

Categorical Color Perception shown in a cross-lingual comparison of visual search

Authors

Elley Wakui¹, Dimitris Mylonas², Serge Caparos^{3,4}, Jules Davidoff⁵

¹School of Psychology, University of East London, United Kingdom

² Faculty of Computing, Mathematics, Engineering & Natural Sciences, Northeastern University London, United Kingdom

³Department of Psychology, DysCo lab, Université Paris 8, France

⁴Institut Universitaire de France, Paris, France

⁵Department of Psychology, Goldsmiths, University of London, United Kingdom

Correspondence

Dimitris Mylonas, Northeastern University London, Faculty of Computing, Mathematics, Engineering & Natural Sciences, Devon House, 58 St Katharine's Way, London, E1W 1LP, UK.

Email: dimitris.mylonas@nulondon.ac.uk

ORCID

Dimitris Mylonas <https://orcid.org/0000-0002-9467-6081>

Acknowledgements

This work was supported by the British Academy/Leverhulme Small Research Grants - SRG 2017. Dimitris Mylonas was partly supported by the University College London (UCL) Computer Science — Engineering and Physical Sciences Research Council, Doctoral Training Grant: EP/M506448/1 – 1573073 and by the FY22 TIER 1 Seed Grant from Northeastern

University, USA. We thank Trinity Smithers EUSA intern for UK data collection and Gary Lupyan for comments on an earlier version.

Abstract

Categorical Perception (CP) for colors entails that hues within a category look more similar than would be predicted by their perceptual distance. We examined color CP in both a UK and a remote population (Himba) for newly acquired and long-established color terms. Previously, the Himba language used the same colour term for blue and green but now they have labels that match the English terms. However, they still have no colour terms for the purple areas of colour space. Hence, we were able to investigate a colour category boundary that exists in the Himba language but not in English as well as a boundary that is the same for both. CP was demonstrated for both populations in a visual search task for the one different hue among 12 otherwise similar hues; a task that eliminated concerns of label matching. CP was found at the color-category boundaries that are specific to each language. Alternative explanations of our data are discussed and, in particular, that it is the task-dependent use of categorical rather than non-categorical (perceptual) color networks which produces CP. It is suggested that categorical networks for colors are bilaterally represented and are the default choice in a suprathreshold similarity judgment.

Keywords

Categorical Perception, Color; Visual Search, Cross-lingual

Introduction

Color terms affect performance on many color similarity judgments (Lupyan et al., 2020) but definitely not on all such tasks (Davidoff et al., 2012; Grandison et al., 2014; Martinovic et al., 2020; Roberson et al., 2009a; Webster & Kay, 2012). Similarly, while one's native language can promote access to visual consciousness in some color tasks (Maier & Rehman, 2018), it is not agreed that it affects subjective experience of colors in other tasks (Lupyan et al., 2020). However, subjective appearance of color is our current concern. In particular, we are concerned with the effect of subjective appearance known as Categorical Perception (CP) described by Harnad (1987). CP means that stimuli within a category look/sound more similar to each other and that stimuli from different categories look/sound more different than would be predicted from their perceptual distance. The most pronounced case of CP is in speech perception where all the members of a category can even sound identical (Goto, 1971; Liberman et al., 1957). For color CP, the claim is that hues with the same name just look more similar to each other (Bornstein & Korda, 1984) as, somehow, labeling causes the perceptual warping within the color category (Bornstein & Korda, 1984; Kay & Kempton, 1984; Lupyan et al., 2020; Roberson et al., 2000). More recently, (Witzel & Gegenfurtner, 2016; see also Martinovic et al., 2020) have proposed an alternative model of CP called cognitive facilitation where effects are limited to category boundaries

To some, CP is a cornerstone of visual perception (Aerts & Arguelles, 2022; Green et al., 2020) but any claim that might be seen as showing thought or language influencing perception (cognitive penetrability) has been fiercely contested (Firestone & Scholl, 2016; Pylyshyn, 1999). Firestone and Scholl (2016) would argue that to find CP is paradoxical if the stimuli are already equally spaced as for instance they are in the Munsell system to be used in our study. Their argument goes that a color difference cannot both be equal and not equal at the same time. However, long ago, Kay and Kempton (1984) argued that the

observer can take either a perceptual or a categorical stance in making a color judgment. In their study, observers carried out two tasks with the same stimuli, one that favoured perceptual discrimination and the other categorical discrimination. CP was only found in the latter. So, it is not necessarily paradoxical to find CP and we will contribute to this issue primarily by providing reliable evidence for color CP from a cross-lingual analysis (see Gutchess & Rajaran, 2022).

We will examine a language (Otjihimba) with different numbers of color terms to English and where CP has been aligned to the presence of a color term in that language (Roberson et al., 2005). When tested by Roberson et al., (2005), Otjihimba had only 5 basic color terms (*serandu, burou, vapa, dumbu, zoozu*). In common with many others, it was a ‘grue’ language where the same word is used for *blue* and *green* terms. Unlike for Western populations, the Himba did not show CP for *blue* or *green* colors though they did for their own color terms. However, CP in Roberson et al. (2005) was obtained from a short-term memory paradigm and thereby contained the potential for naming artifacts (Cibelli et al., 2016; Davidoff, 2015; Munnich & Landau, 2003). Besides the obvious concern that it is name memory rather than perception that is being examined, there is the possibility of an inconsistent use of category labels depending on a hue’s position in a category (Hanley & Roberson, 2011) though note the counter evidence in Best and Goldstone (2019). At the very least, name matching artifacts can be avoided if we use a visual search paradigm where the task is to find the odd-one-out that is different from other colors (Brederoo et al., 2019; Brown et al., 2011; Daoutis et al., 2006; Gilbert et al., 2006; He et al., 2019; Witzel & Gegenfurtner, 2011; Yokoi & Uchikawa, 2005); such tasks can be performed very quickly (Treisman & Souther, 1985). The odd-one-out in our task is either from the same or different color category to the identical colors. CP is observed if quicker responses are found when the odd-one-out is from a different category. In

the visual search task, naming individual colors to find the odd-one-out would be ineffective as correct responses are typically given with latencies of not more than 1s.

Our previous Himba naming data were collected in 2004. Since that time, the Himba have had more contact with urbanized communities. Indeed, we have documented the cognitive changes induced by that contact (Bremner et al., 2016; Caparos et al., 2013; De Fockert et al., 2011; Linnell et al., 2013, 2018). We have even noted the effects on similarity judgments of just a few visits to a small town (Caparos et al., 2012). There was reason to suspect from a brief report (Grandison et al., 2014) that greater contact with other cultures had also led to an enlargement of the Himba color lexicon. We now know that is the case and have recently reported that Otjihimba can be regarded as a 7-color term language (*serandu, burou, grine, vapa, dumbu, zoozu, and vinde*) where both new terms have probably been imported from Herero where these terms have a European origin (Mylonas et al., 2022), unlike English which can be regarded as a language with 13 terms (Mylonas & MacDonald, 2016). English terms consist of 11 (*black, white, red, blue, green, yellow, orange, purple, brown, pink, grey*) regarded as basic for some time (Berlin & Kay, 1969/1991; Paramei & Bimler, 2021) with the recent additions of *lilac* and *turquoise* that also cannot be subsumed by another term (Mylonas & MacDonald, 2016). It is important to note that while Otjihimba terms can be translated by English terms, they cover a more extensive area in color space than those English terms (Mylonas et al. 2022). For our study, this is of particular importance for *serandu* which we could gloss as ‘red’ and *burou* that we could gloss as ‘blue’. In Otjihimba, there is a boundary between *serandu* and *burou* but there is no boundary in English between *red* and *blue* because of *purple* terms; so, we will from now on not use gloss terms.

A requirement for conducting studies of CP is that color categories occupy sufficient areas of color space to allow pairs of stimuli to be discriminable but still be within the same color category. So, it is not surprising that most of the research with CP has used *green* vs *blue* as

those colors occupy around half of color space. Our predictions, from the new color naming data, were that for both Otjhimba and English speakers a green stimulus would be more easily found among blue distractors but not so readily if the green stimulus was among other green stimuli. A similar prediction would be for quicker detection of a *blue* stimulus when it is among cross-category (*green*) stimuli but not so readily if it is among within-category (*blue*) stimuli. However, the predictions were different for other color categories, specifically within the *serandu* and *burou* denotations of color spaces. In Otjhimba, the color area *serandu* has a boundary with *burou*. In English, there are many names (*blue, lilac, pink and purple*) for the colors around the *serandu/burou* boundary; because of this it is only Otjhimba that has a within-category condition. CP is predicted for both populations for the colors used in the Otjhimba cross-category condition but the within-category condition would be different. The Himba should find their within-category search harder than the UK population.

Methods

Participants

Forty-three native Himba speakers (30 female, 13 male) aged between 15-44 years, with a mean age = 23.63, $SD = 7.77$, from remote villages in north-west Namibia completed the experiment. One further participant did not complete both tasks. None had taken part in any other study. Participants were compensated for their time with gifts of sugar and flour. The study received ethical approval from Goldsmiths University of London (N°1390, 4th of June 2018). Further information on Himba cognition is available in Trémolière et al. (2022). Each observer carried out the visual search task for both *blue/green* and *serandu/burou* boundaries. Different UK observers carried out the two tasks. For the *blue/green* search, the data from Davidoff et al. (2012 Experiment 3) consisting of 14 participants (10 female, 4 male) aged between 19-38 years, with a mean age of 23.86 years, $SD \approx 4.75$ recruited at Goldsmiths,

University of London were combined with 14 (2 male, 12 female) new observers aged between 19-21 years, with a mean age 20.26 years, $SD = 0.83$, recruited from the University of East London. For the *serandu/burou* search, a further 43 participants (15 male, 28 female, aged between 18-59 years, with a mean age of 29.79 years, $SD = 9.71$), were recruited at the University of East London (Ethics approved by the University of East London Research Ethics Committee). All UK participants were native English speakers, reported normal or corrected to normal vision and had normal color vision as tested using the Ishihara (2001) plates for red-green color vision.

