $p=.266$	.03

*Note:** = data failed assumptions of ANCOVA and so the data were analysed using a Welch t test.

7.3.2.3 Statistics

Table 7.5 shows the number of children in the HIGH THIRST and LOW THIRST group at baseline and test and the mean self-rated thirst scores. Exploration of the self-rated thirst data showed that the scores became more extreme in each group at test, than baseline, as the HIGH THIRST score increases whereas the LOW THIRST score decreases.

Table 7.5

Frequency, Mean and Median Scores of Participants in each DRINK and THIRST condition

	Baseline scores Median Score = 46		Test scores Median Score = 48.5	
	Number of participants	Mean score	Number of participants	Mean score
High Thirst	43	63.81	42	76.70
Low Thirst	42	24.00	42	15.17

Table 7.6 shows the test means and SDs for mood and cognitive task scores by THIRST condition. Participants in the HIGH THIRST group rated themselves as more tired than the participants in the LOW THIRST, (t(82)= -2.069,p=.042,r =.22). Participants also rated themselves as more hungry in the HIGH THIRST group than the LOW THIRST group (t(82)=-2.215,p=.030, r =.24). There were no other statistically significant findings.

Table 7.6

Test Means, SD and Significance Levels (t-test) for Mood and Task Scores in High Thirst and Low Thirst Groups

	HIGH THIRST		LOW THIRST		
Task	Mean Test	*SD*	Mean Test	*SD*	*t*-test
Self-Rated Hunger	57.09	33.61	40.95	33.18	***p*=.030**
Fatigue	3.95	1.99	3.09	1.79	***p*=.042**
Happiness	74.56	26.01	63.19	33.84	*p*=.092
Handwriting Speed	200.28	44.35	199.65	64.57	*p*=.959
Handwriting Quality	16.64	2.01	15.70	2.00	*p*=.299
Finger Tapping	50.01	11.24	51.16	12.12	*p*=.654
Bead Threading	8.61	2.34	8.49	3.14	*p*=.843
Figure-Ground	15.38	2.67	15.88	2.63	*p*=.500

7.3.3 Supplementary Analysis: the Correlation between Self-Rated Thirst Scores when Measured by Visual Analogue Scales and Likert Scales (Hypothesis 3).

7.3.3.1 Data Preparation

The data were explored to confirm that it met the assumptions for a Spearman's Rank-Order Correlation Coefficient.

7.3.3.2 Inferential Results

Table 7.7 shows the Spearman's rank-order correlation coefficient and significance between self-rated thirst at baseline and test measured using a

VAS and a Likert scale. Observation of the table shows that there was a strong, positive correlation between self-rated thirst measured by VAS and Likert scales at baseline ($r_s(84) = .672$, $p < .001$) and test ($r_s(84) = .839$, $p < .001$).

Table 7.7.

Spearman's Rank-Order Correlation Coefficients between Self-Rated Thirst using VAS and Likert Scales.

	r_s	p
Baseline Thirst VAS and Likert Scale	.672	**<.001**
Test Thirst VAS and Likert Scale	.839	**<.001**

7.4 Discussion

7.4.1 Summary of Findings

The first hypothesis argued that having a drink would improve fine motor, visual perception skills and mood. The results show that handwriting speed became significantly faster in children that had a drink compared to children that did not, thus supporting the suggestion that skills requiring visual-motor integration may be improved by water consumption. Bead threading was not found to be affected by water consumption. However, children who had a drink trended towards becoming faster in the finger tapping task than children that did not, suggesting that fine motor speed is sensitive to water consumption. There were no significant findings for hand writing quality or Figure-Ground task. As expected children that had a drink rated themselves as less thirsty than children that did not have a drink. There were no other effects of water consumption on mood.

There was no support for the hypothesis that children in the high thirst group, compared to children in the low thirst group, would score more poorly in tasks requiring visual perception or visual motor integration skills. However, levels of self-rated fatigue and hunger were significantly higher in children that rated themselves high on the thirst scale.

Lastly, the results from the correlation of scores from the self-rated thirst scales measured by Likert Scales and Visual Analogue Scales supported the hypothesis that they would correlate. The two measures correlated highly and were statistically significant. The implications of these results will be discussed in the next section.

7.4.2 Examination and Implications of the Findings

A significant finding in this study was that handwriting speed was improved by water consumption. Motor speed and manual dexterity has been shown to be improved by water consumption in study 1 and 2. Although, it should be noted that these effects on bead threading were not replicated in this study and only weakly replicated in the finger tapping task. Interestingly, there were no significant differences in handwriting quality between children that had a drink or did not have a drink. It might be expected that there would be a speed, quality trade-off. However, in a study by Smits-Engelsmen et al. (2001) children that were poorer writers wrote more slowly and had lower quality handwriting. After an intervention of physiotherapy both speed and quality increased. It seems that quality of handwriting, for example fluency, enables faster handwriting.

However, handwriting quality did not improve in this study, only speed. Alternatively, it may be that the measure of quality used in this study may not have been sensitive enough to show the effect of water consumption. Issues with the measure of handwriting quality are elaborated upon in 7.4.3.

The results from the performance in the Figure Ground task, in this study, suggest that the visual perception aspect of the handwriting task was not sensitive to water consumption. The Figure-Ground task was considered a pure test of visual perception and the analysis showed no effects of water consumption. Therefore, it is considered that it was the motor aspects of handwriting performance that were most affected by water consumption.

The notion that motor speed may be improved by water consumption is supported by the trend in the present study of children that had a drink performing better in the finger tap task than those who did not have a drink. In study 2 the difference in performance between the two conditions was much more robust. One potential reason for the difference in findings in this study compared to study 2 is that the method of finger tapping was different in study 2 than the present study which may have affected results. In study 2, the children were seated to complete the tasks but did not have a desk. In the present study the children each had a desk and were advised to rest the elbow of the finger tapping hand on the desk for stability. Therefore, in study 2 the finger tapping task placed a greater demand on the larger muscle groups as the children had to maintain a stable posture, throughout the task, without help from props. Previous research literature (Erkmen et al., 2010; Gauchard et al., 2002) shows that not having a drink has a negative effect on posture compared to having a drink. The significant difference in the number of finger taps in those children in study 2 that did not have a drink, compared to those that had a drink may be a cumulative effect of maintaining a stable posture and finger tapping. Hence, the difference in finger tapping performance, between those that had a drink and those that did not, may not be as robust as the finding in study 2, as in the present study finger tapping performance was not compromised by postural requirement.

Additionally, in study 2 the children were asked to tap their fingers for 30 seconds and this was repeated twice. In the current study, the participants were only asked to tap their fingers for a period of 10 seconds, three times using a number counter. The change in design was an attempt to ensure that the task could be controlled more easily when administered in a group setting. However, the consequences may have been that the children in Study 1 became more fatigued and found it harder to increase and maintain speed, than in the current study when children only had to tap for 10 seconds and had a rest in between. The duration of the task may be a critical factor in performance, and this should be examined further in the future.

It was expected that bead threading performance would be improved by water consumption in this study, as there was a significant difference between the drink and no drink group in study 1 (see Table 3.2). Thus, it was a surprise when there were no significant results. This discrepancy in results between study 1 and the current study may in part be explained by differences in timings. Due to an error participants were only given 30 seconds to thread the beads in the current study, compared to 45 seconds in study 1, thus participants threaded more beads in study 1 than the current study. Additionally, in study 1 there were six tasks to complete at each timeline and bead threading took place last whereas in this study only four tasks were given at baseline and test and bead threading took place third. Therefore, participants may have been fresher and less fatigued when completing the task in the current study. This theory is substantiated by the results of the finger tapping task.

Based on the results from previous studies, it is suggested that the effects of water consumption on motor performance in this study are likely to be a result of those that are dehydrated being unable to improve and maintain performance over time as much as those that were hydrated. In study 2, the number of finger taps increased between baseline and test, in children that had a drink, and further exploration in study 3 showed that all the children's performance improved except for those that were dehydrated and did not have a drink. A possible explanation for a deterioration or plateauing in fine motor performance in children that are dehydrated is that they are unable to maintain the required effort for optimum neuromuscular function (Smith, Newell and Baker's,2012) . This idea is consistent with Montain and Tharion's (2010) study, in which participants performed isometric thumb contractions repetitively until exhausted in a hydrated condition and again in a dehydrated condition whilst having somatosensory evoked potentials (SEPs) recorded. There was no significant difference between the two conditions in the time to exhaustion, but participants reported feeling significantly more fatigued in the dehydrated condition and results from the SEPs implied that there may be a change in central nervous system signal processing. These findings are also in keeping with a study by Kempton et al. (2011). In this study a greater fronto-parietal blood oxygen- level-dependent (BOLD) response was observed in participants undertaking a task when they were dehydrated than when they were euhydrated. Although there were no differences in task performance between the hydration conditions it was suggested that increased effort was required by participants when they were dehydrated to maintain the same performance as when they were euhydrated. Results from Szinnai et al. (2005) supports the notion that participants in a dehydrated condition felt as if they were making more of an effort, to complete tasks, than when they were in a euhydrated condition. In the present study, participants that did not have a drink had not improved as much as those that did have a drink, suggesting that children in the no drink condition required more effort to carry out the same task as those in the drink condition.

However, in the present study, the level of self-rated effort required to complete each task was not measured. A measure of fatigue was used but the children's scores were collected before they completed the tasks and not after. Further investigation into the relationship between water consumption, hydration status and effort using a using a specific method of measuring perceived workload such as the NASA-TLX (Wetherell, Atherton, Grainger, Brosnan, & Scholey, 2012) should be carried out in further studies.

No significant difference was found in self-rated levels of fatigue between children that had a drink and those that did not have a drink. However, results did show that participants in the present study in the high thirst group rated themselves as being more tired than participants in the low thirst group. It is difficult to explain these results as previous research literature (see review Chapter 2) has found that dehydrated participants are likely to feel more tired than hydrated participants, yet results from study 3 has found no relationship between self-rated thirst and hydration status. If it is to be considered that the sensation of thirst is more than a proxy measure for hydration status and psychological factors such as desire and habit influence the level of thirst (Ramsay & Booth, 1991) then more empirical research needs to be carried out to assess how and why self-rated thirst and fatigue are related.

