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A Multimodal Approach to Measure the Distraction Levels of Pedestrians using Mobile Sensing

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Abstract

The emergence of smart phones has had a positive impact on society as the range of features and automation has allowed people to become more productive while they are on the move. On the contrary, the use of these devices has also become a distraction and hindrance, especially for pedestrians who use their phones whilst walking on the streets. This is reinforced by the fact that pedestrian injuries due to the use of mobile phones has now exceeded mobile phone related driver injuries. This paper describes an approach that measures the different levels of distraction encountered by pedestrians whilst they are walking. To distinguish between the distractions within the brain the proposed work analyses data collected from mobile sensors (accelerometers for movement, mobile EEG for electroencephalogram signals from the brain). The long-term motivation of the proposed work is to provide pedestrians with notifications as they approach potential hazards while they walk on the street conducting multiple tasks such as using a smart phone.

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1. Introduction

Over the last decade, the usage of smart mobile phones has increased exponentially, which has led to these devices becoming an integral part of people's daily lives, such as shopping, banking, social media interaction, playing games, listening to music or even watching movies. The ubiquitous nature of the

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services provided by a smart phone allows the end user to engage with them on the go. Recent statistics show that over 68 percent of the world's population own a mobile phone, this is expected to increase to 72 percent by 2019 [1]. Even though these devices offer convenience, they also pose a threat to the safety and well-being of the end users. Studies have shown that pedestrians have slower reaction times and decreased situation awareness whilst using a mobile phone, thus they are also more prone to be involved in motor vehicle collisions [2, 3]. This is a concern, as the increase in the availability of mobile phones naturally leads to an increase in the time spent using them, and the number of injuries related to mobile phones usage is also likely to increase [4]. Being able to understand and recognise the impact of distractions can be complex, as many researchers have attempted this by collecting and interpreting data from multiple sensors. The work in this paper looks to build on existing work, with the emphasis on the relationship between the data captured from body movements (accelerometers) and the signals from the brain (mobile EEG) and muscles (mobile EMG). This paper proposes a multi-modal based approach that measures the different levels (with and without a mobile phone) of distraction encountered by pedestrians whilst they are walking. A series of experiments have been conducted to measure the levels of distraction while walking on the street. The novelty aspect of this work is the adoption of a *multimodal approach* where data has been analysed from mobile sensors such as accelerometers, surface EMG (i.e. muscular) and scalp EEG (i.e. brain) signals captured from a mobile EEG unit. The remainder of the paper is organised as follows. Section 2 provides an overview of the related literature, while Section 3 describes the key characteristics of the proposed approach. Section 4 describes the user study and experimental set up followed by the results in Section 5 that validate the findings of the proposed work.

2. Related Work

A study by Nasar and Troyer [4] compared the number of injuries between drivers and pedestrians who were using a mobile phone while walking and driving. This study revealed that the number of injuries among pedestrians in the USA was around 1506. The nature of these injuries ranged from contusions to fractures around different parts of the body (e.g. head, limbs, back, chest). The number of mobile phone related injuries to pedestrians is likely to increase due to the surge in mobile phones, as in 2017 the population of people with mobile phones reached 4.77 billion worldwide and 53.7 million in the United Kingdom [1].

Gallahan et al. [5] developed a system to reduce distractions encountered by drivers by inferring potential distractions based on the head and neck movement of the driver. This system was based on the deployment of a series of sensors that detected movement in the head and upper skeleton. An example of the detected movement would be reaching an object, talking on the phone or looking away from the road. If any of these movements was constant for more than 2 seconds then the system would alert the drivers by using sounds at different frequencies. A limitation of this system is the potential false positives that could be generated given the neck movement, and the inclusion of motion capture and eye tracking would improve distraction recognition results.

EEG signals have been used in another study [6] to measure attention during controlled movements. This study recorded these signals in three different conditions: sitting, cycling and walking. Beside EEG, EOG and EMG signals have been also acquired as references for the event related potentials measuring cognitive activity reflecting the attention. It was claimed that the available approaches of measuring attention during movement were not adequate, as kinematic research study have mainly concentrated on the employment of the motion sensing systems. These systems are accurate and can provide a quantitative approach, however they do not provide an effective brain activity acquisition to measure the attention. Hence the work by Killane et al [6] measured the cortical activity through the amplitude and latency of potentials related to externally cued auditory events: same levels of attentions were observed in all the performed experimental conditions, suggesting this as a valid method to investigate attention during gait. However, this work did not show the relationship between gait and attention and how it could benefit the monitoring of mobile activities.