Stimuli and Materials

Previous studies with the Himba, like for other populations in the World Color Survey (Kay & Maffi, 1999), assessed color judgments by presenting Munsell chips under controlled illumination. However, doubts have been expressed about the spacing of *green* and *blue* colors in Munsell space that has been commonly used in these studies and also about the control of the color reproduction (Brown et al., 2011; Lindsey et al, 2010; Witzel & Gegenfurtner, 2011, 2013; see Witzel, 2019). To respond to these criticisms, we used the same calibrated monitor to present our color stimuli in both UK and Himba participants ensuring that the differences between measured colors across and within categories were equivalent using the current recommended CIE ΔE_{2000} color difference formula. All stimuli were presented on a 13" Apple MacBook Pro (mid-2010) and responses were collected using an external number pad. To maintain consistent color appearance of the simulated Munsell chips on the digital display that supports the widely used D65 standard white point of sRGB, we adapted the xyY (1931) coordinates of the simulated Munsell chips from Illuminant C to D65. We also calibrated the monitor towards D65 in accordance with sRGB and confirmed that the reproduction of the intended and achieved color stimuli was within the invisibility error threshold, assuming a just-noticeable difference of 1 ΔE_{00} in CIELAB.. The measured CIE 1931 chromaticity coordinates of the white point of the monitor was $x = 0.3116$, $y = 0.3274$ with a correlated temperature of

6581K and luminance of 160 cd/m². Repeating the spectro-radiometric measurements of the monitors after the fieldwork showed only a minimal drift of the white point over time (< 0.003). The stimulus presentation was controlled by PsychoPy v.1.90.2 software (Peirce, 2007). There were two sets of stimuli, one for each boundary tested (*blue/green* and *serandu/burou*). Each set consisted of 4 pairs of stimuli; for the Himba there were two cross-category pairs and two within-category pairs for both boundaries. For English speakers, it was the same for the *green/blue* boundary, but all comparisons were cross-category pairs for the *serandu/burou* search task. All stimulus displays consisted of 12 square (2.15°) color patches arranged as in an offset clock face (see Figure 1) in which 11 of the colors were identical and one was an odd-one-out. Across the experiment, each stimulus in a pair was presented as either the target odd-one-out (appearing in each of the 12 possible positions) or as the surrounding distractors in random order. Color stimuli for all visual search tasks were presented against a neutral grey background with luminance of 38 cd/m².

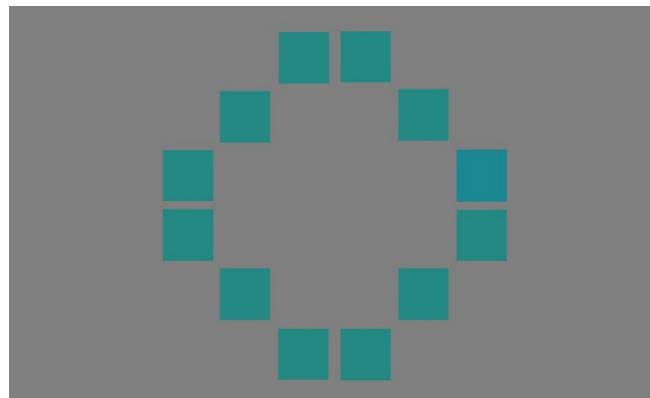


Figure 1. Example stimulus display. Here the target is on the right-hand side of the screen.

The *blue-green* boundary was placed at 6.25BG (Davidoff et al., 2012), with each stimulus in a pair separated by 5 Munsell steps and pairs evenly arranged around the boundary, as can be seen in Figure 2a. The two cross-category pairs were 5BG-10BG, and 2.5BG-7.5BG. The two within-category pairs were 8.75G-3.75BG and 8.75BG-3.75B. All were presented at equal Value = 5 and Chroma = 6. The mean color difference between stimuli was $\Delta E_{00} = 6$, STD =

1. None of the stimuli were repeated across category conditions. The Otjihimba boundary between *burou/grine* is at the same place as the English *blue/green* boundary (Mylonas et al., 2022). A note needs to be added about these stimuli given that a *turquoise* term is becoming more common in English (Mylonas & MacDonald, 2016; see also Lindsey & Brown, 2014) and in other languages (Paramei & Bimler, 2021; Witzel & Gegenfurtner, 2011; Zimmer, 1982). It might have been that the 5BG and 7.5BG samples could be called *turquoise* in English by some of our observers but we did not establish whether that was the case. However, our pairings of stimuli have been chosen so that whether they are both called *turquoise* or one *green* and the other *blue*, the pairings used are cross-category for English speakers.

The *serandu/burou* boundary was placed at 7.5P (Mylonas et al., 2022) with each stimulus in a pair separated by 7.5 Munsell steps and pairs evenly arranged around the boundary, as can be seen in Figure 2b. For the Himba, the two cross-category pairs were 5P-2.5RP and 2.5P-10P. The two within-category pairs were 5P-7.5PB and 10P-7.5RP. Here we used only 6 different colors with the two stimuli closest to the boundary (5P and 10P) used in both cross and within conditions. The mean color difference between stimuli was $\Delta E_{00} = 9$, $STD = 1$. All were presented at equal Value = 5 and Chroma = 6. Figure 3 shows that the naming of the colors is quite different for English speakers (Mylonas, 2020). 7.5PB is called *blue*, 2.5P is called *lilac*, 5P and 10P are called *purple*, 2.5RP and 7.5RP are called *pink* though we did not examine the particular names given by our UK participants. Nevertheless, it can be assumed that, all combinations used with the *serandu/burou* boundary are cross-category for English speakers.

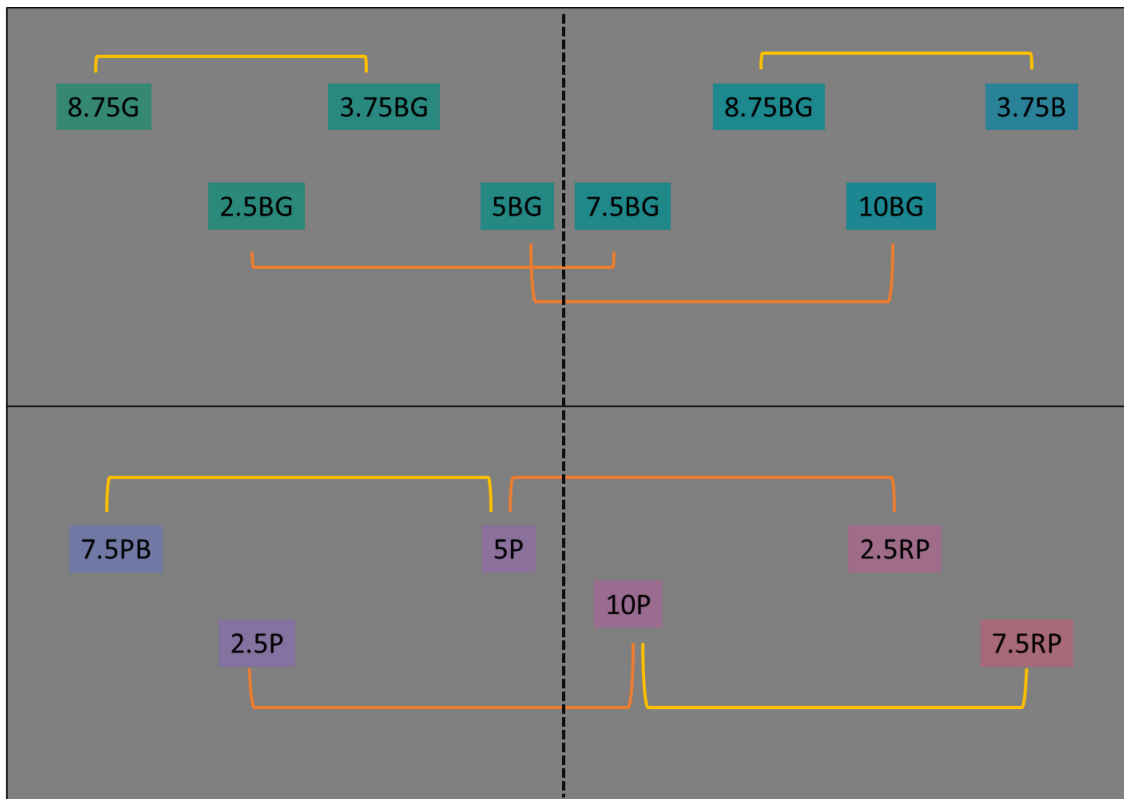


Figure 2. (a) Top panel shows stimuli in Munsell notation for tests across the blue-green boundary, and (b) Bottom panel shows stimuli for the serandu/burou boundary tests. Within-category pairs for the Himba are indicated by yellow lines and cross-category by orange lines. The same applies to English speakers for the blue-green boundary but all pairings are cross-category for them for the serandu/burou boundary (see Figure 3). The boundary between categories is shown with a black dashed line.

