

**Investigating the underlying mechanisms of categorical perception of colour using the  
Event-Related Potential technique**

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*Abstract*

Categorical perception (CP) of colour is demonstrated by faster and more accurate discrimination of colours that cross a category boundary than equivalently spaced colours from the same colour category. Despite a plethora of behavioural research investigating the origin and nature of colour CP, the underlying mechanisms involved in the effect are still unresolved. A recent body of work has made use of the Event-Related Potential (ERP) technique, which involves the measurement of event-related brain potentials at the scalp, enabling exploration of the time course of neural processes that are involved in colour CP. The merits of the ERP technique are presented and five studies that have used this approach to investigate colour CP and colour categorisation are reviewed. Each is discussed in relation to the debate about the origin and nature of colour category effects.

**Keywords:** colour, event-related potentials, categorical perception, visual oddball, visual search

### *Introduction to the debate*

Although the colour spectrum is a physical continuum of light, we perceive it as a series of discrete categories. The categories that make up the colour spectrum are marked by our language in the terms that we use for colour. For example, the English language uses terms such as *red, orange, yellow, green, blue, purple*, etc., to define colour categories, but other languages use different numbers of colour terms and place category boundaries in different locations (e.g., MacLaury, Paramei & Dedrick, 2008). As well as being present in language, colour categories are also evident in the way that we respond to colour. Indeed, there appear to be qualitative differences between colour categories, coupled with a heightened discriminability around category boundaries that affects our perceptual and cognitive judgements about colour. For example, it is easier to distinguish between two colours that are from different categories than two colours that are from the same category, even when chromatic separations are equivalent. This effect is known as ‘categorical perception’ (Harnad, 1987).

Categorical perception (CP) of colour appears to be a robust phenomenon that can be demonstrated using a range of techniques, stimuli, colour spaces and measures. However, there is no clear consensus on the origin of colour categories or the underlying mechanisms of colour category effects. A key point of contention is whether there are universal restrictions on how colour categories form, or whether the way that the colour spectrum is divided up into categories is arbitrary (e.g., Berlin & Kay, 1969). There is variation in how

the world's languages segment colour space and this may suggest that the formation of colour categories is arbitrary (e.g., Roberson, Davies & Davidoff, 2000). For example, the location of colour category boundaries and the number of basic colour terms used differs across languages; and colour lexicons have also been found to evolve over time (e.g., MacLaury et al., 2008). Conversely, investigation of over one-hundred of the world's unwritten languages has provided evidence to suggest that the colour naming systems of different languages share some commonality, with statistical tendencies for colour categories to form at certain points in colour space (e.g., Kay & Regier, 2003).

Despite a large amount of debate there is currently little agreement on the origin and nature of colour category effects such as CP. The term 'categorical perception' suggests a role for perceptual mechanisms, and some have argued that category effects could be due to greater perceptual discriminability around category boundaries than within categories (e.g., Harnad, 1987). This 'warping' of colour space at the boundaries between categories could be innate or pre-linguistic (e.g., Franklin & Davies, 2004), or it could be learned under the influence of language, as the Linguistic Relativity hypothesis suggests (e.g., Roberson, Davidoff, Davies & Shapiro, 2004). Another possibility is that colour CP could be due to the direct or 'on-line' use of language during task execution, with discriminations made on the basis of verbal as opposed to perceptual codes (e.g., Roberson & Davidoff, 2000). Here, the influence of language could be explicit, through the use of category labels. It could also be implicit, involving a category code at the semantic level (Bornstein & Korda, 1984), or even some pre-phonological representation such as the 'lemma' (Caramazza, 1997).