Pedestrians can be distracted on the road by approaching vehicles, especially during crossing. Hamaoka et al. [7] analysed the head movement of pedestrians crossing the road while a vehicle was approaching them. The frequency of the turning head increased at the beginning of the crosswalk and at unfamiliar points. This frequency also changed based on the time (day-night) and the people (young-elderly). Therefore, pedestrians safety can be ensured based on some key locations that can be used to determine the vehicle approaching. In another study [8], mobile phone were used to detect attention, gait phase and gait velocity approaches, which however took a long time to detect changes as in need for an accurate step detection to be implemented at the same time, which made immediate detection not possible.

Another example of driver distraction related work was conducted by Mizoguchi et al. [9], who however utilised only eye-movement data whereas the use of multiple sources would have provided more meaningful results. For example, the inclusion of EEG signals could have enhanced the recognition of the distraction. Zaki et al. investigated the possibility of detecting pedestrians level of distractions by using their gait parameters [10]: it was indeed stated that walking patterns can be changed based on the complexity of which activity is being conducted. The distracted behaviour was recognised based on the analysis of video dataset, but this data was again only one dimensional and the use of a richer dataset from multiple sources would have enhanced the recognition process. In [11] the pedestrian distraction data was manually collected through monitoring the crossing and analysis showed that using mobile Internet is more likely to lead to traffic accidents among the young pedestrians. It was found that the use of the phone can lead to significant alterations in the walking patterns and body posture [12].

Schwebel et al. investigated the impact on the safety of pedestrians while they used their mobile phones without considering the cognitive demands and the effects of distraction [13]. Also, mobile internet on the go can have an impact on the daily life of people and can lead to distraction while walking in different environments. This type of distraction leads to delay in crossing, missed safe chances to cross, longer time to initiate a cross, looking away for longer time, thus to an increasing possibility to be hit by the coming vehicle [14, 15]. Young people were not affected by changing the environmental setting (high distraction level) while texting and walking, which leads to growing concerns about the safety of these pedestrians [16, 17].

EEG signals have been captured in [18] to evaluate 42 drivers distraction levels in a simulated driving sessions: the results showed that the cognitive assignment distracted the drivers and affected their driving performance. This study was conducted in a simulated environment without any pedestrians, therefore a higher distraction level is expected in the real urban environment. EEG signals have also been captured to assess the brain activity against musical distraction within different conditions [19]. Another study showed that measuring the EEG signals in a real environment represents a challenge within the increment of the brain load cognitive activity [20].

Uemura et al. [21] deployed a method based on acceleration sensing to detect distracted pedestrians walking while consuming working memory. It was assumed that the pedestrians go through the distracted state when working memory is highly used, which leads to divert the walking pattern from normal. However, to test this hypothesis subjects were simply asked to "think about something" which might not be enough distractive as the consumption of working memory varies widely based on other simultaneous brain activities (e.g. talking) and the personality of the participants. Besides that, this work did not capture EEG signals to recognise distracted pedestrians, and it did not distinguish different levels of distraction. Moreover, people with disabilities would be discriminated by only using the acceleration sensor.

The objective of the work described in this paper is much the same as that of the approaches mentioned above, however the proposed work extends existing work by adopting a *multimodal approach*, where data has been captured and analysed from multiple sensors such as accelerometers, mobile EEG and EMG unit.

3. Distraction Recognition

The *multimodal approach* that has been proposed in this paper for distraction recognition is based on three sub components: modeling walking behavior, brain activity modeling and analysis, which is based on a correlation phase and working memory.

3.1. Modeling Walking Behavior: Extraction of Gait Measurements

First of all various gait parameters are recorded in order to model the walking behavior. The parameters selected were based on data extracted from Force Sensing Resistor Sensors (FSRs), accelerometers and gyroscope. These gait measurements are used to differentiate various gait patterns. It is assumed that if the pedestrian is distracted then the most reliable indicator could be the change in the walking behavior. The walking behavior is also influenced by the leg muscle activities and the decrease in these activities would be an evidence of less control of the lower limbs. These activities were modeled from the right and left Tibialis Anterior (TA) and Soleus using EMG measurements. All these measurements could lead to dependable gait properties for modeling and extricate walking patterns.

3.2. The Brain Activity Modeling: EEG Signal Extraction

The brain wave patterns are commonly considered helpful in order to obtain the type and location of the activity in the brain during a task. One of the accepted methods is electroencephalography (EEG) that is an electrophysiological recording technique able to non-invasively record electrical activity of the brain. Changes across conditions of the intensity of the EEG oscillatory waves as expressed through measures of mean Power Spectral Density (PSD) in the Frequency bands of Interest (FOI) of θ (4-7 Hz), α (8-12 Hz) and β (15-30 Hz) could provide decisive results. The quantitative Electroencephalography (qEEG) brain map are considered in this study.