In the present study participants also rated themselves as more hungry in the high thirst Group compared to the low thirst group. This finding replicates the results from study 2, in which participants in the high thirst group rated themselves as hungrier than those in the low thirst group. Results from previous research literature show that hunger and thirst sensations correlate highly in children (Buehrer et al., 2014). The relationship between self-rated thirst and hunger is discussed further in study 4 (4.4.2). Levels of thirst did not have an effect on happiness.

Furthermore, handwriting speed, handwriting quality and performance in the Figure Ground task were not affected by thirst, suggesting that visual perception and visual motor integration skills may not be sensitive to the thirst sensation. Previous tasks which have been affected by thirst include the Simple Reaction Time task (Edmonds, Crombie & Gardner, 2013) and StopSignal task (study 2) suggesting that tasks requiring attention but additionally speed of processing may be more sensitive to the thirst sensation. Further research needs to investigate which cognitive aspects are more responsive to self-rated thirst.

A secondary aim of this study was to investigate whether self-rated thirst measured by a Visual Analogue Scale and Likert Scale would differ. It was considered that the VAS might offer too big a range of choice which may be confusing and children may randomly pick a point on the scale. Hence a Likert

Scale was selected as an alternative measure as the child only has to choose from seven options and may find it easier to match how thirsty they feel to one of the choices. The results showed that the children's level of thirst on both measures correlated highly. These findings suggest that a Likert scale is not useful as an alternative method of measuring self-rated thirst. However, it is considered that the terms used in the Likert Scale i.e. not tired at all, not tired, not very tired were not very distinct from each other and may have been confusing to the children. In the future, a smaller scale Likert Scale should be considered with terms that are clearer and more distinct from each other.

7.4.3 Methodological Issues

Only a reduced number of participants work were scored for handwriting quality because coding the script was extremely labour intensive, thus it was not continued. It is noted that handwriting speed was measured in all participants. The handwriting quality score was a cumulative score from 6 different measures and the process was extremely lengthy. The analyses of 30 participant's data showed that there were no significant differences or trends between children that had a drink and did not have a drink or between thirst groups.

In this study the design for the finger tapping and bead threading tasks were not consistent with the design in previous studies. This was a big oversight as results could not be compared directly. Additionally, in this study, to save time, the children counted and recorded the number of beads threaded on to the string whereas in study 1 the researcher walked around and counted and recorded the number of beads threaded. Therefore there is the possibility that the children may have incorrectly recorded or counted the number of beads that were threaded. In future, tasks such as the bead threading task should only be administered to individual children so that the recording of beads threaded can be thoroughly controlled.

Furthermore, there was a timing error in the administration of the Figure-Ground task. This task was the last task to be completed and the design required that the children carry out this task in their own time without any time pressure. Unfortunately, in two of the classes the children were asked, by their class teacher, to finish off the task quickly and to hurry up. These papers were, therefore, removed from the analysis. The results of the remaining papers did not show a significant result or trend.

7.4.4 Conclusion

In conclusion, it was shown that handwriting speed improved after water consumption. These results suggest that fine motor speed is sensitive to hydration status. These results are important because so many practical activities require fine motor speed. In the classroom, handwriting is an essential skill and handwriting performance at an early age has implications for academic success in later life. Further research is needed to determine whether motor speed is sensitive to hydration status in adults, or whether it is of particular importance in children because they are still developing their motor skills, which have not yet become automatic processes.

Chapter 8

General Discussion

8.1 Introduction to General Discussion

A central aim of this thesis was to determine the effect of water consumption on cognitive and motor performance in children. Previous research had mostly focussed on the effects of deliberate dehydration, rather than water consumption, by means of heat exposure, exercise or water deprivation, on adults (Masento et al., 2014). The findings in adults were inconsistent (see Chapter 2 for review), which may have been a result of methodological differences in study design. When the current work began only one similar study had been carried out in children but dehydration was voluntary, rather than deliberately induced. Results from Bar-David et al. (2005) showed that short-term memory was negatively affected by mild dehydration. Thus, there was a need for more research into the effects of hydration status on cognitive performance in children.

At the start of this work, a small but growing area of research had investigated the effects of water consumption on cognitive performance. Three papers had been published that showed that water consumption improved short-term memory, perceptive discrimination, visual search and attention in children (Benton & Burgess, 2009; Edmonds & Burford, 2009; Edmonds & Jeffes, 2009). One study (Rogers et al., 2001) of adults showed that thirsty participants that had a drink showed greater improvements in a task requiring sustained attention and working memory, than participants who did not have a drink or who were not thirsty. Since then, there have been further publications on the effects of water consumption, particularly in adults, in which drinking water has been reported to improve simple reaction time task performance (Edmonds, Crombie & Gardner, 2013) and letter cancellation task performance (Edmonds et al., 2013). Given the literature, the aim of this thesis was to investigate whether specific cognitive domains were more sensitive to water consumption, or whether water consumption had a general effect, and to consider what the mechanism for these effects might be. This discussion chapter will take the following format. The research aims are described in detail below. The summary of aims is followed by an overview of the studies and the main findings. The implications of the findings and issues identified in this thesis are then considered, methodological limitations discussed and ideas for further research addressed. Finally, the conclusions from this thesis are presented.

8.2 Brief Summary of the Aims and Rationale

1. To consider whether being given a bottle of water may have a psychological effect on mood or performance which is separate to a physiological effect resulting from drinking the water.

2. To broaden existing knowledge on which specific motor skills, cognitive domains and moods are affected by water consumption. In previous research (Edmonds & Burford, 2009) performance in tasks such as the letter cancellation task has been improved. However, it is not known whether there is a specific aspect of the letter cancellation task that is

sensitive to hydration, for example motor speed or attention, or whether it is a general effect. Here, potential underlying mechanisms were explored.

3. To assess whether, in children, hydration status, volume drank and self-rated thirst moderate the effect of water consumption. Previous research (see Benton, 2011 for review) has shown that performance in some tasks deteriorated in dehydrated participants but not euhydrated participants. Therefore, this thesis sought to determine whether the benefits of water consumption are due to the reversal of cognitive deficits due to dehydration or additive gains as a result of hyperhydration.

4. To examine whether urine osmolality (Uosm) and measures of self-rated thirst are effective measures of changes in hydration status over a short time period. Rogers et al. suggested in their (2001) study that self-rated thirst was a proxy measure of hydration but it was unknown if this was the case for children. Uosm has been the measure of choice in the research literature on water consumption and dehydration (Bar-David et al., 2005; Fadda et al., 2012) in children, but it is unclear how sensitive the measure is to small changes in hydration level.

8.3 Overview of Studies and Main Results

The first aim was to establish whether the effects of water consumption on cognitive performance occur as a result of improvement in mood or changes in motivation due to being given a free bottle of water, rather than the physiological effects of drinking the water. Results from Edmonds and Jeffes' (2009) study showed that children that had a drink self-rated themselves as happier than those who did not have a drink and other findings suggested that positive affect could improve certain aspects of cognitive performance (Erez & Isen, 2002; Fredrickson & Branigan, 2005). Study 1 addressed this aim by using an intervention that had three conditions. In the drink condition the children were supplied with a 330ml bottle of water to drink, in the no drink condition the children were given nothing, and in the gift condition the children were given a 330ml bottle of water to put in their bag and drink later. The measures and a brief summary of the results can be observed in Table 8.1

Table 8.1 *A Summary of the Measures Used in Studies 1,2,3 and 5 and the Findings.*

Study	Measures	Findings
1	Self-Rated Thirst	DRINK group became significantly more thirsty than No DRINK group
	Self-Rated Happiness	ns
	Self-Rated Hunger	ns
	Self-Rated Fatigue	ns
	Immediate Object Recall	ns
	Letter Cancellation Task	NO DRINK & DRINK group improved more than GIFT group
	Spot-The-Difference	ns
	Digit Span	GIFT GROUP improved more than NO DRINK group
	Threading Beads	DRINK group improved more than NO DRINK & GIFT group
	Delayed Object Recall	ns
2	Self-Rated Thirst	Self-rated thirst increased more in NO DRINK condition than DRINK condition
	Self-Rated Hunger	HIGH THIRST group had higher self-rated hunger scores than LOW THIRST group
	Self-Rated Happiness	ns
	Letter Cancellation Task	ns
	Simple Reaction Time	ns
	Choice Reaction Time	ns
	Spot-The-Difference	ns
	Finger Tapping	DRINK condition improved more than the NO DRINK condition.
	StopSignal Task	HIGH THIRST group made more errors than LOW THIRST group
3	Urine Osmolality	Uosm scores increased in the NO DRINK condition vs the DRINK condition over time. In the DEHYDRATED group Finger Tap scores got faster in the DRINK condition vs the NO DRINK condition
	Urine Colour	Correlation between urine colour and Uosm
5	Self-Rated Thirst	DRINK group became significantly more thirsty than No DRINK group
	Self-Rated Hunger	ns
	Self-Rated Happiness	ns
	Self-Rated Fatigue	ns
	Handwriting Test	Handwriting speed was faster in the DRINK group vs NO DRINK group. No difference in handwriting quality.
	Finger Tapping	A trend for the DRINK group to be faster vs NO DRINK group.
	Bead Threading	ns
	Figure-Ground	ns

As shown in Table 8.1 the results showed that being given a bottle of water to drink immediately or to save for later had no effect on levels of happiness and that the children in the gift condition did not perform better than the children in the no drink condition. However, in the bead threading task the children that had a drink increased the number of beads threaded between baseline and test more than the children in the no drink and gift condition. This differential effect of drinking on performance compared to receiving a gift or receiving nothing suggests an underlying physiological, rather than a psychological, mechanism of drinking water. Other studies support this interpretation. For example, Edmonds et al. (2013) (2013) and Ganio et al. (2011) showed that there was no effect of participant expectancy of either water consumption or dehydration on cognitive performance.