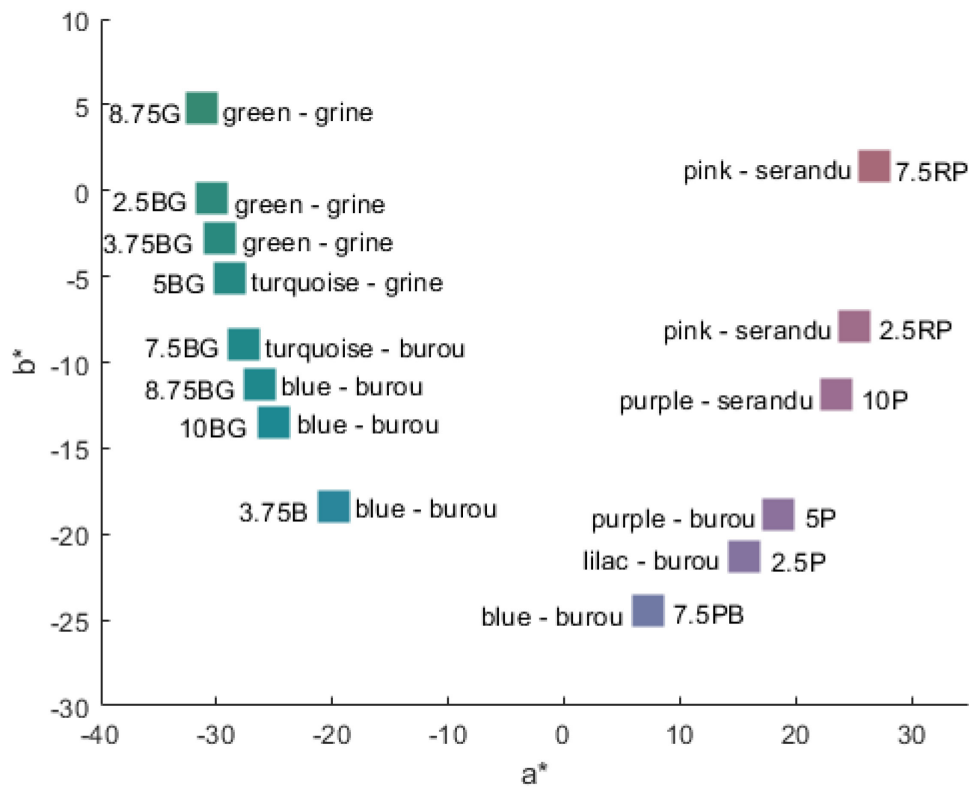


Figure 3. Color stimuli for tests across the serandu/burou boundary in $a^* b^*$ plane of CIELAB with Munsell hue notation and estimated color names in English (Mylonas, 2020) and Otjihimba (Mylonas et. al., 2022).

Procedure

The visual search procedure was based on that of Davidoff (2012, Exp.3) and Gilbert et al. (2006, Exp.1). Each trial started with a fixation cross for 1000ms, followed by the stimulus display of 12 color patches in an offset clock-face arrangement. Participants were asked to decide whether the odd-one-out was on the left- or right-hand side of the screen with a corresponding button press on the number pad. The stimulus display remained on the screen until response, which then initiated a blank screen presented for 250ms, followed by the next trial. Only responses under 2s were included in analyses.

Each stimulus in a pair was presented as target and distractor equally often, in each of the 12 possible locations, in random order. Thus, each block consisted of 96 trials; participants

completed 3 blocks with short self-paced intervening breaks. A practice block of 8 trials using red [255, 0, 0] and yellow [255, 255, 0] stimuli ensured that participants understood the task. All testing was carried out individually, in a testing tent, under conditions of natural light for the Himba and in a laboratory for UK participants. Himba participants carried out both tasks with alternate participants doing each visual search task first. The anonymous datasets generated during the current study are available online in the Open Science Framework (OSF) Repository of the Center for Open Science.

[Available at : https://osf.io/nkruh/?view_only=e93c3fbccaba4f638a27a778ec410bf1].

Results

Analyses were carried out separately on the *green/blue* and *serandu/burou* data. Stimulus separation in the *green/blue* task was smaller and produced longer latencies for both groups of observers. Only the RTs for correct responses were included. For the *green/blue* task, the overall accuracy for the UK participants (N=28) was .99 (within category accuracy (M = .98, SD = .03); cross category accuracy (M = .99, SD = .02)) and for the Himba participants overall accuracy was .96 (within category accuracy (M = .96, SD = .09); cross category accuracy (M = .96, SD = .08)). For the *serandu/burou* task, the overall accuracy for the UK participants was .99 (within category accuracy (M = .99, SD = .02); cross category accuracy (M = .99, SD = .01)) and for the Himba participants overall accuracy was .96 (within category accuracy (M = .96, SD = .09); cross category accuracy (M = .96, SD = .09)).

Data from participants with accuracy less than chance (50%) in any condition were excluded from further analyses but this applied to only one Himba participant.

Green/Blue visual search

The data from the new 14 UK participants and those from Davidoff et al. (2012) were submitted to a mixed 2x2 ANOVA with between-participants factor Group (Old data, New data) x within-participants factor Category (Cross, Within). Consistent with the previous analysis, there was

a statistically significant main effect of Category, $F(1,26) = 99.55, p < .001, \eta_p^2 = 0.793$, with cross-category RTs ($M = 0.868s, SE = .033$) faster than within ($M = 0.972s, SE = 0.32$) but the main effect of Group was not statistically significant, $p > .1$, and neither was the interaction between Group x Category, $p > .4$.

Having confirmed that there was no difference between the new and old UK participants, data were combined in an ANOVA comparing UK with Himba participants. A mixed 2x2x2 ANOVA with between-participants factor Group (Himba, UK) x within-participants factors Category (Cross, Within) and Presentation side (left, right) was performed on the RT. We included side of presentation because of reports of greater CP in the right visual field (Drivonikou et al., 2007; Gilbert et al., 2006). There was a significant main effect of category, $F(1,69) = 284.08, p < .001, \eta_p^2 = 0.805$, with cross-category RTs ($M = 0.900s, SE = .022$) faster than within ($M = 1.014s, SE = 0.23$) (Figure 4). The other main effects (including Group, $F(1,69) = 2.84, p = .096$) interactions did not reach statistical significance, all other $ps > .16$.

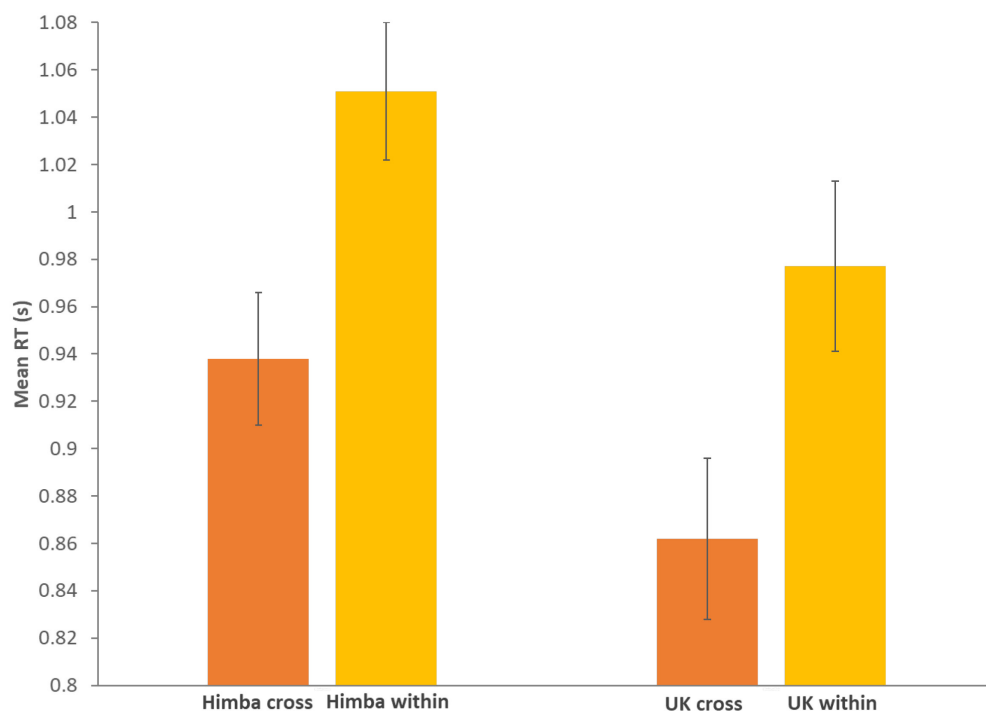


Figure 4. Mean RT in seconds for cross-category (orange bars) and within-category (yellow bars), error bars $\pm 1SE$ for green/blue visual search all Himba ($N = 43$) and UK ($N = 28$) participants.