3.3. Analysis: Correlation Phase and Working Memory

The EEG and EMG data recording is synchronized to heel strikes, pre-processed and eventually segmented into epochs (capturing a full stride). The Root Mean Square (RMS) of each muscle activity is calculated epoch-by-epoch and then averaged across epochs. The EEG mean Power Spectral Density (PSD) in the Frequency bands of Interest (FOI) of θ (4-7 Hz), α (8-12 Hz) and β (15-30 Hz), is calculated for each epoch, and then averaged across epochs for correlation.

The PSD in one Region of Interest (ROI) including pre-frontal and frontal electrodes (PFC) is considered for each FOI during different walking conditions. Statical analysis (such as T-test, etc) could provide critical insight: paired-samples t-Tests were here employed to assess statistical differences between the two walking behaviors (i.e., distracted and non-distracted) for each one of the aforementioned gait, muscular and neural variables.

4. User Study and Data Collection

In this user study, the participants were asked to complete two scenarios: *Single Task (ST): Natural Walking*, during which subjects completed a round of walk without engaging with any secondary task, and a *Dual Task (DT) : Walking & Texting*, during which subjects a round of walk while using a smartphone to reply to an email.

4.1. Experimental protocol

Fourteen right-handed healthy young adults [age mean (\pm standard deviation; SD) = 25 (\pm 3), 5 male/9 female] with no previous history of neurological or gait disorders, volunteered for the study by giving written informed consent. The study was approved by the University of East London Ethics Committee (UREC-1415-29) and all experiments were conducted in accordance with the Declaration of Helsinki. Experiments were conducted at the University of East London, Stratford Campus. Subjects were first prepared in the laboratory room and then guided outside into the garden of the campus. Subjects walked along a predefined path naturally or texting with their smartphone. To standardise the dual-task condition, subjects read and replied to a standard email. In each condition, subjects walked the predefined path twice covering a total distance of 200 metres.

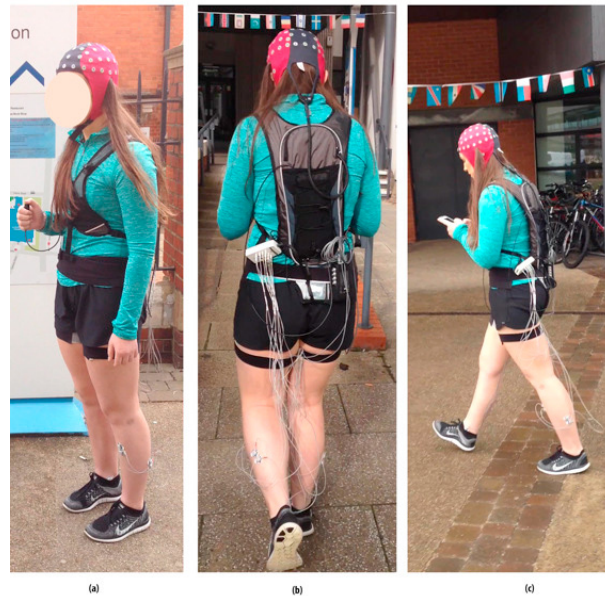


Fig. 1: A typical participant wearing high-density 64 channel Waveguard Cap and other measurement sensors. (a) Front view , b) Back view and (c) Walking & texting during experiment.

4.2. Experimental Setup

The fully mobile setup allowed the recording of brain activity via a high-density 64 channel Waveguard cap (ANT Neuro, Enschede, Netherlands), as well as of muscles activity from the right/left Tibialis Anterior and Soleus by superficial electrodes. EMG and EEG activities were simultaneously recorded by an EEGoPro amplifier (ANT Neuro, Enschede, Netherlands) at a sampling frequency of 1 kHz. During the recording, EEG data were referenced to the FCz channel and electrodes impedances were kept below 5 kOhm. A Samsung Galaxy S4 mini smart phone was fixed at the subject's lower back with an elastic belt and data from its internal accelerometers and gyroscope were recorded at a frequency of 200 Hz. Data from two digital Force Sensing Resistor Sensors (FSRs), placed underneath the subject's heels to detect times of heel strikes, were recorded at 1 kHz by a 14 bit analog-to-digital converter fixed at the subject's hip by the elastic belt. A digital button was also connected to the converter and pressed by the subject at the beginning and at the end of each condition to define time points of start and finish. Elastic bands were also placed around the subject thighs to fix the cables of contact switches and surface EMG electrodes to prevent the subject from falling (see Figure 1). Data synchronization between the different devices was obtained by sending a common TTL pulse at the beginning and in the end of the recording, further used to realign the time axes.