The relative contributions of perceptual and linguistic mechanisms to colour category effects are unresolved because performance on behavioural tasks used to investigate colour CP could be influenced by perceptual processes, or by linguistic processes, or by a combination of the two. For example, on a ‘triads task’, where three stimuli are presented and participants must identify the stimulus they think is most different, a stimulus may be selected as the odd-one-out for several reasons. Selection may be made on the basis of a perceptual difference, choosing the stimulus that looks the most different, or on the basis of a nominal difference, choosing the stimulus with a different name. Or, a stimulus may be chosen as the odd-one-out for both these reasons. Similarly, behavioural studies that measure performance using accuracy and / or reaction times are unable to attribute variations in these measures to specific cognitive processes (e.g., Luck, Woodman & Vogel, 2000). Therefore, behavioural investigations of colour category effects can be problematic as it is difficult for them to isolate the different mechanisms involved in CP and determine the relative contributions of processes such as perception and language. Indeed, the findings of behavioural studies of colour CP present a complicated picture of the roles that language and perception play. Category effects on perceptual tasks such as visual search tasks implicate perceptual mechanisms in colour CP (e.g., Daoutis, Pilling & Davies, 2006). Additionally, studies of CP in pre-linguistic infants suggest that language is not the origin of CP (e.g., Franklin & Davies, 2004). However, studies of cross-cultural differences (e.g., Roberson et al., 2000), and hemispheric asymmetries (e.g., Gilbert, Regier, Kay & Ivry, 2006), point to a role for language in the development and maintenance of category effects, but have not shown conclusively whether language affects perception or whether it is merely used as a task strategy. Studies of category learning have shown that colour CP can be induced following

relatively short-term category training (Özgen & Davies 2002), but it is not clear what mechanisms cause acquired CP, or how long they last. Therefore, despite a plethora of research in this area, debate about the underlying mechanisms of colour CP continues.

### *The ERP approach*

To further understand the processes involved in colour CP, an alternative approach that builds upon the findings of behavioural studies is required. Electrophysiological measures such as Event-Related Potentials (ERPs) have been used in studies of CP in domains other than colour, for example, phoneme CP (e.g., Dehaene-Lambertz, 1997) and CP of facial expressions (e.g., Rossignol, Anselme, Vermeulen, Philippot & Campanella, 2007). The ERP technique involves the measurement of event-related brain potentials at the scalp, enabling exploration of the time course of neural processes that occur during a defined period of time within which a stimulus is shown or an event occurs. ERP waveforms consist of a sequence of positive and negative voltage deflections, which are referred to as ‘peaks’ or ‘waves’, or more generally as ‘components’. ERP components relate to specific neural processes and are typically defined by three key features: polarity (whether the peak or wave is positive or negative), latency (the time at which it occurs) and general scalp distribution. The naming of ERP components often takes a format in which the letters ‘P’ or ‘N’ are followed by a number. P and N refer to the polarity of a component, indicating positive-going and negative-going components respectively, and the number indicates a component’s ordinal position within the waveform. It is possible to measure the amplitude and the latency of ERP components and to apply statistical analyses to these measurements. An example of an adult ERP waveform can be seen in Figure 1.

@@ Insert Figure 1 here

Because of their excellent temporal resolution, ERPs have the potential to show when in the processing stream categorical effects may occur, and to distinguish early perceptual effects from later post-perceptual ones (see Rugg & Coles, 1995). The ERP technique is still a relatively novel approach in the field of colour perception and to date there have only been four studies that have used ERPs to investigate colour CP (Clifford, Franklin, Davies & Holmes 2009; Fonteneau & Davidoff, 2007; Holmes, Franklin, Clifford & Davies, 2009; Liu, Li, Campos, Wang, Zhang, Qui, Zhang & Sun, 2009). In addition, Thierry, Athanasopoulos, Wiggett, Dering and Kuipers (2009) used the ERP technique to investigate effects of colour language on colour perception, making a further contribution to the debate about the origin and nature of colour categories. We review each of these studies in turn.

***Fonteneau and Davidoff (2007): Unattended colour change***

Fonteneau and Davidoff (2007) provide the first electrophysiological evidence of colour CP. They recorded ERPs in adults during a visual oddball task. Oddball tasks entail the presentation of infrequent (deviant) stimuli among high-frequency (standard) stimuli, and are particularly appropriate for investigating CP as the waveforms elicited by deviant stimuli correspond to processes involved in event categorization. The task used by Fonteneau and Davidoff required the detection of infrequent cartoon characters amongst a sequence of colour patches. Within each block there were two colours appearing in the sequence, a standard that was presented frequently and a deviant, which was presented infrequently. Colours differed only in hue with lightness and saturation kept constant. No differential

response to the colours was required, only a response following the detection of the infrequent cartoon characters. The crucial manipulation was the nature of the difference between the two colours in the sequence, which were either within-category (e.g., two greens) or cross-category (e.g., a green and a blue). The hue difference between stimuli, as specified in Munsell colour space, was the same for within- and cross-category conditions.