Study 2 addressed the second aim of whether specific skills were affected by water consumption. Tasks were chosen that tested a unitary function as far as possible. For example, a finger tapping task was chosen as this task essentially measures motor speed, with only a minimal demand for cognitive performance. Children were tested at two time points on two occasions. On one occasion they were given a 500ml bottle of water to drink, of which they could consume as much or as little as they wished. On the other occasion they were not offered a drink. The results, as observed in Table 8.1, showed that the number of finger taps increased when children had had a drink of water compared to when they did not. Thus, these results supported the notion that motor speed was sensitive to water consumption.

To partially address the third aim, study 2 also investigated the moderating effects of volume of water drank and levels of thirst on motor and cognitive performance skills. To test whether self-rated thirst moderated the effect of drinking on performance, the children were divided into a low thirst group and a high thirst group on the basis of their self-rated thirst scores at baseline and group differences at test were examined. The results showed conflicting effects on different outcomes. There were no differences between thirst groups in the finger tapping performance. However, children in the high thirst group made more go errors in the StopSignal task at test, than children in the low thirst group, regardless of whether they had a drink or not. The results suggest that motor speed is sensitive to water consumption but not sensitive to self-rated thirst, and attention is sensitive to self-rated thirst but not to water consumption. A correlational analysis compared volume drank, cognitive and motor performance scores and self-rated thirst but found no relationship. This lack of dose response relationship between volume drank and self-rated thirst scores could imply that self-rated thirst is not a sensitive proxy of acute hydration status in children. This important finding is discussed further in section 8.4.2.

To complete assessment of the third aim of the thesis, study 3 analysed whether Uosm, as a measure of hydration status, moderated the effect of water consumption on motor and cognitive performance, particularly finger tapping. Exploratory analyses showed that the only children that did not improve finger tapping performance between baseline and test were dehydrated and did not have a drink. Children that are dehydrated may require more effort to complete the same task as those that are euhydrated. As resources dwindle so performance plateaus or deteriorates. These results are in line with findings from Kempton et al.(2009). The implication of this finding are discussed further in section 8.6

To address the fourth aim of thesis, which was whether Uosm and measures of self-rated thirst were effective measures of acute changes in hydration status, the relationship between self-rated thirst, Uosm and volume drank was investigated. No relationship was found between thirst ratings and Uosm inferring that self-rated thirst was not a proxy measure of hydration. Thus, it was suggested that errors associated with high thirst (such as more go errors in the StopSignal task in study 2) occurred because the children’s attention was diverted by the sensation of thirst rather than due to a physiological mechanism due to dehydration. In support of this notion, study 2 found that Uosm did not correlate with volume drank. The lack of relationship between Uosm and volume drank brings into question the validity of Uosm as a measure of small changes in hydration over a short period and this is discussed in more detail in section 8.6

Study 4 tested the relationship between Uosm, volume of fluid consumed in both beverages and food and self-rated thirst. Three children were observed over five days and descriptive data were discussed. The findings showed that the participants did not habitually consume the daily volume of fluid recommended by EFSA (2010) guidelines. These results were in line with findings from previous research (Gandy, 2012; Stahl et al., 2007), which have shown that the population does not consume the volume of fluid recommended by various health and government agencies. Issues related to reference guideline are discussed further in section 8.4.4.

The results also showed, that in this small sample of children, self-rated thirst scores were not associated with Uosm and the volume of fluid consumed. The volume of fluid consumed in a three hour period before urine was collected was negatively related to Uosm scores. However, Uosm scores had a large range of interindividual and intraindividual variation both daily and across the five days. More recent researchers (Perrier et al., 2012) have reported that 24 hour Uosm is a reliable method of assessing daily hydration status but that individual Uosm measurements are not sensitive to small changes in hydration status over a short period, which supports the results from study 3 and 4. These results were important as they were instrumental in the decision not to use Uosm as a measure of hydration status in future studies.

Study 5 was designed to further address aim 2 which was to examine the specificity of the effects of drinking on motor and cognitive performance. Having ascertained that water consumption improved performance in the bead threading and finger tapping task it seemed likely that motor skills were particularly sensitive to water consumption. Therefore, in the last study motor skills were reduced to their component parts and tested to see if specific domains were more responsive to drinking than others. The results, as seen in Table 8.1, showed that water consumption improved handwriting speed and performance of the finger tapping task showed some evidence of being affected by drinking. This study also found that self-rated thirst did not affect motor skill, thus supporting the argument that motor skill is not sensitive to the effects of perceived thirst but instead is dependent on resources available to sustain effort. Tasks with a large attentional component may be more likely to be negatively affected by high scores of self-rated thirst and this is discussed further in section 8.6

8.4 Implications

A number of issues have been identified in the summary of results. Firstly, results indicate that self-rated thirst may have an effect on attention, and hydration status was found to affect fine motor skills, but there was little evidence to suggest that hydration status had an effect on any other cognitive skills. The implications of this will be discussed in section 8.4.1.

Secondly, the results from studies 2, 3 and 4, showed no correlation between volume drank, hydration status and self-rated thirst. The implication that self-rated thirst may not be solely dependent on hydration status is discussed in section 8.4.2. Thirdly, the implication of intra and inter-individual differences in self-rated thirst and Uosm, identified in study 4, is discussed in section 8.4.3. Fourthly, the findings in study 4 showed that the participants and children in previous surveys (Gandy, 2012; Stahl et al., 2007) do not drink the volume of fluid recommended by EFSA (2010) guidelines. The issues surrounding reference guidelines are discussed in section 8.4.4.

Furthermore, some issues have been identified in previous chapters, which need further discussion. Chapter one describes the importance of electrolyte balance in water balance and thus how diet is an important factor in hydration status. The implications of diet on the results of the studies carried out will be discussed in section 8.4.5. Lastly, the effects of chronic dehydration on cognitive performance are acknowledged and the implications of the effect of chronic dehydration on the results are discussed in section 8.4.6.

8.4.1 Effect of Hydration on Cognition

A review of the literature led to an expectation that water consumption or dehydration would have an effect on cognitive performance in children, particularly memory and perceptive discrimination task performance. However, the findings presented in this thesis only found an effect of hydration status on fine motor skills. Additionally, there is some suggestion that self-rated thirst may have an effect on tasks with a large attentional component.

The literature review found that dehydration in children had a negative effect on short term memory of numbers, in the form of digit span performance, (Bar-David et al., 2005; Fadda et al., 2012) but these findings were not replicated in this thesis. However, the digit span task was only used in study 1, in which children’s hydration status was not formally measured, thus, we cannot be certain if children were dehydrated at baseline or became more dehydrated over time. Studies in adults suggests that water consumption only improves digit span performance if deficits in performance have already occurred due to dehydration. Thus, children in study 1 may not have been sufficiently dehydrated for digit span performance to be impaired and therefore, water consumption would have had no beneficial effect.

The literature review also found that memory of pictures in an object recall task and a spot-the-difference task was sensitive to water consumption in children (Edmonds & Burford, 2009; Edmonds & Jeffes, 2009; Benton & Burgess, 2009). However, these results were not replicated in this thesis. As argued above with respect to digit span, it is possible that the visual memory performance of children in study 1 did not improve with water because the children were not dehydrated. However, the spot-the-difference task was included again in study 3 in which the results showed that a large proportion of the children were dehydrated, but still there was no improvement in performance after water consumption. This result suggests perhaps that visual memory is not reliably improved in individuals who are either dehydrated or well hydrated. As so few studies have been carried out in this area, more research needs to be completed before firm conclusions can be drawn on the effects of hydration status, on memory in children.

Previous research into the effects of water consumption on perceptive discrimination has shown consistently that letter cancellation task performance is improved by having a drink in adults and children. However, this effect has not been replicated in this programme of study. In study 1 the drink group performed significantly better than the gift group in the letter cancellation task but not the no drink group. It was considered that this result was an idiosyncrasy. However, when the task was repeated in study 2 and 3, but with two different versions, one that required speed of processing and one that did not, no differences were found between drink conditions in either version of the task. It may be that having to repeat the letter cancellation task four times during the testing period was too repetitive and that participant's became less focussed and their performance suffered as a consequence. It seems very likely, based on the many positive results in previous studies, that a component of the letter cancellation task is sensitive to hydration status, despite the lack of findings. Combined with the results of study 5 that formally examined the effect of drinking on handwriting speed, it is speculated that in previous research (Edmonds & Burford, 2009; Edmonds & Jeffes, 2009) participants get higher scores in the letter cancellation task because having a drink of water increases the speed at which they are able to physically complete the task. Alternatively or in combination with improved handwriting speed, high scores of self-rated thirst may have a detrimental effect on attention and thus thirsty participants may have not attended to the letter cancellation task as well as those with lower self-rated thirst scores. Thus, the findings in this thesis may be applicable to the consistent effect of water consumption on the letter cancellation task in previous studies. However, further studies are required to test these speculations.

In the literature review it was speculated that motor speed, rather than accuracy, was sensitive to hydration status. Previous studies in which the effect of hydration status on speed during psychomotor task performance has been assessed have consistently shown an effect of hydration status. In this thesis the results are consistent with this notion that speed rather than accuracy have improved when children have a drink compared to when they do not have a drink.

In summary, the results in this thesis did not find an effect of hydration status on cognitive performance. Rather, an effect of self-rated thirst, which may not be associated with hydration status, was found on attention and an effect of hydration status was found on motor speed. It may be that in previous research performance has improved in the drink group, or deteriorated in the dehydration group, because the motor speed component of a task has got faster, or slower, rather than a cognitive component of the task being affected by hydration status. Alternatively, cognitive task performance may have deteriorated in previous research because the participants have not attended to the task if they felt thirsty. Future research needs to investigate these notions further.

8.4.2 Self-Rated Thirst

In this thesis, self-rated thirst scores were not related to Uosm scores or volume drank. It was suggested in previous chapters that self-rated thirst may not be solely dependent on hydration and that other factors such as habit and desire (Saltmarsh, 2001) have a large influence on the sensation. However, there is a body of research that contends that self-rated thirst is a proxy for hydration (Rogers et al., 2001),and that the volume and frequency of drinking should be based on the thirst sensation (MacGregor, 2014). Additionally, Sawka et al. (2005) argues that the sensation of thirst is an essential requirement for water balance. Furthermore, it has been suggested that the sensation of thirst is not easily recognised by children (Kenney & Chiu, 2001) but is more dependable in adults.