Serandu/Burou Visual Search

In this analysis, we use the label ‘within-category’ when comparing two colors that are both labelled *serandu* or both labelled *burou* in Otjihimba. The label ‘cross-category’ refers to comparing one color labelled *serandu* with one labelled *burou* in Otjihimba. Note however that both the cross-category (*serandu/burou*) and the within-category (*serandu* or *burou*) conditions are in fact cross-category for UK observers. A 2x2x2 ANOVA was also performed for the Otjihimba *serandu/burou* boundary. There were significant main effects of both Category (within vs cross -as defined by Otjihimba but not English), $F(1, 83) = 81.29, p < .001, \eta_p^2 = 0.495$, and Group (Himba vs UK), $F(1, 83) = 76.44, p < .001, \eta_p^2 = 0.479$, and these were modified by a significant interaction between Group x Category, $F(1, 83) = 19.37, p < .001, \eta_p^2 = 0.189$. Simple main effects analyses confirmed both groups of participants were faster in cross-category than in within-category conditions (Himba cross $M = 0.803s, SE = .021$; within $M = 0.850s, SE = .023, p < .001$ and UK cross $M = 0.550s, SE = .021$; within $M = 0.566s, SE = .022, p = .002$). The difference between cross-within category RTs was significantly greater for Himba participants ($M = 0.471s, SE = .007$) than UK participants ($M = 0.162s, SE = .003$), $t(83) = 4.40, p < .001$. The other main effects and interactions did not reach statistical significance, although the interaction between Group x Side narrowly missed statistical significance ($F(1,83) = 3.80, p = .055$). However, the direction of that effect is in the opposite direction to those found by Gilbert et al., (2006) and Drivonikou et al., (2007). The UK participants RT were faster than the Himba participants RT for both sides. Only the UK participants showed a difference between left ($M = .552s, SE = .022$) vs right ($M = .563s, SE =$

.22), $p = .052$, whereas for the Himba there was no significant difference between left $M = .829$, $SE = .022$ vs right $M = .824$, $SE = .022$), $p = .43$. All other $ps > .41$.

Unlike for the *green/blue* task, Himba RTs were overall longer than UK participants. However, it was possible to obtain a sub-sample ($N = 9$) of Himba and ($N = 9$) UK participants with comparable RTs. In order to find this sub-sample, the average RT (across cross and within) for each participant was calculated and ordered. The fastest Himba participant's average RT was .57 s, the closest UK participant average was .565s. Consecutive data sets from both Himba and UK participants were then selected for a range of 0.57-0.67s for the Himba participants and 0.565-0.645 for the UK participants. The overlapping data can be seen in Figure 5.

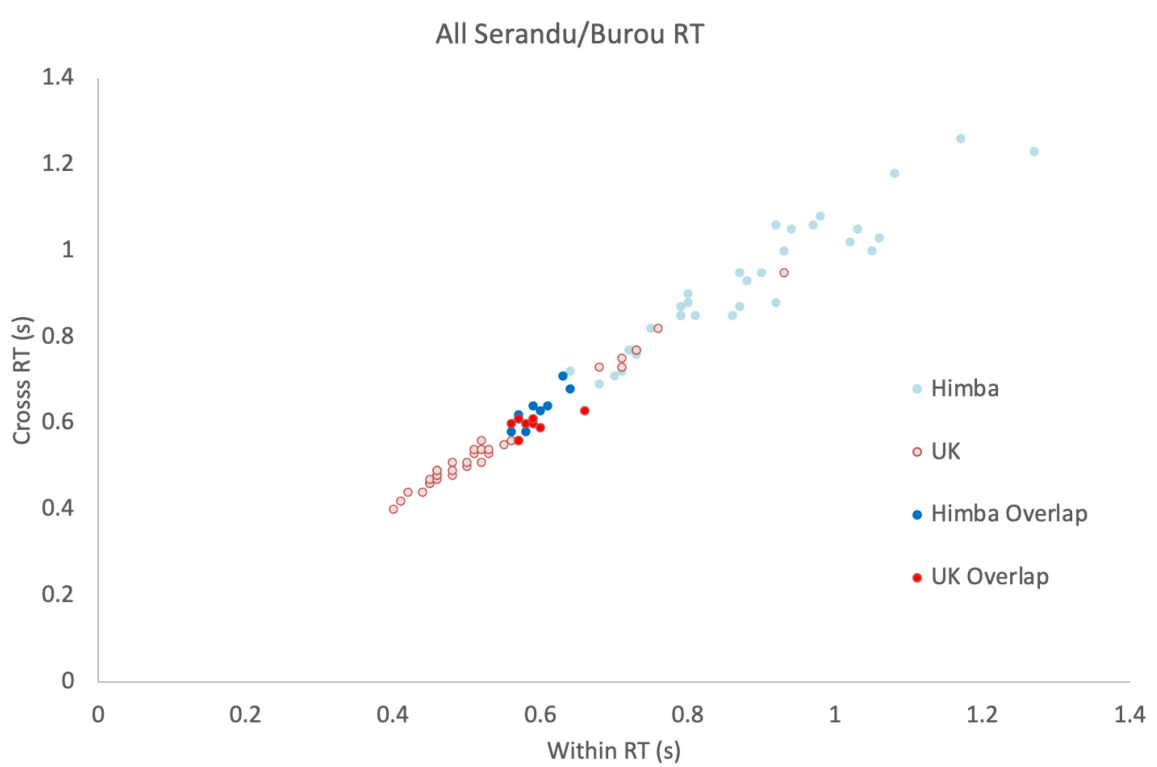


Figure. 5 Response Time (RT) for all participants in the serandu/burou visual search task, The participants from the Himba and UK participants whose data overlap are shown by the filled-in circles.

The mixed 2x2x2 ANOVA on this smaller sample again revealed a significant main effect of Category $F(1,16) = 14.04, p = .002, \eta_p^2 = 0.467$. The main effect of Group was not statistically significant, $p = .073$. There was however still a significant interaction between Group x Category $F(1,16) = 5.29, p = .035, \eta_p^2 = 0.249$ (Figure 6). All other main effects and interactions did not reach statistical significance $p > .071$.

Given the debate about how to deal with within-subjects effects in mixed design analysis (Howell, 2010, pg 482), we conducted separate analysis of the within-subjects effects for Himba participants; this produced a significant main effect of Category $F(1,8) = 17.45, p = .003, \eta_p^2 = 0.686$. The mean cross-category RTs ($M = 0.60s, SE = .009$) were faster than within-category, ($M = 0.636s, SE = .014$) $p = .003$. However, a similar analysis for UK participants found no main effect of Category, $p = .325$, cross $M = 0.588s, SE = .010$; within $M = 0.596s, SE = .008$.

There was no difference between Himba ($M = .601s, SE = .01$) and UK ($M = .588s, SE = .01$) 'cross-category' RTs, $p = .340$, but, most importantly, the Himba participants took longer to respond in the within-category condition ($M = .636s, SE = .012$) than UK participants for whom this was a cross-category condition, ($M = .596s, SE = .012$) $p = .027$ (see Figure 6).

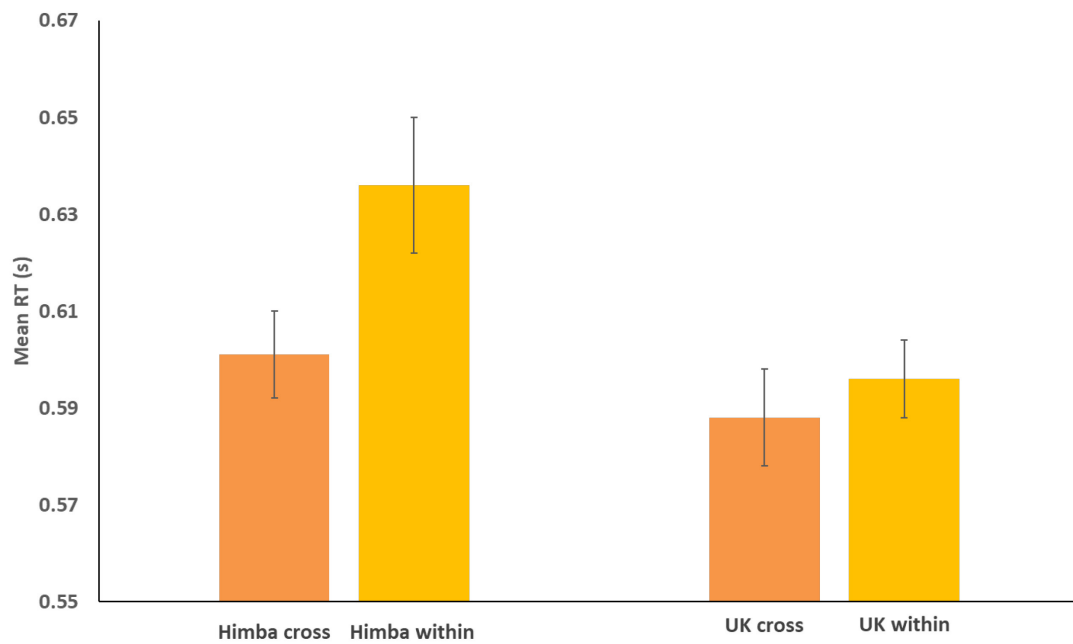


Figure 6. Mean RT in seconds, error bars $\pm 1SE$ serandu/burou visual search, participants with comparable RT Himba ($N = 9$) and UK ($N = 9$). Note that both the cross-category (serandu/burou: orange bars) and the within-category (serandu or burou: yellow bars) conditions are cross-category for UK observers.

We conducted one further analysis on our data. In many visual search tasks for colored targets, latencies are determined by other aspects of the display besides CP (Martinovic & Hartman, 2023). For example, latencies are faster to prototype colors. So, perhaps the observers learn what is the middle of the range and this becomes some sort of prototype though, of course, that would not explain the Himba performance with the *serandu/burou* task. Latencies may also be faster if attention is drawn to that color and Witzel and Gegenfurtner (2015) argued that CP is, in fact, found because attention is drawn to boundary colors (here the middle of the range). Both of these explanations might predict that CP would develop during the task. Hence, we examined performance in the first block of trials compared to later blocks. A 2(Block: first vs later) x 2 (Category : within vs cross) ANOVA

was performed on the Himba green/blue data (see Figure 7). There was a main effect of Block $F(1.42, 59.46) = 59.35, p < .001$ due to observers getting faster across blocks and a main effect of Category $F(1,42) = 183.61, p < .001$ with cross category trials being faster. There was no statistically significant interaction $p = .182$.