Several differences for within- and cross-category conditions were revealed through analysis of the ERP waveforms (using analysis of variance [ANOVA] and Fisher LSD tests for post-hoc comparisons). First, an ‘oddball effect’ was observed for cross-category and within-category conditions during the 160-200 ms time range, where the deviant elicited an ERP with greater amplitude than the standard. However, for the within-category condition only, this oddball effect was also present during the extended 200-280 ms time range. The extension of the oddball effect for the within-category condition was interpreted as evidence that within-category discrimination was more difficult than cross-category discrimination. Additionally, the morphologies of the ‘difference waves’ of within- and cross-category conditions from the standard were found to differ. The peak latency (the time at which the maximum amplitude was elicited) for the cross-category difference wave occurred at 195 ms, which was 19 ms earlier than for the within-category difference wave. Fonteneau and Davidoff interpreted this difference in peak latency as a neural correlate for colour CP. This can be linked to a late phase of the N1 component, which occurs after an initial stage of discriminative perceptual processing (Ritter, Simson & Vaughan, 1983; see also Vogel & Luck, 2000, for a review on the visual N1 component). Thus, it can be argued that this study provides evidence for the involvement of post-perceptual mechanisms in colour CP. However, Fonteneau and Davidoff directed participants’ attention away from the colour



patches, towards the cartoon characters and participants were not aware that the task was even concerned with colour. It is therefore possible that sensitivity to early perceptual effects of colour CP may occur on a different task or on a task where attention is directed towards deviant colour stimuli.

***Holmes et al. (2009): Attended colour change***

Holmes and colleagues (2009) also employed the ERP technique to investigate the time course and neural markers of colour CP. They used a visual oddball task that differed in several ways from that used by Fonteneau and Davidoff. Crucially, Holmes et al.'s task required participants' attention to be focused on the coloured stimuli, by instructing them to mentally count the number of deviants occurring in each block. It has been suggested that early perceptual effects of CP are more likely to be exhibited if attention is explicitly directed towards the feature being categorized (e.g., Luck, et al., 2000). Additionally, Holmes and colleagues used two deviant colours instead of one, one of which was within-category and the other cross-category. The separation sizes between stimuli were equated in Munsell colour space but were considerably less than Fonteneau and Davidoff's stimulus separations, being more typical of those commonly used in experiments on colour CP (e.g., Drivonikou, Kay, Regier, Ivry, Gilbert, Franklin & Davies, 2007). Unlike Fonteneau and Davidoff, Holmes and colleagues also collected behavioural data from a separate group of participants. The behavioural data revealed that participants were faster and more accurate at detecting cross-category deviants compared to deviants that were within-category, thereby confirming the presence of classic CP effects (see e.g., Bornstein & Korda, 1984).

ERP analysis (using ANOVA and planned linear [Helmert] contrasts) also revealed the presence of category effects, with differences in the waveforms for within- and cross-category deviants occurring during several time periods. First, greater mean amplitude was elicited during the P2 and P3 time windows for cross-category relative to within-category deviants. The P2 and P3 components (occurring 210-270 and 350-600 ms post-stimulus onset respectively) are linked to post-perceptual stimulus evaluation and typically have larger amplitude for novel or infrequent stimuli (Patel & Azzam, 2005). It is possible that verbal labelling contributes to CP during this stage of processing, although the P2 and P3 components can reflect a wide range of post-perceptual processes (e.g., McCarthy & Donchin, 1981). This evidence for post-perceptual involvement in colour CP is consistent with the findings of Fonteneau and Davidoff. However, unlike Fonteneau and Davidoff, category effects were also found during earlier time ranges. Cross-category deviants elicited earlier peak latencies compared to within-category deviants for P1 and N1 components, with differences in the waveforms occurring as early as 90 ms post-stimulus onset. Category differences in peak latencies were typically smaller than those found in the Fonteneau and Davidoff study (~6 ms vs. ~19 ms, respectively [effect sizes not provided]). It should be noted, however, that peak latencies were measured from original ERP waveforms in the former case whereas they were taken from difference waves in the latter, and so a comparison of the magnitudes of these effects is not entirely meaningful. The P1 component (80-120 ms post-stimulus) and the early phase of the N1 component (130-190 ms post-stimulus) correspond to early perceptual and sensory processes in the brain (e.g., Polich, 1998). These components are primarily sensitive to the physical characteristics of sensory stimuli as well as reflecting manipulations of attention (e.g., Luck et al., 2000). This finding provides