Thirst is an incredibly complex sensation. It is defined as being “a sensation caused by a need for increased fluid intake to maintain an optimum balance of water and electrolytes in the body tissues”(Corsini, 1999, p. 999). Yet, the thirst sensation can also be experienced when there is no water deficit but because we have a desire for a drink due to habit, or the situation in which one finds oneself. For example, we often feel thirsty when we have a dry mouth which may be due to being in a stressful situation (Bergdahl & Bergdahl, 2000; Booth et al., 2011). Additionally, in study 4 and elsewhere it has been shown that many participants rate themselves as thirsty yet do not voluntarily consume fluid even when it is readily available (McKiernan, Hollis, McCabe, & Mattes, 2009). Hence, it is difficult to delineate the thirst sensation. To date, thirst has been measured by asking participants to rate how thirsty they are, by rating the dryness of mouth, or the fullness of stomach or by choosing what volume of fluid they would choose to drink (Brunstrom & Macrae, 1997). However, the results of this thesis suggest that the sensation of thirst is yet to be fully understood.

In terms of water balance, thirst is a sensation that is triggered by the secretion of vasopressin. In Baylis and Robertson's (1980) experiment adults were infused by drip with a hypertonic saline solution so that they would gradually become dehydrated and vasopressin would be secreted. Blood plasma osmolality (Posm) gradually increased as participants became dehydrated. All participants expressed that they experienced the first sensation of thirst when their blood plasma readings were between 293 to 305 mmol/kg. The mean Posm was 299 mmol/kg which is high considering that 295 mmol/kg is the level at which urine is maximally concentrated. In a healthy, hydrated population 95 % of people have a Posm reading of between 275 and 296 mmol/kg (Cheuvront et al., 2010). Conversely, Phillips, Rolls, Ledingham and Morton's (1984) reported mean blood plasma osmolality levels, from blood samples taken when participants expressed they wished to drink because they were thirsty, ranged between 284 and 286 mosm/kg. Phillips et al. (1984) suggest that the thirst sensation has evolved to prevent dehydration rather than a signal that dehydration has occurred.

Harshaw (2008) argues that recognition of the thirst sensation is not automatic or innate, in humans or animals, but has to be developed throughout childhood. Children have to learn to match uncomfortable interoceptive feelings with the requirement for food or drink, similarly to the way in which they learn to recognise emotional feelings. Harshaw (2008) suggests that they learn this through caregiver responses and social feedback. Wright, Fawcett and Crow (1980) showed that breast fed babies learned that they needed to consume more milk the longer the interval between feeds, whereas bottle-fed babies were content to have the same volume of milk at set times every day. It was argued that the babies' ability to adjust their volume of intake to match their feeding schedule showed that they learnt to recognise feelings and intensity of hunger and thirst.

If thirst is a learned sensation it could suggest that thirst is immature in childhood. Children may be less sensitive to the thirst sensation than adults because they are still learning to recognise the thirst sensation and match it with a need to drink (Kenney & Chiu, 2001). For example, in a study in which children fasted from food for a median time of 12:03 hours and fluids for a median time of 7:57 hours, only 26.7 % of the children felt very thirsty at the end of the fasting period (Engelhardt, Wilson, Horne, Weiss, & Schmitz, 2011). In Bar-Or et al. (1978), children with ad-libitum access to water did not drink enough to replace fluid lost whilst exercising in the heat. As children have greater fluid needs due to a greater body surface to mass ratio, than adults insufficient fluid replacement is likely to lead to faster dehydration.

However, there is no empirical evidence to show that thirst sensitivity differs between adults and children, or that adults are better at drinking in response to thirst than children. Indeed, McKiernan et al. (2009) argue that because our society has a constant supply and availability of beverages, with hedonic properties which encourage us to drink, people no longer associate drinking with relieving thirst. Evidence from the study of McKiernan et al. (2009) supports the notion that drinking and thirst are not associated. McKiernan et al.

(2009) had 128 adults' record hunger and thirst every hour between 9:00 and 21:00 for 7 days on a handheld PC. Participants also recorded their entire food and drink intake. The results showed that thirst did not correlate with drinking and that the participants only drank water in response to thirst on 2 % of thirst occasions. These results are consistent with the findings from study 2 and 5 that showed no correlations between volume drank and self-rated thirst, and study 4 results which showed that participants did not drink in response to self-rated thirst scores. Furthermore, McKiernan et al. (2008) showed that self-rated thirst was relatively high and stable over all time periods, with very little variation throughout the day, when presumably participants did not have an all-day hydration deficit. The explanations for the consistently high thirst score may be that adults are constantly drinking so their thirst score does not vary, or that they are not able to recognise their thirst sensation. Alternatively the scores in McKiernan et al. (2008) may not have reflected intra-individual differences because they are mean values. In support of this, study 4 showed that there were wide intra-individual variations in self-rated thirst scores. Intra-individual and inter-individual variations in both thirst and Uosm will be discussed in 8.4.3.

In summary, here it is argued that the thirst sensation is not a useful proxy measure of hydration and does not have a close association with drinking. Furthermore, thirst is a sensation that cannot be easily delineated. Yet evidence suggests that the sensation of thirst may divert attention away from a task (study 2; Edmonds, Crombie & Gardner, 2013). This is a paradox, how can cognitive deficits be reduced by removing distractions which are a result of thirst sensations when the sensations are not guided by an objective measure such as volume drank or hydration status? Future research should further investigate the relationship of thirst with cognition and develop a fuller understanding of the thirst sensation in children and adults. The next section will discuss the implications of inter and intra-individual variation found in thirst scores and Uosm.

8.4.3 Inter-Individual and Intra-Individual Variations in Self-Rated Thirst and Uosm.

As discussed above, the sensation of thirst has been found to be consistently high across time in adults, but this might be due to mean scores masking individual differences (McKiernan et al., 2008). The findings in this thesis show that self-rated thirst scores have large *SD*s suggesting that there were large inter-individual differences. Furthermore, study 4 showed that there was a large intra-individual variance in self-rated thirst scores across the morning tested and over the full 5 days of testing. It could be considered that children may have more individual differences in thirst responses than adults because of their immature processes. However, observation of data from an adult study (Edmonds, Crombie & Gardner, 2013) also show large SDs for self-rated thirst scores, and extremely large SDs for those participants who had a drink of water before filling in the Visual Analogue VAS. Thus, it is probable that contrary to the reported group-averaged findings of McKiernan et al. (2008) in which self-rated thirst scores were consistently high and stable, self-rated thirst does have both wide intra and inter-individual differences. However, there is no empirical evidence to suggest that there is a distinction in self-rated thirst variation between children and adults and this should be explored further in future work

Additionally, study 4 highlighted that Uosm levels have a large inter and intra-individual variation. Baseline scores ranged widely from day to day in each individual child and between children. Interindividual variation has been shown previously in a study by Perrier et al. (2013), in which there was a range of between Uosm 435 and 1,123 mOsm/kg at baseline. Yet, participants in Perrier et al.'s study were consuming a strict standardised diet and volume of fluid. Inter-individual differences were particularly noteworthy in study 4, as two of the participants were monozygotic twins, who were consuming a very similar diet, took part in the same activities and operated in the same environment, but who on occasions had very different Uosm readings. The difference in Uosm readings may have been due to a very small disparity in food or drink consumed, in the timing of consumption or urine collection. Alternatively, the variation in Uosm scores may have been a result of differences in metabolism due to dissimilar sleep patterns, levels of stress, temperament and so forth. However, the difference in Uosm levels in these twins highlights the problem of how to educate the public on how much fluid intake is healthy when each individual will metabolise fluid dependent on the external and internal environment. The following section expands on the issue of current fluid intake reference guidelines.

8.4.4 Reference Guidelines

As discussed in the summary of results, findings from study 4 and previous research studies suggest that children do not adhere to the European Food Safety Authority (EFSA) guidelines as they are consuming less than the EFSA adequate intake (AI) recommendation (Gandy, 2012; Stahl et al., 2007).

Hence, the usefulness or efficacies of AI recommendations are questioned (Drewnowski, Rehm, & Constant, 2013; Gibson & Shirreffs, 2013). This section will discuss how the recommendations were developed and their validity.

Both the EFSA (EFSA, 2010) and Institute of Medicine (IOM) (Sawka et al., 2005) recommend water intake based on Adequate Intake (AI) of water from food and beverages. The EFSA list the health risks associated with acute and chronic dehydration and the risk to cognitive function and motor control. However, the recommendation was not motivated by health risks associated with dehydration, unlike most other food and nutrients, for example, salt intake guidelines were introduced with a view to reducing cardiovascular disease (Salt and Health, 2003). Instead the EFSA AI water guidelines were driven by reporting of average consumption, but it is vital that water intake recommendations are scientifically robust as the information is used by healthcare professionals to guide and advise patients (Holdsworth, 2012).

AI was calculated by using data from studies in which the participants were healthy individuals, who had Uosm levels of about 500 mosm/L, and who ‘consumed average diets and partook in moderate levels of physical activity’ (EFSA, 2010, p.37). Each individual survey, included in EFSA’s calculation, used their own guideline for ‘average diets and moderate levels of physical activity.’ The EFSA report states that very few studies of children were included when calculating AI, because the estimates of fluid intake from the different studies were not comparable as studies used different methods of assessment and categorised fluid and drinks in different ways, thus the validity of the recommendations are questionable (Gandy, 2015) .

The volumes recommended as an AI by EFSA were 25 % larger than the mean scores of the average fluid intake of the different groups in the population. The 25 % addition may seem counterintuitive but the extra volume is to allow for SDs which were 22 % to 24 % of the mean scores. Thus, while study data suggested that the average intake of European girls aged 9 to 13 years was approximately 1,520ml per day, an additional 25 % of volume was added to that figure, to allow for individual differences, leading to an AI recommendation of 1,900ml. The same calculation was carried out for boys and the mean reported intake of 1,700ml per day was increased to an AI recommendation of 2,100ml per day. Hence, these recommendations are very high, particularly for those children who naturally fall into the group that consume less than the initial mean score of the average fluid intake. Because of the way that these recommendations were developed it might be expected that a large proportion of the population is thought to be under consuming, according to the guidelines (Gandy, 2015).