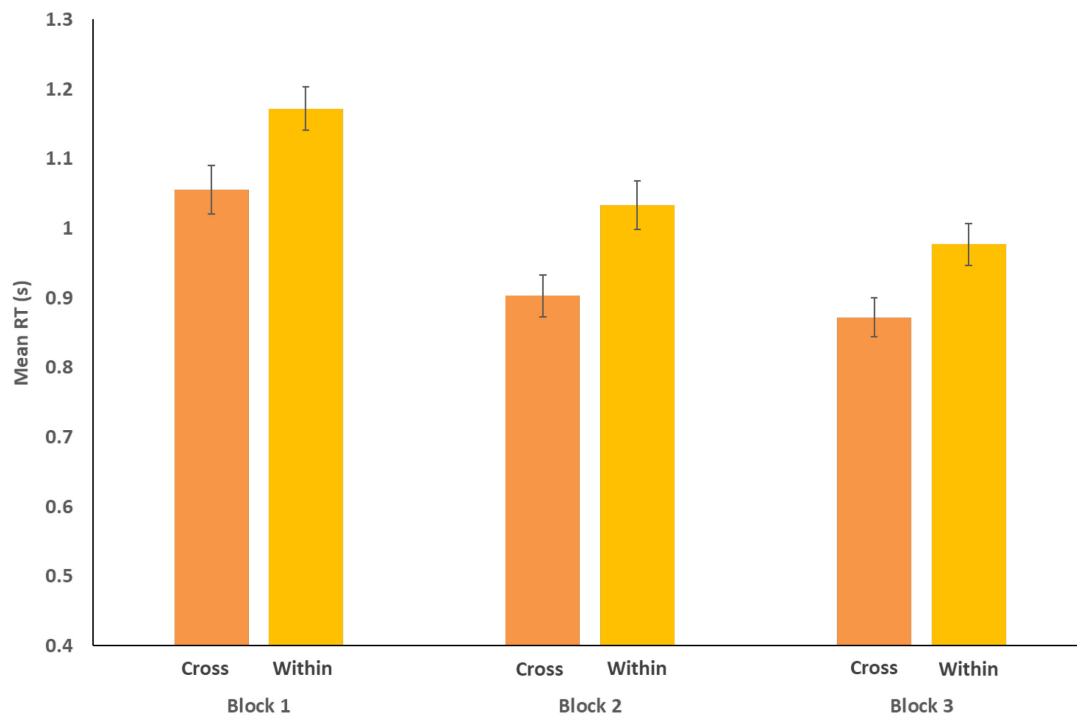


Figure.7 Mean latencies (cross and within) for Himba observers for the three blocks of trials in the blue/green visual search task.

Data storage for the data from Davidoff et al. (2012) did not allow for analysis by Block but a similar analysis on the more recent UK participants gave the same outcome. As for the Himba participants, the main effect of Block $F(2,26) = 8.71, p = .001$ and Category $F(1,13) = 77.60, p < .001$ were statistically significant, but the interaction Block x Category was not, $p = .134$.

Discussion

CP was examined with a visual search paradigm that produced fast responses in all participants. Two color boundaries were used for both UK and Himba observers: English *green/blue* and the Otjihimba *serandu/burou* boundary. The *green/blue* boundary is present in both English and Otjihimba. CP was predicted for both populations; this turned out to be the case and with no latency differences between the populations. The *serandu/burou* boundary is present in Otjihimba but not in English. In English, the closest boundary colors between *serandu* and *burou* would be called *purple* and the other colors *blue, lilac* or *pink*. CP was predicted for all presentations because they were all cross-category for the UK population. However, for the Himba there were presentations that were within-category and these would not offer CP and so they would be slower to find the odd-one-out stimulus. Again, the predictions were fulfilled for both populations. We therefore provide evidence that, within a color category, colors look more similar than would be predicted from their perceptual distance in color space.

In giving an explanation of these findings one could look no further than the recent accounts of the top-down effects of labels (label feedback hypothesis) in color tasks (Lupyan et al., 2020; Forder & Lupyan, 2019). For example, Forder and Lupyan (2019) showed that it was only after hearing a color name (e.g., *green*) that observers were more accurate (showed CP) in the immediate discrimination between targets and non-targets when they spanned a color boundary (e.g., a *green* among *blues*). These top-down effects have been argued to act at early vision and

some research has found category effects on the early (P1) component of the EEG trace (Forder et al., 2017; Maier & Rahman, 2018, Thierry et al., 2009) that might be interpreted as showing a change in perception. Others have found effects only at later components (Clifford et al., 2012; Fonteneau & Davidoff, 2007) but as Siuda-Krzywycka et al. (2019) point out it is not clear that any part of the EEG trace can be observed independent of top-down effects. Could it be that changes to perception observed in our studies are just another example of the top-down effects of labels? Perhaps during the task, our observers label even covertly (Lupyan, 2012; Lupyan et al., 2010; Raftopoulos & Lupyan, 2018) the stimuli and carry those labels into subsequent trials. There is no evidence that the observers in Forder and Lupyan (2019) did this but, in any case, what use is that information when any label would not be predictive of the upcoming target. Similarly, enhancement of target colors due to attention (see Oxner et al., 2023) cannot be effective when the target is unknown. Anyway, feedback from labeling cannot be the only cause of CP for other populations; patients who cannot label colors nevertheless show color CP (Haslam et al., 2007; Kinsbourne & Warrington, 1964; Roberson et al., 1999; Siuda-Krzywycka et al., 2019).

Another potential explanation of our CP findings is that CP is likely to be weak or non-existent in tasks that ask for color discrimination rather than categorization provided by color terms (Martinovic et al., 2020; Roberson et al., 2009b; Witzel, 2019, Witzel & Gegenfurtner, 2013, 2015). It could be argued that our odd-one-out task (Gilbert et al., 2006) would necessarily prompt categorization rather than discrimination. though it is not certain why CP is found so reliably with 11 distractors but not in a design with only 3 distractors (Forder & Lupyan, 2019). Perhaps our design allows for pop-out which is known to be affected by set size (Baldassi & Burr, 2004). In any case, task demands that facilitate discrimination rather than categorization cannot explain the lack of CP in other suprathreshold tasks. For example, the assessment of the overall color of an ensemble of colors is not sensitive to CP (Maule et

al., 2014; Rajendran et al., 2021), nor is perceptual grouping (perceived orientation) of colored dots (Webster & Kay, 2012) and nor the division of colors that span a color boundary (Davidoff et al., 2012).

It could be that finding CP depends on the stance (perceptual or categorical) of the observer (Kay & Kempton, 1984). Such a possibility is enhanced by the findings in Webster and Kay (2012) and, importantly, by the discovery of two types (perceptual and categorical) of color sensitive networks in the brain (Bird et al., 2014; Brouwer & Heeger, 2013; see also Siuda-Krzywicka et al., 2021). Thus, finding or not finding CP is like the different perceptions of the 'dress' as either white and gold or blue and black (Brainard & Hurlbert, 2015; Witzel, Wuerger & Hurlbert, 2016). What we have to explain, for the dress, is why observers interpret the lighting conditions differently and this is explained by Witzel et al. (2017).; For color, we still have to explain why we adopt a categorical rather than a perceptual stance and admittedly that may not be easy (Davidoff, 2015; Witzel, 2019). Take for example, the two studies of Sun et al. (2018, 2020) where perceptual distances were equalised in both studies. In the former study, observers were asked to track moving lines all drawn from the same color category among distractor moving lines drawn from the same and a different color category. In the latter study, the target lines were also drawn from the two categories. CP was not found in the former study, but it was in the latter but even there CP was not always present. Sun et al. (2020) concluded that color categories can dynamically modulate preattention visual processing when color working memory is involved, but that attention is necessary to produce CP effects when color is irrelevant to the task. So, explanations for such subtle differences are often post-hoc resorting to attention (Witzel and Gegenfurtner; 2015) and subjective evaluation (Roberson et al., 2009a; Witzel & Gegenfurtner, 2014, 2015, 2016)

Regarding the Himba, Davidoff et al. (2012) found that categorical similarity rather than perceptual similarity was more reliably used in implicit than in explicit categorization. Thus,

for the Himba, but also for Westerners, category boundaries were overridden in the explicit task of matching-to-sample. Both populations showed a similar strong tendency to ignore color boundaries and to divide the range of colored stimuli into two equal groups. In contrast, and without recourse to attentional explanations, CP occurs so readily in implicit tasks that it would be easy to describe it as automatic. In line with this view, one notes that CP is present in a severely aphasic patient who cannot name or categorize colors (Roberson et al., 1999; see also Siuda-Krzywicka et al., 2019).

Roberson et al. (1999) reported a series of experiments on a patient (LEW) with virtually zero color naming and color categorization ability. LEW was able to show implicit understanding of classic hallmarks of CP; for example, in experiments requiring the choice of an odd-one-out, the patient chose alternatives dictated by category rather than by perceptual distance. Thus, underlying categories appeared normal and boundaries appeared intact. Furthermore, in a two-alternative forced-choice recognition memory task, performance was worse for within-category decisions than for cross-category decisions and for LEW there cannot be a naming artifact. LEW showed that his similarity judgments for colors could be based on perceptual or categorical similarity according to task demands. His inability to make explicit use of his intact (implicit) knowledge was seen as related to his language impairment; see also Bohil et al., 2023 for an account of how implicit vs explicit knowledge might differently guide visual search.