5. Results and Discussion

After the experiment, the raw data was collected and paired-samples t-test were performed to assess statistically significant changes in walking behaviour, EMG and EEG activities across the two experimental conditions. Table 1 shows a total of seventeen measures of gait for both scenarios (Single Task (ST): Natural Walking and Dual Task (DT) : Walking & Texting). It can be seen that twelve p value are below 0.05, depicting that these are statistically different between the two conditions, with a decrease of performance when walking while using the mobile phone.

Table 2 shows the condition-by-condition root mean square (RMS) results of the right and left Tibialis Anterior (TA) and Soleus obtained from surface EMG measurements. It can be seen from the statistical

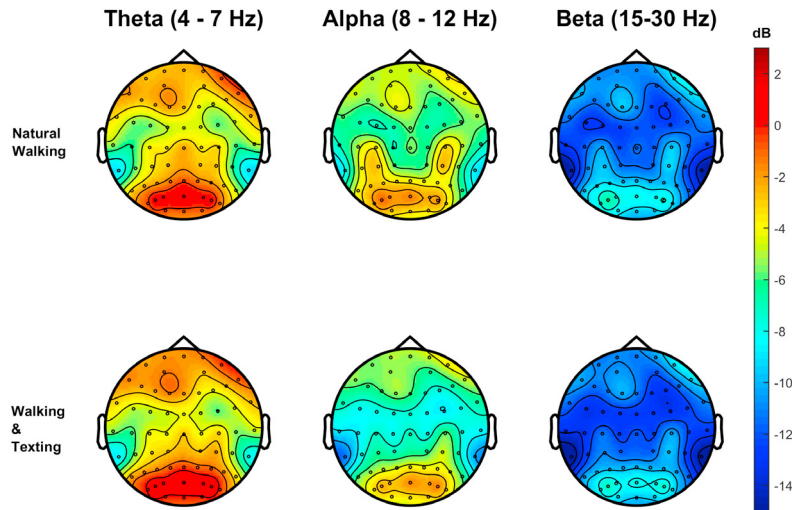


Fig. 2: The Quantitative Electroencephalography (qEEG) brain mapping of a typical participant during Single- and Dual-task conditions; i.e., Natural Walking and Walking & Texting.

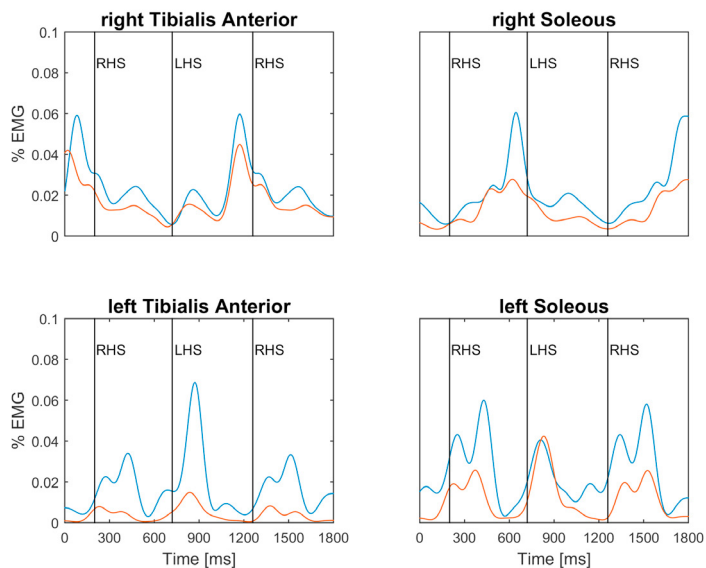


Fig. 3: A typical participant's muscle activity recorded from the right/left Tibialis Anterior and Soleus by surface electrodes.

analyses run on these muscle activities that muscular correlates of the gait pattern were significantly impacted when walking while using the mobile phone. Figure 3 shows the Single- and Dual-task conditions EMG profiles from each muscle for a typical subject. It can be seen that texting while walking has considerable impact on the gait. Table 3 shows the average power spectral density (PSD) across subjects for the region of interest PFC = (Pre-) Frontal Cortex for each frequency band of interest; i.e., θ (4-7 Hz), α (8-12 Hz) and β (15-30 Hz). A slight decrease of activity is observed when walking and texting in com-

Table 1: **Single- and Dual-task conditions gait measures.** Condition-by-condition (n = 2) mean (± std) of the measures of gait of interest. Paired-samples t-Test t- and p-values are reported in the last two columns on the right and significant comparisons are highlighted with *.