Furthermore, the general public is confused as to how much they should drink (Lunn & Foxen, 2008), following mixed messages that have appeared in the media, which may be in part due to the poorly worded health claims given by EFSA. Health claims are often used in support of scientific recommendations in order that the public feels more informed about the benefit of following the recommendations. EFSA will only allow the health claims, “water contributes to the maintenance of normal physical and cognitive functions” and, “water contributes to the maintenance of normal regulation of the body’s temperature (Sadler, 2014, p. 377).” EFSA will also only allow these claims to be applied to tap water or mineral water, which can be confusing as the fluid intake recommendations are for fluid in food and all beverages, yet the message implies only fluid volume consumed as water is included in a person's daily fluid intake. To put these health claims into context, the health claims for calcium which have been agreed by EFSA are: "calcium contributes to normal blood clotting; calcium contributes to normal energy yielding metabolism; calcium contributes to normal muscle function; calcium contributes to normal neurotransmission; calcium contributes to the normal function of digestive enzymes; calcium has a role in the process of cell division and specialisation; calcium is needed for the maintenance of healthy bones and calcium is needed for the maintenance of healthy teeth" (EuropeanCommission, 2015). In contrast to water, these claims can be applied to all food which is a source of calcium and not just calcium in its pure form. The health claims for drinking water are very brief and confusing and may not encourage the general public to drink more water.

Lack of adherence to recommended guidelines is not isolated to water intake as surveys show that compliance to other food and nutrition intake recommendations in the UK is generally low (Philpott, 2009). For example: the 'five a day 'message has encouraged greater consumption of fruit, but not vegetables, and fruit and vegetable intake is still below the recommendations; consumption of oily fish is below recommended guidelines and salt intake is much higher than the guidelines (Philpott, 2009). In the UK , Dietary Reference Values (DRV) were first introduced in 1991 for 33 nutrients and were intended to give advice, rather than guidelines, to the public as to how much of a nutrient they should be consuming per day, based on scientific evidence. However, most of the DRVs set are based on "hypothetical judgements" (Philpott, 2009.p1) as there were insufficient data to establish requirements for food and nutrients. Guidelines for consumption of food are also given using Reference Nutrient Intakes (RNIs), which are based on DRVs, but are set for different groups, for example genders and age groups, as well as AI. Thus food and nutrition guidelines are often confusing and are generally not successful (Philpott, 2009), so perhaps it is not surprising that the guidelines for water are not adhered to and similarly opaque.

In summary, current fluid EFSA recommendations are calculated using average fluid intake, and inflated to include individual differences, from data based on very few studies which have collected information using a variety of methods. Findings from surveys of fluid intake suggest that the population, particularly children, do not drink enough but as comparisons are made with AI recommendations these conclusions made be misleading. Moreover, members of the public are generally confused as to how much fluid they should drink which may be a consequence of the badly worded health messages accompanying the fluid guidelines.

In view of the lack of adherence to the current guidelines for fluid intake and the different individual requirements of fluid, due to variation in diet, exercise and environmental factors, it is suggested that an alternative method to recommended intake be given. A possible alternative is that guidelines are given that allow individuals to assess the impact of their own water consumption and assess whether they need to be drinking more or less. One method of easily monitoring approximate hydration levels is to assess colour of urine (Armstrong, 2005). Further ways in which the public could be informed and educated about optimum fluid intake should be explored in future studies.

8.4.5 Diet

One of the aims of this PhD was to explore whether hydration status had an effect on motor and cognitive performance. The assumption throughout the thesis is that children were not drinking adequate quantities to maintain euhydration. However, to maintain euhydration a balance of water and sodium electrolytes, such as salt needs to occur, thus salt intake is an important consideration when studying the effects of hydration. This section will discuss the effects of salt intake and diet generally on hydration status, and the implications for the research in this PhD.

Hydration status, particularly if measured by urine osmolality, is dependent upon the concentration of solutes excreted by the kidney (renal solute load), as much as the volume of water in body fluid. As explained in Chapter 1, for euhydration to occur a balance of water and solutes, the most important solute being sodium, must be maintained both in the ICF (intracellular fluid) and ECF (extracellular fluid). If the concentration of sodium is higher on one side of the cell membrane than the other, then water will move along the osmotic gradient until the balance of sodium is restored which may possibly cause either hypotonic (swollen cells) or hypertonic dehydration (shrunken cells). Hence, if the volume of water stays constant but the kidney solute load doubles urine osmolality will also double in concentration (Cheuvront & Kenefick, 2014). However, hypotonic dehydration, which occurs due to a deficit in sodium, generally only occurs due to severe vomiting or diarrhoea or as a result of taking certain medications. Very rarely does hypotonic dehydration occur because of over consumption of fluid, or under consumption of sodium (Bhalla et al., 1999).

Sodium is a found in salt and salt is added to processed foods such as bread, cereals and meat products. The National Food Survey (Salt and Health, 2003) showed that 86 % of the total intake of salt in UK households was from processed foods and the remaining 14 % was from naturally occurring sodium in unprocessed food and salt, added to food either during cooking or when the food is on the plate. Salt intake is high in the UK (Salt and Health, 2003). The UK government guideline RNI for 7 to 10 year olds is 3.06 g/d but estimated salt intake, in the National Diet and Nutrition Survey (1997), was 6.1grams per day for males and 5.5 grams per day for females and these are likely to be underestimates (Smithers et al., 2000). Therefore, voluntary dehydration in the participants in this thesis may have occurred because of over consumption of salt or under consumption of fluid, or a combination of both, but consumption of plain water will rehydrate regardless of the cause of the underlying imbalance.

Hydration status may be influenced not only by the volume of fluid drank and salt consumed but also by the general content of the diet. Fluid is contained not only in beverages but also in food, thus a diet consisting of lots of fruit and vegetables would contribute more fluid than a diet of dry foods such as crisps and pizza. Therefore, it is not surprising that in the study of Stahl et al. (2007), children that were better hydrated had eaten more foods with a higher water content and also these foods had less fat content than foods eaten by children that were less well hydrated. In a review, Benton (2011) suggests that better hydrated children may be eating a better diet, and thus any relationship between hydration and cognitive performance may be in part due to the diet rather than hydration status per se.

Evidence supports that socio-economic background is associated with quality of diet (Roberts, Cavill, Hancock, & Rutter, 2013). However, in this thesis, there was no evidence of differences in hydration status or cognitive performance at baseline, between children that came from different socio-economic backgrounds. In study 2, children from two different schools participated: the schools were located in a middle-class area in Essex and a deprived area in Newham, and so the children in each school generally came from very different backgrounds. However, despite observation of the food diary entries showing that the children in the two schools ate very different breakfasts; the children in the Essex school consumed mostly cereal based foods whereas the children in the Newham school had a very eclectic diet, no difference in hydration status was found between the different schools at baseline. Furthermore, although it is supported that quality of diet is associated with better physical health, evidence on the association between cognitive performance and diet is inconclusive (Ells et al., 2008). In both study 2 no differences were found in baseline or test performance in the cognitive tasks between the schools from the different socioeconomic areas. Thus, diet did not seem to have a significant effect on results.

In summary, this section has argued that dehydration in children can be reversed by water intake, as water imbalance is likely to occur because of insufficient consumption of fluid or over consumption of salt. Furthermore, , although observation of the food diaries suggested that there was a difference in the diet consumed in schools from different socioeconomic areas, there was no evidence to suggest that there was any significant difference in hydration status or cognitive performance in the different schools. Thus, it is argued that any changes in cognitive performance after a drink were mostly due to the hydrating properties of the water and not as a result of diet.

8.4.6 Chronic Dehydration

This thesis targeted the effects of acute dehydration and rehydration on cognitive and motor performance. Chronic dehydration was not part of the remit but the implications of chronic dehydration, to this thesis, are that a proportion of the children arriving at school in a dehydrated state may be suffering from chronic rather than acute dehydration. Chronic dehydration may have a different effect on cognitive performance than acute dehydration and may moderate the effect of acute water consumption on cognitive and motor performance. This section will discuss the current literature on chronic dehydration and the impact it may have on rehydration.

A large body of research has been carried out on the effects of chronic dehydration on health. For example, long term low water intake, over a number of years, is associated with a higher risk of developing hyperglycaemia and higher water intake is associated with a decreased risk of developing chronic kidney disease (Lotan et al., 2013). To date, there has been very little research investigating the prevalence of long-term dehydration or the effects on cognitive performance.

There is some evidence from experiments on animals that chronic dehydration can cause cognitive deficits. For example, findings from studies of rats suggest that neuronal activity may be altered by chronic dehydration, which may have implications for cognitive performance. Di and Tasker's (2004) study shows that rats that are chronically dehydrated have increased spontaneous release of glutamate and GABA. Glutamate is an extremely important excitatory, neurotransmitter, but elevated concentrations of it can be toxic to neurons. Conversely, GABA is a main inhibitory neurotransmitter. Additionally, the action of noradrenaline is enhanced, which is known to affect concentration, alertness and memory (Purves et al., 2001). It is unknown if these changes in neuronal activity are easily reversible or if chronic dehydration has the same effect on neuronal activity in humans.

In humans, the evidence for the effects of chronic dehydration on cognitive performance is less robust. A study by Niehaus et al. (2002) found that children, living in Brazil, that have suffered from heavy bouts of diarrhoea in their first 2 years, a cause of dehydration, showed significant cognitive deficits when aged between 6 and 10 years. However, diarrhoea is also a serious cause of malnutrition so there are many nutritional factors other than dehydration that could affect cognitive performance. Additionally, there is some evidence that dehydration in young children and infants can cause brain lesions which may have permanent effects on cognitive performance. However, these studies looked at the effect of severe dehydration, caused by illnesses, on children requiring hospitalisation and not as a result of long-term mild dehydration (Finberg, Luttrell, & Redd, 1959; Macaulay & Watson, 1967).