What have these studies told us about the organization of color categories? The foremost answer is that, despite the uncertainty about which tasks promote CP, a speeded odd-one-out task from 12 stimuli allows CP to be reliably shown without any concern of naming artifacts. CP was shown in the Himba for both a newly acquired category (*green*) and longer standing categories (*serandu* vs *burou*). The origin of these within-category similarities could be based on perceptual similarities that produce similar color clusters in all languages (Regier et al.,

2007) but are better explained by linguistic similarity (Mylonas et al., 2022). However, despite linguistic similarity being the most likely origin of CP in the adult, the current data would seem to play down any role of language areas located in the left hemisphere. The present studies failed to find any lateralized effects but eye movements were not controlled (see Roberson et al., 2009b) and that will limit our conclusions given that the lateralization data are fragile (Webster & Kay, 2012; Witzel & Gegenfurtner, 2011, 2016). Nevertheless, the same lack of lateralization is also found in stimuli that were presented so quickly as to prevent eye movements (Brown et al., 2011; Suegami et al., 2014). Indeed, given that neural networks for color categorization, unlike color naming, have been found to be represented in both halves of the brain (Siuda-Krzywicka et al., 2021), it is a reasonable prediction that there should be no effect of side of presentation. It could be that color terms are important, perhaps essential, for laying down those bilateral categorical networks but, as shown in Roberson et al., (1999) and Siuda-Krzywicka et al., (2019, 2021) their production has become independent of language.

References

- Aerts D., Arguëlles, J.A. (2022) Human Perception as a Phenomenon of Quantization. *Entropy* 24(9), 1207. DOI: [10.3390/e24091207](https://doi.org/10.3390/e24091207)
- Baldassi, S., & Burr, D. C. (2004). “Pop-out” of targets modulated in luminance or colour: The effect of intrinsic and extrinsic uncertainty. *Vision Research*, 44(12), 1227–1233. DOI: [10.1016/j.visres.2003.12.018](https://doi.org/10.1016/j.visres.2003.12.018)
- Best, R. M., & Goldstone, R. L. (2019). Bias to (and away from) the extreme: Comparing two models of categorical perception effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 45(7), 1166-1176. DOI: [10.1037/xlm0000609](https://doi.org/10.1037/xlm0000609)
- Berlin, B., & Kay, P. (1969/1991). *Basic color terms: Their universality and evolution*. University of California Press.

- Bird, C. M., Berens, S. C., Horner, A. J., & Franklin, A. (2014). Categorical encoding of color in the brain. *Proceedings of the National Academy of Sciences*, *111*(12), 4590-4595. DOI: [10.1073/pnas.1315275111](https://doi.org/10.1073/pnas.1315275111)
- Bohil, C.J., Phelps, A., Neider, J.B. & Schmidt, J. (2023) Explicit and implicit category learning in categorical visual search. *Attention, Perception & Psychophysics*, *85*(7), 2131-2149. DOI: [10.3758/s13414-023-02789-z](https://doi.org/10.3758/s13414-023-02789-z)
- Bornstein, M.H. & Korda, N.O. (1984). Discrimination and matching within and between hues measured by reaction times: some implications for categorical perception and levels of information processing. *Psychological Research*, *46*(3), 207-22. DOI: [10.1007/BF00308884](https://doi.org/10.1007/BF00308884)
- Brainard, D. H., & Hurlbert, A. C. (2015). Colour vision: understanding #TheDress. *Current Biology*, *25*(13), R551-R554. DOI: [10.1016/j.cub.2015.05.020](https://doi.org/10.1016/j.cub.2015.05.020)
- Brederoo, S. G., Nieuwenstein, M. R., Cornelissen, F. W., & Lorist, M. M. (2019). Reproducibility of visual-field asymmetries: Nine replication studies investigating lateralization of visual information processing. *Cortex*, *111*, 100–126. DOI: [10.1016/j.cortex.2018.10.021](https://doi.org/10.1016/j.cortex.2018.10.021)
- Bremner, A. J., Doherty, M. J., Caparos, S., De Fockert, J., Linnell, K. J., & Davidoff, J. (2016). Effects of culture and the urban environment on the development of the Ebbinghaus illusion. *Child Development*, *87*(3), 962-981. DOI: [10.1111/cdev.12511](https://doi.org/10.1111/cdev.12511)
- Brouwer, G. J., & Heeger, D. J. (2013). Categorical clustering of the neural representation of color. *Journal of Neuroscience*, *33*(39), 15454-15465. DOI: [10.1523/JNEUROSCI.2472-13.2013](https://doi.org/10.1523/JNEUROSCI.2472-13.2013)
- Brown, A. M., Lindsey, D. T., & Guckes, K. M. (2011). Color names, color categories, and color-cued visual search: Sometimes, color perception is not categorical. *Journal of Vision*, *11*(12), 2-2. DOI: [10.1167/11.12.2](https://doi.org/10.1167/11.12.2)

- Caparos, S., Ahmed, L., Bremner, A. J., de Fockert, J. W., Linnell, K. J., & Davidoff, J. (2012). Exposure to an urban environment alters the local bias of a remote culture. *Cognition*, *122*(1), 80-85. DOI: [10.1016/j.cognition.2011.08.013](https://doi.org/10.1016/j.cognition.2011.08.013)
- Caparos, S., Linnell, K. J., Bremner, A. J., de Fockert, J. W., & Davidoff, J. (2013). Do local and global perceptual biases tell us anything about local and global selective attention? *Psychological Science*, *24*(2), 206-212. DOI: [10.1177/0956797612452569](https://doi.org/10.1177/0956797612452569)
- Cibelli, E., Xu, Y., Austerweil, J. L., Griffiths, T. L., & Regier, T. (2016). The Sapir-Whorf hypothesis and probabilistic inference: Evidence from the domain of color *PLOS ONE*, *11*(7), e0158725. DOI: [10.1371/journal.pone.0158725](https://doi.org/10.1371/journal.pone.0158725)
- Clifford, A., Franklin, A., Holmes, A., Drivonikou, V. G., Özgen, E., & Davies, I. R. L. (2012). Neural correlates of acquired color category effects. *Brain and Cognition*, *80*(1), 126–143. DOI: [10.1016/j.bandc.2012.04.011](https://doi.org/10.1016/j.bandc.2012.04.011)
- Daoutis, C. A., Pilling, M., & Davies, I. R. (2006). Categorical effects in visual search for colour. *Visual Cognition*, *14*(2), 217-240. DOI: [10.1080/13506280500158670](https://doi.org/10.1080/13506280500158670)
- Davidoff, J. (2015). Color categorization across cultures. In A. J. Elliot, M. D. Fairchild, & A. Franklin (Eds.), *Handbook of Color Psychology* (pp. 259–278). Cambridge University Press.
- Davidoff, J., Goldstein, J., Tharp, I., Wakui, E., & Fagot, J. (2012). Perceptual and categorical judgements of colour similarity. *Journal of Cognitive Psychology*, *24*(7), 871-892. DOI: [10.1080/20445911.2012.706603](https://doi.org/10.1080/20445911.2012.706603)
- De Fockert, J. W., Caparos, S., Linnell, K. J., & Davidoff, J. (2011). Reduced distractibility in a remote culture. *PLoS One*, *6*(10), e26337. DOI: [10.1371/journal.pone.0026337](https://doi.org/10.1371/journal.pone.0026337)
- Drivonikou, G. V., Kay, P., Regier, T., Ivry, R. B., Gilbert, A. L., Franklin, A., & Davies, I. R. (2007). Further evidence that Whorfian effects are stronger in the right visual field

- than the left. *Proceedings of the National Academy of Sciences*, 104(3), 1097-1102.
DOI: [10.1073/pnas.0610132104](https://doi.org/10.1073/pnas.0610132104)
- Firestone, C., & Scholl, B. J. (2016). Cognition does not affect perception: Evaluating the evidence for “top-down” effects. *Behavioral and Brain Sciences*, 39. e229. DOI: [10.1017/S0140525X15000965](https://doi.org/10.1017/S0140525X15000965)
- Fonteneau, E., & Davidoff, J. (2007). Neural correlates of colour categories. *NeuroReport*, 18(13), 1323–1327. DOI: [10.1097/WNR.0b013e3282c48c33](https://doi.org/10.1097/WNR.0b013e3282c48c33)
- Forder, L., He, X., & Franklin, A. (2017). Colour categories are reflected in sensory stages of colour perception when stimulus issues are resolved. *PLOS ONE*, 12(5), e0178097.
DOI: [10.1371/journal.pone.0178097](https://doi.org/10.1371/journal.pone.0178097)
- Forder, L., & Lupyan, G. (2019). Hearing words changes color perception: Facilitation of color discrimination by verbal and visual cues. *Journal of Experimental Psychology: General*, 148, 1105–1123. DOI: [10.1037/xge0000560](https://doi.org/10.1037/xge0000560)
- Gilbert, A. L., Regier, T., Kay, P., & Ivry, R. B. (2006). Whorf hypothesis is supported in the right visual field but not the left. *Proceedings of the National Academy of Sciences*, 103(2), 489-494. DOI: [10.1073/pnas.0509868103](https://doi.org/10.1073/pnas.0509868103)
- Goto, H. (1971). Auditory Perception by Normal Japanese Adults of the Sounds L and R. *Neuropsychologia* 9(3), 317–323. DOI: [10.1016/0028-3932\(71\)90027-3](https://doi.org/10.1016/0028-3932(71)90027-3)
- Grandison, A., Davies, I. R., & Sowden, P. T. (2014). The evolution of grue. In Anderson, W., Biggam, C.P., Hough, C., Kay, C. (Eds.). *Colour studies: a broad spectrum*. (pp. 53-66). John Benjamins.
- Green, P.A., Brandley, N.C., & Nowicki, S. (2020). Categorical perception in animal communication and decision-making. *Behavioral Ecology*, 31, 859-867. DOI: [10.1093/beheco/araa004](https://doi.org/10.1093/beheco/araa004)