Measures of gait of interest	Single Task (ST): Natural Walking	Dual Task (DT) : Walking & Texting	t - value	p - value
Stride Duration (ms)	1054 (±87)	1106 (±107) *	-3.793	0.002
Cadence (step/min)	107 (±10)	99 (±16) *	2.772	0.016
Mean Step Length (m)	0.53 (±0.06)	0.51 (±0.07)	1.370	N.S.
Velocity (m/s)	0.90 (±0.10)	0.78 (±0.12) *	6.847	0.001
Vertical(Ver)-RMS	2.65 (±0.56)	2.26 (±0.63) *	4.880	0.001
Medio-Lateral(ML) RMS	1.48 (±0.32)	1.37 (±0.40) *	3.100	0.008
Antero-Posterior-RMS	2.19 (±0.28)	0.96 (±0.33) *	4.848	0.001
Vertical(ver)-RMSR	0.70 (±0.05)	0.67 (±0.06) *	2.325	0.037
Medio-Lateral-RMSR	0.40 (±0.07)	0.41 (±0.08)	-1.674	N.S.
Antero-Posterior(AP) RMSR	0.59 (±0.06)	0.60 (±0.06)	-1.910	N.S.
Ver-Step Regularity	0.75 (±0.09)	0.69 (±0.13) *	2.700	0.018
Ver-Stride Regularity	0.75 (±0.07)	0.65 (±0.16) *	2.802	0.015
Ver-Symmetry	0.03 (±0.02)	0.06 (±0.04)	-2.085	N.S.
AP-Step Regularity	0.76 (±0.09)	0.71 (±0.09) *	3.542	0.004
AP-Stride Regularity	0.72 (±0.08)	0.65 (±0.12) *	3.061	0.009
AP-Symmetry	0.03 (±0.02)	0.07 (±0.05) *	-2.418	0.031
ML-Stride Regularity	0.46 (±0.20)	0.35 (±0.16)	2.078	N.S.

Table 2: **Single- and Dual-task conditions EMG measures.** Condition-by-condition (n = 2) mean (± std) of the measures of Root Mean Square (RMS) for each lower limb muscle. Paired-samples t-Test t- and p-values are reported in the last two columns on the right and significant comparisons are highlighted with *.

Muscle RMS [a.u.]	Single Task: Natural Walking	Dual Task: Walking & Texting	t-value	p - value
Right Tibialis Anterior	0.03 (±0.01)	0.02 (±0.01) *	3.653	0.003
Right Soleus	0.023 (±0.01)	0.02 (±0.01) *	2.855	0.014
Left Tibialis Anterior	0.02 (±0.01)	0.02 (±0.01)	2.158	N.S.
Left Soleus	0.02 (±0.01)	0.01 (±0.01) *	3.256	0.006

Table 3: **Single- and Dual-task conditions Power Spectral Density (PSD) measures.** Average PSD (mean (±std)) across subjects (N = 14) is here reported for the region of interest PFC = (Pre-) Frontal Cortex for each frequency band of interest (θ (4-7 Hz), α (8-12 Hz) and β (15-30 Hz)) in each experimental condition. Reported values are in dB. Paired-samples t-test t and p values are reported in the last two columns on the right.

ROIs	FOIs	Single Task: Natural Walking	Dual Task: Walking & Texting	t - value	p - value
PFC	θ	-3.0 (±2.4)	-3.2 (±2.4)	0.950	N.S.
	α	-5.3 (±3.1)	-5.9 (±2.9)	10.708	N.S.
	β	-11.1 (±3.1)	-11.3 (±2.8)	1.716	N.S.

parison to naturally walking, even if no statistical significance is reached. Figure 2 shows the quantitative electroencephalography (qEEG) brain map of a typical subject.

6. Conclusion

This paper described a *multimodal approach* to measure the distraction of pedestrians with and without a mobile phone. The experiment results indicate that the proposed approach has considerable potential for recognising distractions while pedestrians are walking from different perspectives, both behavioural and neurophysiological. This initial work is a good foundation for achieving the long term motivation of our work, which is to provide pedestrians with safety notifications as they approach potential hazards while they conduct multiple tasks such as using a smart phone while walking.

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