There are no studies which have specifically investigated the prevalence of chronic dehydration in the population. Previous research investigating the effects of habitual low and high drinkers on physiology may give an estimate of the population that are consuming consistently low volumes of fluid and therefore are most at risk of being chronically dehydrated. In Perrier et al's (2012) study, from an original screening of 274 subjects, 39 participants met the criteria to be classified as a habitual low intake drinker, and kept to the protocol. To meet the criteria the low-intake drinkers needed to consume less than 1.5 L/d for 3 consecutive days. The low-intake drinkers drank a mean volume of 0.74 L/d and consumed 0.55 L/d of fluid in food, mean Uosm from 24 hour urine collections was 767 mOsm/kg. The Uosm score is under the commonly used dehydration threshold of 800 mOsm/kg but distribution of the Uosm scores shows that more than 45 % of the 39 participants had a mean Uosm ranging between 801and 1200 mOsm/kg. Thus, from the 274 subjects originally screened, a possible 6.4 % may be chronically dehydrated. Further research will need to carry out long term projects to determine the proportion of the population that is chronically dehydrated.

In summary, there is no empirical evidence to determine whether mild, chronic dehydration in humans causes long-term cognitive deficits in humans and if these cognitive deficits exist whether they can be reversed, in the short-term or over an extended period, by water consumption. Further research needs to be carried out to determine what proportion of the population may be chronically dehydrated, if their cognitive performance responds differently to water consumption in the short-term, compared to participants who are only temporarily dehydrated, and if euhydration can reverse cognitive deficits.

8.5 Potential Study Limitations

Potential limitations which are specific to each study have already been addressed in the relevant chapters and are listed below in Table 8.2.

Table 8.2
A Summary of Study Limitations.

Study	Limitations
1	Children able to go out to play between baseline and test. Possibility of cluster effects. Not exact replications of tasks used in previous literature. Difficult to control data collection in group testing environment.
2	Food and drink consumed before baseline estimated rather than recorded in detail. Breakfast food not regulated.
3	Used Uosm 800mOsm/kg as threshold for dehydration despite reservations as to the authenticity.
4	Problems with protocol adherence. Diet not regulated. The 3 case studies ranged in ages between 7 and 10 years old.
5	Reduced number of participants scored for handwriting quality. Reduced number of data for Figure Ground task due to timing error in administration. Design of finger tapping and bead threading task not replicated from previous studies. Difficult to control data collection in group testing environment.

This section will discuss two general issues which are not specific to one study but can be applied more generally to the water consumption research area. The study of the effects of water consumption on cognitive performance in both children and adults is in its infancy with very little previous research literature available. Furthermore, the study of the effects of water consumption on fine motor skills is completely original and unique. This is a new and exciting area of investigation with lots of scope for exploration but a potential limitation is the lack of comparative studies. However, the field of study into the effects of dehydration on cognitive and sports performance is much larger and well developed, thus, it has been possible to compare findings from my thesis to research in this area. It has been ensured that the method and design of the studies in this PhD are consistent with previous research, into the effects of water consumption on cognitive performance, so that findings from this thesis can be synthesized with previous work and a robust research literature developed. However, further research in this field is required to qualify the robustness of some of the findings in this thesis.

To ensure that the results of the effects of water consumption on task performance in this thesis could be compared to results from previous research (Bar-David et al., 2005) the same method of defining children as either dehydrated or euhydrated was used. Previous research has measured hydration status of participants by collecting and analysing urine samples and by labelling participants with a Uosm above 800 mOsm/kg as dehydrated, and participants with a Uosm of below 800 mOsm/kg as euhydrated or well hydrated. To be consistent this PhD also defined hydration status by measuring Uosm and used the same threshold to label participants dehydrated or euhydrated. However, it is acknowledged that there is little evidence to support that the cut-off of Uosm 800 mOsm/kg is significant in terms of effects on health or cognitive performance and as Uosm scores have a large inter-individual variation it is likely that thresholds of dehydration may differ from person to person. It is suggested that an alternative method of measuring hydration status and defining participants as dehydrated or hydrated be used in further studies. This is discussed further in section 8.6

8.6 Further Work

Researching the effects of hydration status or self-rated thirst on fine motor skills and cognitive performance in children is an area of research still in its infancy. Thus the findings in this thesis are suggestive, rather than conclusive and open up numerous avenues for future empirical work. Ideas for future work have been proposed throughout this thesis and in the preceding paragraphs and this section will clarify some of those ideas and unanswered questions.

A major question that has arisen is, how best to measure hydration status in studies that assess the acute effects of drinking on cognitive and motor performance? In the design stage of this thesis and when planning study 3, urine osmolality scores were deemed the best measurement but the findings have shown that it is not effective in showing small changes to hydration in a short time period. Recently published research (Perrier et al., 2013) suggests that measurement of urine osmolality from 24 hour collection is the best method for day to day hydration status. However, a 24 hour method is not effective when trying to measure small, acute changes and when trying to assess whether these small changes make a difference to cognitive performance. New approaches will need to be tested in future work.

Additionally, the sensation of thirst, its relationship to hydration status and a definition of how an individual rates their sensation of thirst, needs further investigation. An understanding of the thirst sensation is required because research suggests that self-rated thirst may affect cognitive performance. Previous work and work presented here, suggest that reaction time and visual attention may be sensitive to different levels of self-rated thirst, thus inferring that a change in thirst may consequently result in a change in cognitive performance (study 2; Edmonds, Crombie & Gardner, 2012). An experimental manipulation of an individual's self-rated thirst, to explore the effect on cognitive performance further, can only be made reliably, if the mechanism for perception and recognition of thirst is fully understood.

To date, little is known about how the brain functions during dehydration, and why changes may impact on motor skills and cognitive performance. Although theories have been suggested as to why performance deficits occur during a dehydrated state, there has been very little targeted research observing functional brain activity changes. Further studies using techniques to study brain activity whilst performing tasks, under conditions of dehydration and hydration, need to be conducted.

This thesis has studied the acute effects of water consumption on mood, motor skills and cognitive performance. However, there is a need to study the long-term effects of water consumption on mood, motor skills and cognitive performance, particularly if a large proportion of the public are chronically dehydrated (Gandy, 2012). Furthermore, if neuronal activity has changed due to chronic dehydration, as suggested in Di and Tasker's (2004) study, it needs to be determined whether long term increases in water consumption can reverse these changes.

The future research areas discussed above are all big research questions. However, this thesis has also left some smaller but still very important avenues of study to be carried out. In study 1, children that had a drink of water threaded more beads than children that did not have a drink. This result was not replicated in study 5. Additionally, in study 5, there was trend toward faster finger tapping in those children that had a drink compared to those children that did not have a drink, whereas in study 2 when children had a drink they tapped their fingers significantly faster. Further studies need to be carried out to discover whether the effect of water consumption on bead threading and finger tapping can be replicated. Furthermore, as the writing task was only introduced in study 5 a replication of this study also needs undertaking.

8.7 Conclusions

In conclusion, water consumption has been observed to affect children's performance on tasks requiring motor speed. This effect is not moderated by self-rated thirst or a change in mood or motivation as a result of being given a free bottle of water. These findings have not previously been reported and provide new and original knowledge.

It is speculated that dehydration impairs motor speed performance and that water consumption reverses this effect. Children that are dehydrated may have to make more effort in order to achieve the same level of performance as children that are euhydrated. This additional effort demands more resources and once these resources are exhausted performance begins to plateau or worsen (Kempton et al., 2011). As a large proportion of children appear to arrive at school in a dehydrated state (Barker et al., 2012; Stookey et al., 2012), the reversal of negative effects of dehydration could potentially benefit a large percentage of children.

Tasks requiring motor speed, such as handwriting, are essential in a classroom environment. Thus it is hoped, that if the results from this thesis can be replicated, it will motivate both teachers and parents to encourage children to drink more fluid both before school and during the school day. Furthermore, motor speed is also essential to many adults in their daily lives, being key, for example, in typing on a keyboard, thus the results from this thesis are relevant to a large proportion of the general population.

Additionally, self-rated thirst was found to have an effect on the number of go errors in the StopSignal task. This effect seemed to not be dependent on hydration status. These results and results from previous literature (Edmonds, Crombie & Gardner, 2013; Rogers et al., 2001) suggest that the sensation of thirst may distract participant’s attention and thus task performance deteriorates.

No effects of hydration status or thirst were found on any other cognitive domains. However, as so few studies have been carried out in this area it is too early to come to any strong conclusions. Further research should investigate whether task performance improved by water consumption may be due to an increase in motor speed or attenuation of a distraction due to high levels of self-rated thirst, rather than an effect on any other cognitive domains.

Another important finding is this thesis was that urine osmolality is not the most appropriate measure of small changes in hydration status over a short period of time. Furthermore, measures of self-rated thirst, in children, are not associated with urine osmolality measures or volume of fluid consumed. These findings will be useful when designing further studies in this area of research and interpreting results from previous studies.

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Appendices

Appendix I: Example of Parent and Children's Information and Consent Form

A scientific study at school.

Parent and Children Consent Form

I have read and understood the information sheet relating to the study (see attached parent and child information sheets)

The nature and purposes of the research, as well as the procedures involved have been explained to me, and I have been given the opportunity to discuss these, and the opportunity to ask questions about them.

I understand that any involvement in this study and any data collected from this study will remain strictly confidential. I understand that only the researchers involved in this study will have access to the data. I understand what the data may be used for once the research programme has been completed.

I understand that I/my child will not participate in the study if I do not consent. I/my child will have the right to end the assessment session at any time.

I hereby freely declare that I give consent for myself/my child to participate in this study.

Having given this consent I understand that I have the right to withdraw myself/ my child from this study and the right to withdraw any of my/our child's data from this study at any time and without being obliged to give any reason.

PLEASE COMPLETE AND RETURN TO SCHOOL

Children's Consent Form

Do you wish to take part in the study.