- Gutchess, A. & Rajaran, S. (2022). Consideration of culture in cognition: How we can enrich methodology and theory. *Psychonomic Bulletin and Review*, 30(3), 914-931. DOI: [10.3758/s13423-022-02227-5](https://doi.org/10.3758/s13423-022-02227-5)
- Hanley, J. R., & Roberson, D. (2011). Categorical perception effects reflect differences in typicality on within-category trials. *Psychonomic Bulletin & Review*, 18(2), 355-363. DOI: [10.3758/s13423-010-0043-z](https://doi.org/10.3758/s13423-010-0043-z)
- Harnad, S. (1987). Psychophysical and cognitive aspects of categorical perception: A critical overview. In Harnad, S. (Ed.) *Categorical Perception: The Groundwork of Cognition*, (pp. 1-52). Cambridge University Press.
- Haslam, C., Wills, A. J., Haslam, S. A., Kay, J., Baron, R., & McNab, F. (2007). Does maintenance of colour categories rely on language? Evidence to the contrary from a case of semantic dementia. *Brain and Language*, 103(3), 251–263. DOI: [10.1016/j.bandl.2007.08.007](https://doi.org/10.1016/j.bandl.2007.08.007)
- He, H., Li, J., Xiao, Q., Jiang, S., Yang, Y., & Zhi, S. (2019). Language and Color Perception: Evidence From Mongolian and Chinese Speakers. *Frontiers in Psychology*, 10, 551. DOI: [10.3389/fpsyg.2019.00551](https://doi.org/10.3389/fpsyg.2019.00551)
- Ishihara, S. (2001). *The series of plates designed as a test for colour deficiency*. Kanehara.
- Kay, P., & Kempton, W. (1984). What is the Sapir-Whorf hypothesis? *American Anthropologist*, 86(1), 65-79. DOI: [10.1525/aa.1984.86.1.02a00050](https://doi.org/10.1525/aa.1984.86.1.02a00050)
- Kay, P., & Maffi, L. (1999). Color appearance and the emergence and evolution of basic color lexicons. *American Anthropologist*, 101(4), 743-760. <https://www.jstor.org/stable/684051>
- Kinsbourne, M., & Warrington, E. K. (1964). Observations on colour agnosia. *Journal of Neurology, Neurosurgery & Psychiatry*, 27(4), 296–299. DOI: [10.1136/jnnp.27.4.296](https://doi.org/10.1136/jnnp.27.4.296)

- Liberman, A. M., Harris, K. S., Hoffman, H. S. & Griffith, B. C. (1957). The discrimination of speech sounds within and across phoneme boundaries. *Journal of Experimental Psychology*, 54(5), 358 – 368. DOI: [10.1037/h0044417](https://doi.org/10.1037/h0044417)
- Lindsey, D. T., Brown, A. M., Reijnen, E., Rich, A. N., Kuzmova, Y. I., & Wolfe, J. M. (2010). Color channels, not color appearance or color categories, guide visual search for desaturated color targets. *Psychological Science*, 21(9), 1208–1214. DOI: [10.1177/0956797610379861](https://doi.org/10.1177/0956797610379861)
- Lindsey, D.T., Brown, A.M. (2014). The color lexicon of American English. *Journal of Vision*, 14(2), 17. DOI: [10.1167/14.2.17](https://doi.org/10.1167/14.2.17)
- Linnell, K. J., Bremner, A. J., Caparos, S., Davidoff, J., & de Fockert, J. W. (2018). Urban experience alters lightness perception. *Journal of Experimental Psychology: Human Perception and Performance*, 44(1), 2. DOI: [10.1037/xhp0000498](https://doi.org/10.1037/xhp0000498)
- Linnell, K. J., Caparos, S., de Fockert, J. W., & Davidoff, J. (2013). Urbanization decreases attentional engagement. *Journal of Experimental Psychology: Human Perception and Performance*, 39(5), 1232. DOI: [10.1037/a0031139](https://doi.org/10.1037/a0031139)
- Lupyan, G. (2012). Linguistically modulated perception and cognition: The label-feedback hypothesis. *Frontiers in Psychology*, 3:54. DOI: [10.3389/fpsyg.2012.00054](https://doi.org/10.3389/fpsyg.2012.00054)
- Lupyan, G., Rahman, R. A., Boroditsky, L., & Clark, A. (2020). Effects of Language on Visual Perception. *Trends in Cognitive Sciences*, 24(11), 930–944. DOI: [10.1016/j.tics.2020.08.005](https://doi.org/10.1016/j.tics.2020.08.005)
- Lupyan, G., Thompson-Schill, S. L., & Swingle, D. (2010). Conceptual penetration of visual processing. *Psychological Science*, 21(5), 682–691.
- Maier, M., & Abdel Rahman, R. (2018). Native Language Promotes Access to Visual Consciousness. *Psychological Science*, 29(11), 1757–1772. DOI: [10.1177/0956797618782181](https://doi.org/10.1177/0956797618782181)

- Maule, J., Witzel, C., & Franklin, A. (2014). Getting the gist of multiple hues: metric and categorical effects on ensemble perception of hue, *Journal of the Optical Society of America. A*, 31(4), A93-A102. DOI: [10.1364/JOSAA.31.000A93](https://doi.org/10.1364/JOSAA.31.000A93)
- Martinovic, J., & Hardman, A. (2023). Color and visual search, color singletons. In R. Shamey (Ed.), *Encyclopedia of Color Science and Technology* (pp. 235-238). Springer.
- Martinovic, J., Paramei, G. V., & MacInnes, W. J. (2020). Russian blues reveal the limits of language influencing colour discrimination. *Cognition*, 201, 104281, 1-15. DOI: [10.1016/j.cognition.2020.104281](https://doi.org/10.1016/j.cognition.2020.104281)
- Munnich, E., & Landau, B. (2003). The effects of spatial language on spatial representation: Setting some boundaries. In D. Gentner & S. Goldin-Meadow (Eds.), *Language in mind: Advances in the study of language and thought* (pp. 113–155). MIT Press.
- Mylonas, D. (2020). *Colour communication within different languages* (Doctoral dissertation, University College London, UK, URI: <https://discovery.ucl.ac.uk/id/eprint/10089125>).
- Mylonas, D., Caparos, S., & Davidoff, J. (2022). *Augmenting a colour lexicon. Humanities and Social Sciences Communications*, 9(1), 1-12. DOI: [10.1057/s41599-022-01045-3](https://doi.org/10.1057/s41599-022-01045-3)
- Mylonas, D., & MacDonald, L. (2016). Augmenting basic colour terms in English. *Color Research & Application*, 41(1), 32–42. DOI: [10.1002/col.21944](https://doi.org/10.1002/col.21944)
- Oxner, M., Martinovic, J., Forschack, N., Lempe, R., Gundlach, C., & Müller, M. (2023). Global enhancement of target color—not proactive suppression—explains attentional deployment during visual search. *Journal of Experimental Psychology: General*, 152(6), 1705-1722.
- Paramei, G.V., & Bimler, D.L., (2021). Language and psychology. In: Steinvall A, Street S (Eds.) *A Cultural History of Color, Vol. 6, The Modern Age: From 1920 to present* (pp. 117–134). London: Bloomsbury

- Peirce, J. W. (2007). PsychoPy—Psychophysics software in Python. *Journal of Neuroscience Methods*, 162(1–2), 8–13. DOI: [10.1016/j.jneumeth.2006.11.017](https://doi.org/10.1016/j.jneumeth.2006.11.017)
- Pylyshyn, Z. (1999). Is vision continuous with cognition?: The case for cognitive impenetrability of visual perception. *Behavioral and Brain Sciences*, 22(3), 341-365. DOI: [10.1017/s0140525x99002022](https://doi.org/10.1017/s0140525x99002022)
- Raftopoulos, A., & Lupyan, G. (2018). Editorial: Pre-cueing effects on perception and cognitive penetrability. *Frontiers in Psychology*, 9: 230. DOI: [10.3389/fpsyg.2018.00230](https://doi.org/10.3389/fpsyg.2018.00230)
- Rajendran, S., Maule, J., Franklin, A., & Webster, M. A. (2021). Ensemble coding of color and luminance contrast. *Attention, Perception, & Psychophysics*, 83(3), 911-924. DOI: [10.3758/s13414-020-02136-6](https://doi.org/10.3758/s13414-020-02136-6)
- Regier, T., Kay, P., & Khetarpal, N. (2007). Color naming reflects optimal partitions of color space. *Proceedings of the National Academy of Sciences*, 104(4), 1436-1441. DOI: [10.1073/pnas.0610341104](https://doi.org/10.1073/pnas.0610341104)
- Roberson, D., Davidoff, J., & Braisby, N. (1999). Similarity and categorisation: Neuropsychological evidence for a dissociation in explicit categorisation tasks. *Cognition*, 71(1), 1-42. DOI: [10.1016/S0010-0277\(99\)00013-X](https://doi.org/10.1016/S0010-0277(99)00013-X)
- Roberson, D., Davidoff, J., Davies, I. R. L., & Shapiro, L. R. (2005). Color categories: Evidence for the cultural relativity hypothesis. *Cognitive Psychology*, 50(4), 378–411. DOI: [10.1016/j.cogpsych.2004.10.001](https://doi.org/10.1016/j.cogpsych.2004.10.001)
- Roberson, D., Davies, I., & Davidoff, J. (2000). Color categories are not universal: replications and new evidence from a stone-age culture. *Journal of Experimental Psychology: General*, 129(3), 369-398. DOI: [10.1037//0096-3445.129.3.369](https://doi.org/10.1037//0096-3445.129.3.369)
- Roberson, D., Hanley, J.R., Pak H.(2009a) Thresholds for color discrimination in English and Korean speakers. *Cognition* 112(3):482–487. DOI: 10.1016/j.cognition.2009.06.008

- Roberson, D., Pak, H., & Hanley, J. R. (2009b). Categorical perception of colour in the left and right visual field is verbally mediated: Evidence from Korean. *Cognition*, *107*(2), 752-762. DOI: [10.1016/j.cognition.2007.09.001](https://doi.org/10.1016/j.cognition.2007.09.001)
- Siuda-Krzywicka, K., Boros, M., Bartolomeo, P., & Witzel, C. (2019). The biological bases of colour categorisation: From goldfish to the human brain. *Cortex*, *118*, 82–106. DOI: [10.1016/j.cortex.2019.04.010](https://doi.org/10.1016/j.cortex.2019.04.010)
- Siuda-Krzywicka, K., Witzel, C., Chabani, E., Taga, M., Coste, C., Cools, N., Ferrieux, S., Cohen, L., Seidel Malkinson, T., & Bartolomeo, P. (2019). Color Categorization Independent of Color Naming. *Cell Reports*, *28*(10), 2471-2479.e5. DOI: [10.1016/j.celrep.2019.08.003](https://doi.org/10.1016/j.celrep.2019.08.003)
- Siuda-Krzywicka, K., Witzel, C., Bartolomeo, P., Cohen, L. Color Naming and Categorization Depend on Distinct Functional Brain Networks. (2021). *Cerebral Cortex*, *31*(2), 1106-1115. DOI: [10.1093/cercor/bhaa278](https://doi.org/10.1093/cercor/bhaa278)
- Suegami, T., Aminihaajibashi, S., & Laeng, B. (2014). Another look at category effects on colour perception and their left hemispheric lateralisation: No evidence from a colour identification task. *Cognitive Processing*, *15*(2), 217–226.
- Sun, M., Hu, L., Fan, & Zhang, X. (2020). Tracking within-category colors is easier: Color categories modulate location processing in a dynamic visual task. *Memory and Cognition*, *48*(1), 32–41 (2020). DOI: [10.3758/s13421-019-00959-9](https://doi.org/10.3758/s13421-019-00959-9)
- Sun M, Zhang X, Fan L, Hu L. (2018). Hue distinctiveness overrides category in determining performance in multiple object tracking. *Attention, Perception & Psychophysics*, *80*(2), 374-386. DOI: [10.3758/s13414-017-1466-7](https://doi.org/10.3758/s13414-017-1466-7).
- Thierry, G., Athanasopoulos, P., Wiggett, A., Dering, B., & Kuipers, J.-R. (2009). Unconscious effects of language-specific terminology on preattentive color perception.

Proceedings of the National Academy of Sciences, 106(11), 4567–4570. DOI:

[10.1073/pnas.0811155106](https://doi.org/10.1073/pnas.0811155106)

Trémolière B, Davidoff J, Caparos S. (2022) A 21st century cognitive portrait of the Himba, a remote people of Namibia. *British Journal of Psychology.*, 113(2), 508-530. DOI: 10.1111/bjop.12539

Treisman, A., & Souther, J. (1985). Search asymmetry: a diagnostic for preattentive processing of separable features. *Journal of Experimental Psychology: General*, 114(3), 285. DOI: [10.1037/0096-3445.114.3.285](https://doi.org/10.1037/0096-3445.114.3.285)

Webster, M. A., & Kay, P. (2012). Color categories and color appearance. *Cognition*, 122(3), 375-392. DOI: [10.1016/j.cognition.2011.11.008](https://doi.org/10.1016/j.cognition.2011.11.008)

Witzel, C. (2019). Misconceptions about colour categories. *Review of Philosophy and Psychology*, 10(3), 499-540. DOI: [10.1007/s13164-018-0404-5](https://doi.org/10.1007/s13164-018-0404-5)

Witzel, C., & Gegenfurtner, K. R. (2011). Is there a lateralized category effect for color? *Journal of Vision*, 11(12), 16-16. DOI: [10.1167/11.12.16](https://doi.org/10.1167/11.12.16)

Witzel, C., & Gegenfurtner, K. R. (2013). Categorical sensitivity to color differences. *Journal of Vision*, 13(7), 1-1. DOI: [10.1167/13.7.1](https://doi.org/10.1167/13.7.1)

Witzel, C., & Gegenfurtner, K. R. (2014). Category effects on colour discrimination. In Anderson, W., Biggam, C.P., Hough, C., Kay, C. (Eds.). *Colour studies: a broad spectrum*. (pp. 200-211). John Benjamins.

Witzel, C., & Gegenfurtner, K. R. (2015). Categorical facilitation with equally discriminable colors. *Journal of Vision*, 15(8), 22-22. DOI: [10.1167/15.8.22](https://doi.org/10.1167/15.8.22)

Witzel, C., & Gegenfurtner, K. R. (2016). Categorical perception for red and brown. *Journal of Experimental Psychology: Human Perception and Performance*, 42(4), 540-570. DOI: [10.1037/xhp0000154](https://doi.org/10.1037/xhp0000154)

Witzel, C., O'Regan, J. K., & Hansmann-Roth, S. (2017). The dress and individual differences in the perception of surface properties. *Vision Research*, *141*, 76–94.

<https://doi.org/10.1016/j.visres.2017.07.015>

Witzel, C., Wuerger, S., & Hurlbert, A. (2016). Variation of subjective white-points along the daylight axis and the colour of the dress. *Journal of Vision*, *16*(12), 744-744.

DOI:[10.1167/16.12.744](https://doi.org/10.1167/16.12.744)

Yokoi, K., & Uchikawa, K. (2005). Color category influences heterogeneous visual search for color. *Journal of the Optical Society of America A*, *22*(11), 2309-2317. DOI:

[10.1364/josaa.22.002309](https://doi.org/10.1364/josaa.22.002309)

Zimmer, A.C. (1982). What really is turquoise? A note on the evolution of color terms.

Psychological Research. *44*(3):213-30. PMID: 7156266. DOI: [10.1007/BF00308421](https://doi.org/10.1007/BF00308421).

Author Bios

Elley Wakui is a Senior Lecturer in the School of Psychology at University of East London, UK. Her research interests are in visual cognition, attention and object recognition using behavioural measures, eye-tracking and EEG.

Dimitris Mylonas is Associate Professor in Data Science at Northeastern University London, UK. He holds a PhD from the Department of Computer Science, University College London and a MSc in Digital Colour Imaging from London College of Communication, University of the Arts London. Dimitris held research posts in the School of Psychology, University of Liverpool, in the Wellcome Laboratory of Neurobiology, University College London and in the Dept. of Psychology, Goldsmiths College, University of London. His research focuses on the intersection of perceptual, cognitive, and linguistic aspects of color with an aim to augment color communication within and across languages.

Serge Caparos is a lecturer in Cognitive Psychology at Université Paris 8 (France), and a member of the Institut Universitaire de France. After completing a PhD in Cognitive Psychology at Goldsmiths University of London (UK) in 2009, he worked on a postdoctoral research project, studying cross-cultural perceptual differences between Westerners and the Himba of Northern Namibia. He then completed a second postdoctoral research project about the links between emotion and reasoning, at Université du Québec à Trois-Rivières (Canada). Serge was appointed lecturer at Université de Nîmes in September 2014, and then at Université Paris 8 in January 2019.

Jules Davidoff is Professor of Psychology at Goldsmiths, University of London. He has held appointments in University Departments at Essex, Swansea, Edinburgh and the LSE. He has also worked for the Medical Research Council at the University of Oxford and at the National Hospital for Neurology, Queen Square. He has shown the influence of color terms on color perception through both neuropsychological and cross-lingual studies.

Declarations

Data availability statement

The datasets generated during the current study are available online in the Open Science Framework (OSF) Repository of the Center for Open Science,

https://osf.io/nkruh/?view_only=e93c3fbccaba4f638a27a778ec410bf1

Funding

This work was supported by the British Academy/Leverhulme Small Research Grants - SRG 2017. Dimitris Mylonas was partly supported by the University College London (UCL) Computer Science — Engineering and Physical Sciences Research Council, Doctoral Training

Grant: EP/M506448/1 – 1573073 and by the FY22 TIER 1 Seed Grant from Northeastern University, USA.

Conflicts of interest/Competing interests

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Ethics approval

The study received ethical approval from Goldsmiths University of London (N°1390, 4th of June 2018) and the University of East London University Research Ethics Committee, both in accordance with the British Psychological Society Code for Human Research Ethics.

Consent to participate

Informed consent was obtained individually for every participant; these were provided in a culturally sensitive manner. Our Himba interpreter first approached the chief of the village for permission to be there. We never approached participants to ask them to take part. They approached us and the interpreter informed them of our study and that they can withdraw at any time. All participants could not read.

Consent for publication

Consent for publication was integrated within the informed consent.