I do ☐

I do not ☐

My name:………………………………………………………………………………………

Parent's Consent Form

I do / do not give permission for my child to participate in this study (please circle your response)

Child's Name: ....

Parent's Name: ....

Parent's Signature: ....

Date: ....

Assessing the effects of drinking water on cognitive performance and mood.

Parent Information Sheet

Overview
Have you ever heard that it is "good for you" to drink water? This study based at the University of East London is trying to see if drinking water improves children's school work and behaviour or not. We aim to conduct the study in schools as part of the normal school day. We hope that this study will provide important information that could help children to do better in school.

What will happen?
If you agree to let your child take part, testing will take place individually on two mornings as part of the normal school day. Your child will be asked to complete a number of fun tasks but on one day they will be provided with a new sealed bottle of water to drink, and on the other day they will not. The tasks involved assess different types of skills, including memory and how quickly and efficiently the children can process information. An example of a processing task is a "reaction time" task, in which children are asked to hit a key on a computer keyboard when they see a certain type of shape or number on the computer screen. We will also assess the child's level of thirst by asking them to make a mark on a line that has cartoon pictures at either end depicting different extremes of thirst. We have used this and similar tasks in previous studies and children generally find them fun to complete.

We will also be assessing your child's level of hydration. Before testing, your child will be asked to go to the toilet. A portable bidet will be fitted in the toilet, under the toilet seat, to collect the urine. Thus, your child uses the toilet in the normal way, and on their own. Once the child has finished and has left the toilet cubicle, a sample of this urine will be collected by the researcher for analysis. Another urine sample will be collected using this method after testing. The samples will be tested for hydration status; they will not be tested for anything else and will be disposed of immediately after analysis.

Any effects of drinking water may be affected by the children's diet. Therefore, we will ask your child what they have eaten and drank before coming to school.

How long will each session last?
The testing will last for about 1 hour and will take place on two separate days. The testing will begin at the start of the school day and be finished before break-time.

What happens to the data?
Your child will write their answers in an answer booklet. Once this has been handed in, the front page (containing identifiable data e.g. their name) will be torn off and stored separately, thus your child's personal information will not be on their answer booklet. The booklet will have a code written on it so that individual data can be withdrawn at a later stage if necessary, but only the researchers will know this code. We will enter the information given

in the answer booklet, along with other information such as the child's age and gender. This is done to ensure that their data is anonymous. All electronic files will be password protected and all paper files will be stored in a locked room where only the researchers have access. All individual data will be combined with that of other children and analysed as part of a group. The results may be published in scientific journals but individuals will not be identifiable in these. Data obtained from the project will be kept for up to ten years, however once it is no longer needed it will be destroyed by deleting electronic files or shredding paper data.

Ethics and safety

This study has been approved by the University of East London Ethics committee. These committees are independent of the study and exist to ensure that the procedures we use are ethical, safe and appropriate. All our researchers have CRB clearance to work with children. We are very concerned about the safety of children who take part in our studies. In the unlikely event that a child were to become upset at any point during a procedure we will stop it immediately. Children have the right to end an assessment session at any time.
You are under no obligation to permit your child to take part in this study.
If you have any queries regarding the conduct of the programme which your child is being asked to participate in, please contact the Secretary of the University Research Ethics Committee: Ms D Dada, Administrative Officer for Research, Graduate School, University of East London, Docklands Campus. London E16 2RD (telephone 0208 223 2976, email d.dada@uel.ac.uk).

What happens next?

If you would like more information before agreeing to allow your child to participate in this research, please contact the study's Postgraduate: Paula Booth, School of Psychology, University of East London, London, E15 4LZ (telephone 0208 223 4589, e-mail p.booth@uel.ac.uk).

If you are happy for your child to take part in this study please complete and return to school the parent consent form attached.

Thank you in advance for your interest in this study
Your contribution is highly appreciated.

A Scientific Study

Children's Information Sheet

Hi. I work at the University of East London in the Psychology Department. I am going to come to your school to run a scientific study which will look at how you might be able to

do better in your school-work. If you agree to take part, I will see you on two mornings. I will ask you to do some tasks on a computer and some on paper. All the tasks are short and fun and you will enjoy doing them.

Before you start the tasks, and after you have completed them, I will ask you to go to the toilet. You will go to the toilet in the normal way and nobody will come into the cubicle with you. There will be a bowl under the toilet seat to collect urine. When you come out of the toilet cubicle I will collect a urine sample from the bowl.

A number will be put on your urine sample. The same number will be put on your task results so I won't know which task results are yours. No-one else will see the task results after you have filled it in, not your teachers or your parents. This means that you don't have to be nervous, these tasks are meant to be fun, they are not a test.

The University of East London Ethics committee has checked that this study is fun and safe for you to take part. I am very concerned about your happiness and in the unlikely event that you were to become upset at any point during the study I will stop it immediately. You have the right to end a session at any time.

If you would like to take part in this study please fill in your name on the consent form and return it to school.Please ask your mum, dad or carer to fill in the consent form.

Appendix II: Copy of Ethics Approval Letter

University of East London

Dear Dr Edmonds,

<u>Application to the Research Ethics Committee: The Effects of Water Consumption on Schoolchildren's Cognitive Function and Mood and Behaviour (P Booth)</u>

I advise that Members of the Research Ethics Committee have now approved the above application on the terms previously advised to you. The Research Ethics Committee should be informed of any significant changes that take place after approval has been given. Examples of such changes include any change to the scope, methodology or composition of investigative team. These examples are not exclusive and the person responsible for the programme must exercise proper judgement in determining what should be brought to the attention of the Committee.

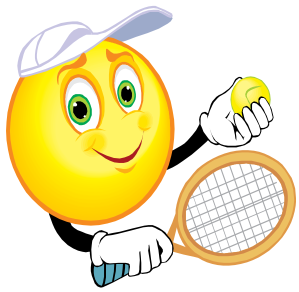
In accepting the terms previously advised to you I would be grateful if you could return the declaration form below, duly signed and dated, confirming that you will inform the committee of any changes to your approved programme.

Yours sincerely

Debbie Dada
Admissions and Ethics Officer
Direct Line: 0208 223 2976
Email: d.dada@uel.ac.

Appendix III: Example of Visual Analogue Scales for Rating Fatigue and Happiness

How are you feeling?



Very Tired Not Tired

Sad Happy

Appendix IV: Example of Object Recall Sheet

Appendix V: Example of the Digit Span Task.

	Trial 1/ Response	Score	Trial 2/ Response	Score	Item score 0,1 or 2
1	2-9		4-6		
2	3-8-6		6-1-2		
3	3-4-1-7		6-1-5-8		
4	8-4-2-3-9		5-2-1-8-6		
5	3-8-9-1-7-4		7-9-6-4-8-3		
6	5-1-7-4-2-3-8		9-8-5-2-1-6-3		
		Digits max forward score =12			

Appendix VI: Timetable of Testing for Study 1

	CLASS A	CLASS B	CLASS C
Tues 1 Feb			
10.00am	Testing (30 mins)		
10.30 am	Given intervention (by assistant)		
10.45 PLAYTIME	Intervention removed		
11.00	Testing (30 mins)		
HOMETIME			
Wed 2 Feb			
10.00am		Testing (30 mins)	
10.30am		Given intervention (by assistant)	
10.45 PLAYTIME		Intervention removed	
11.00am		Testing (30 mins)	
HOMETIME			
Thurs 3 Feb			
10.00am			Testing (30 mins)
10.30am			Given intervention (by assistant)
10.45 PLAYTIME			Intervention removed
11.00			Testing (30 mins)
HOMETIME			

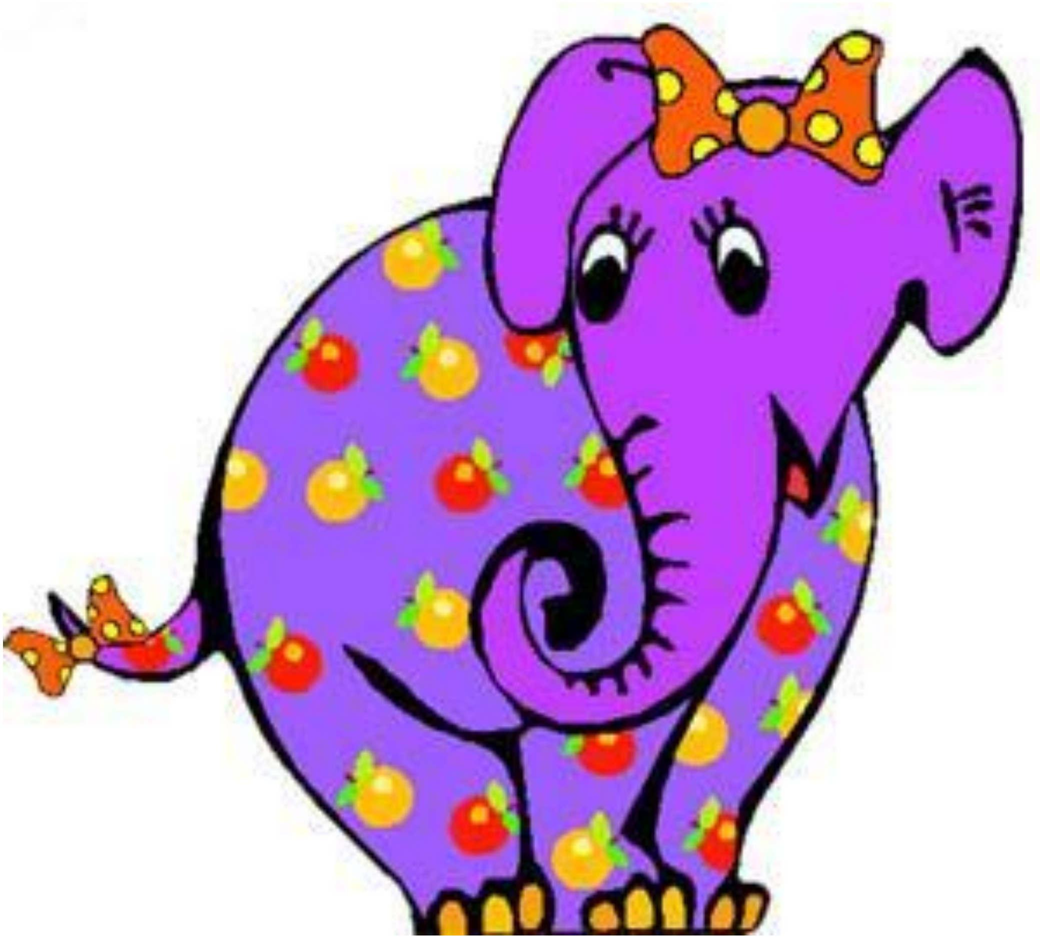
Appendix VII: Example of the Letter Cancellation Task

Spot the ‘C’ task

U	U	U	U	C	U	U	U	U	U	U	U	U	U	V	U	U	O	U	U
U	C	U	U	U	U	C	U	U	U	U	U	U	U	U	U	U	U	U	U
U	U	O	U	U	U	U	U	U	U	U	U	U	C	U	U	O	U	U	U
U	U	U	V	U	U	U	U	C	V	U	U	U	U	U	U	U	U	C	U
C	U	U	U	V	U	U	U	U	U	C	U	U	U	U	O	U	U	U	V
U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	C	U	U
U	U	U	U	C	U	V	U	U	U	U	U	O	U	U	C	U	U	U	U
U	U	O	U	U	O	U	U	U	U	U	U	U	U	U	U	U	U	U	U
U	U	C	U	U	U	U	U	C	U	U	U	U	V	U	U	C	O	U	U
U	O	V	U	C	U	U	U	U	U	U	U	O	U	U	U	U	U	U	U
U	U	C	U	U	O	U	C	U	U	V	U	U	U	U	U	U	O	U	U
U	V	U	U	C	U	U	U	O	C	U	U	U	O	U	U	U	U	V	U
U	U	O	U	U	U	U	C	U	U	U	U	U	C	O	U	U	U	U	U
O	U	U	U	U	U	O	U	U	U	U	C	U	U	U	U	U	U	U	C
C	U	U	U	U	U	U	U	C	O	U	U	U	U	U	V	U	U	O	U
U	U	U	O	U	C	U	U	U	U	U	O	C	U	U	U	C	U	U	U
C	U	U	U	U	U	U	U	U	U	O	U	U	U	C	U	U	U	U	U
U	O	U	U	C	U	U	U	U	U	C	U	U	U	U	U	C	U	U	O
U	U	U	C	U	U	U	U	U	O	C	O	U	U	U	U	U	U	U	U
U	U	U	U	U	U	C	U	U	U	U	U	U	C	U	U	C	O	U	U

Appendix VIII: Example of the Spot The Difference Task

Spot the difference task



Appendix IX: Example of the Food Diary

Day 1 Code........................ Date..................................

Time	Type of Food	Amount or Weight
Example *13.00*	*Cheese sandwich*	*2 slices white bread* *2 slices cheddar cheese* *margarine*
14.35	*strawberries*	*x4*

Appendix X: Example of the SOS-2-EN (Smits-Engelsman,Bommel-Rutgets & Waelvelde, 2014).

the sun is warm
we have a dog
this dog is quick
a fox jumps high
but we feel lazy

The wind was blowing, moving the leaves. The children stood watching them fall. Out of all the leaves, most fell on my car.
The candy store, which was close to my house, was painted blue. I walked in and I was amazed: look at all the different options! I picked a dark chocolate; it melted in my hand.

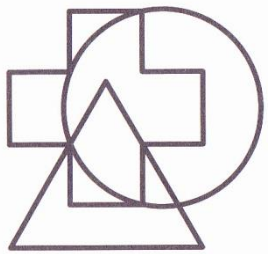
I was too far away; I moved closer, so that I could see. One of the other kids watched me. He signalled that I, too, should join their group.
I listened to them laughing and talking happily. I was pleased because they had asked me to join them. I smiled and then I asked them their names.

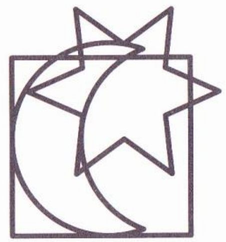
There was a lot of noise, they all spoke in unison, and they told me their names. I said, "I didn't hear each one!", and laughed. The oldest kid looked at me kindly and wanted to know if I was from their block. "Yes, I just moved here," I said. "Then welcome to our group!" he said.

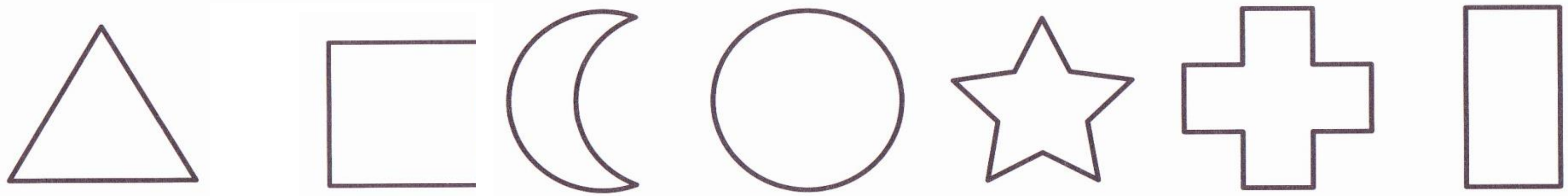
We all tried to think of a game that we could play together. I had a xylophone and I wanted them to sing while I played a song. Some of the others wanted to go to the zoo. After a long discussion, we came to a decision: we would make paper sailboats and sail them at the pond. We decided to separate into smaller groups, to look for materials: paper and other things. But then, it started to rain. So, with my new friends, we laughed and talked while we ran to my house to think of new ideas!

Appendix XI Example of Pages from the Figure-Ground Task Booklet

CODE ....

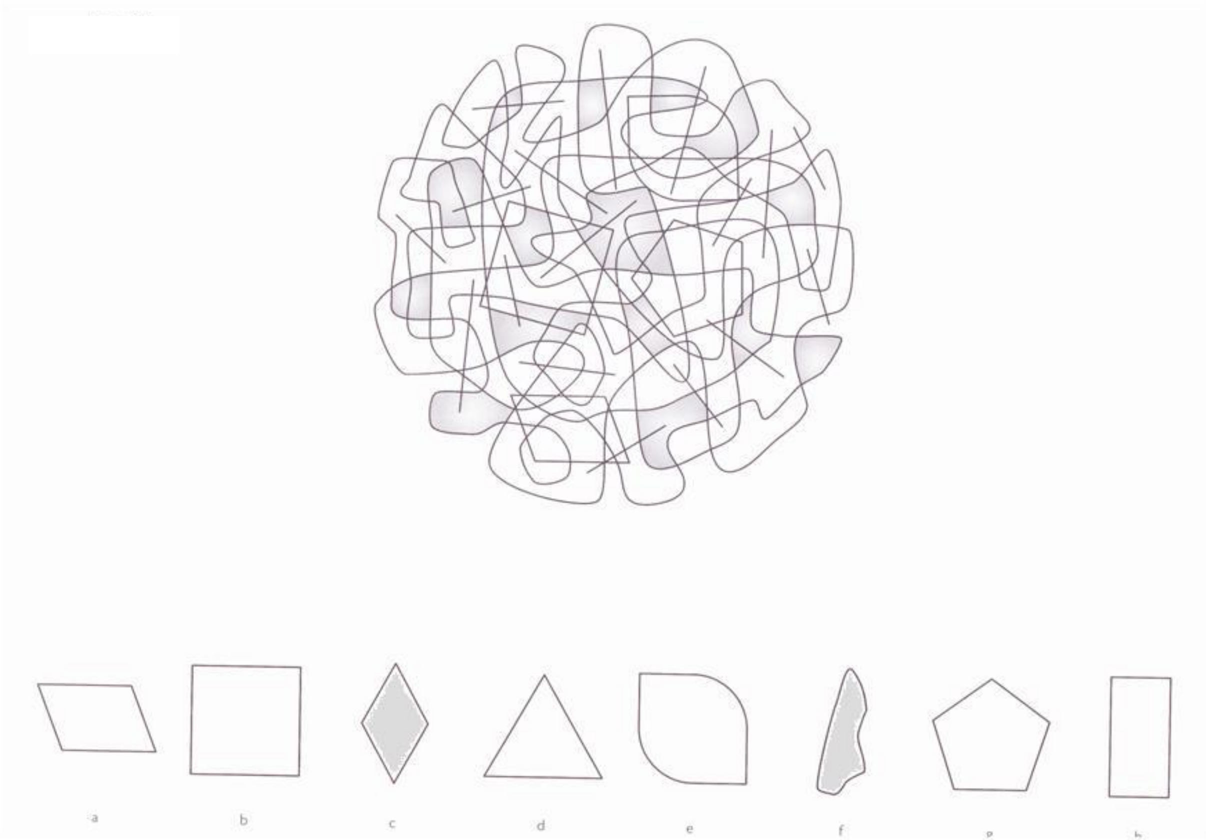






a b c d e f g

Appendix XI Example of pages from the Figure-Ground task booklet



Appendix XII Instructions to Parent

Approximate Time	Instructions
After waking	• Attach podometer to clothes • Record All Food and Drink
9-10am	• Please collect a urine sample after breakfast (between aprox. 9am and 10am) • It should NOT be the first void of the day. • Write the number 1 and the date on the specimen tube. Store it in the freezer • Day 3-5 –researcher to come and do testing
Next 3 hours	• Record all food and drink
12 – 1pm 3 hours after 1st urine sample	• Please collect a urine sample BEFORE LUNCH • Write the number 2 and the date on the specimen tube. Store it in the freezer • Day 3-5 – researcher to come and do testing
Next 3 hours	• Record all food and drink
3 – 4pm 3 hours after 2nd urine sample	• Please collect a urine sample • Write the number 3 and the date on the specimen tube. Store it in the freezer
Remainder of the Day	• Record all food and drink
End of the Day	• Detach podometer. Write score at the bottom of the food diary. Reset the podometer to zero.