evidence for an involvement of early perceptual processes in colour CP, showing stronger early perceptual discrimination for cross- than within-category deviant stimuli.

***Liu et al. (2009): Hemispheric asymmetries***

Liu and colleagues (2009) used a combination of behavioural and electrophysiological measures to explore hemispheric asymmetries in colour CP. Several studies have investigated the lateralization of CP using behavioural techniques (e.g., Gilbert et al., 2006), but the ERP technique had not previously been employed. Studies of hemispheric asymmetries offer a novel approach to exploring the origins of colour CP. As the left hemisphere (LH) of the brain is dominant for language, then CP should be stronger for the LH if language has a role in the effect (e.g., Gilbert et al., 2006). Due to the contra-lateral organisation of the brain, if there is a contribution of language, CP should be more pronounced for target stimuli appearing in the right visual field (RVF) than the left visual field (LVF). An LH advantage for colour CP has been demonstrated by several behavioural studies (e.g., Drivonikou et al., 2007; Gilbert et al., 2006; Roberson, Pak & Hanley, 2008). A recent study by Ting Siok et al. (2009) has also provided functional MRI (fMRI) evidence for the involvement of LH language regions in colour CP. Additionally, the hemispheric asymmetry for colour CP has been found to disappear with verbal interference, adding strength to the argument that linguistic strategies contribute to colour category effects (Gilbert et al., 2006). However, from these findings alone, the nature of the influence of language remains unclear.

Liu et al. used a visual search task that required the detection of a randomly positioned target colour amongst eleven distractors. Stimuli were displayed in a ring around a central fixation

point occupying the twelve positions of a clock face. Targets were either from the same colour category as the distractors (within-category) or from an adjacent colour category (cross-category), with chromatic separations for within- and cross-category stimuli equated in Munsell colour space. Participants were required to respond as to whether the target appeared to the right or left of fixation (see Gilbert et al., 2006). Both reaction times and ERPs were analysed to compare performance on within- and cross-category trials in the LVF and the RVF. The behavioural data revealed that reaction times were faster for cross-category than within-category trials. This was the case for both visual fields, with no significant difference between the LVF and the RVF.

Interestingly, Liu and colleagues' ERP data (for the N2pc component) revealed a different pattern of results to their behavioural data, highlighting the importance of replication using a range of measures. The N2pc (N2 posterior-contralateral) is a component that is commonly exhibited during visual search tasks (e.g., Brisson & Jolicoeur, 2007), and arises at around 180-350 ms after stimulus onset, contralateral to the location of the target (e.g., Holmes, Bradley, Kragh Nielsen, & Mogg, 2009). N2pc activation is thought to reflect the attentional selection of task-relevant stimuli and / or the suppression of irrelevant distractors (e.g., Eimer, 1996). Liu et al. found that an N2pc component was elicited by within- and cross-category targets. In the RVF, N2pc amplitude was larger for cross-category targets than for within-category targets (effect size not provided). However, in the LVF, there was no difference in the mean amplitude of the two conditions. An ANOVA of stimulus type (within- versus cross-category) by hemisphere (left versus right) was not reported and so it is unclear whether these two pairwise comparisons differed significantly from each other. Liu and colleagues argued that the N2pc for stimuli in the RVF (LH) suggested that there was

some kind of linguistic processing of the stimuli that may have enhanced the discrimination of a target amongst distractors with a different name (e.g., a blue amongst greens). It is also conceivable that the presence of category effects in the LVF (RH) in the behavioural data could have arisen as a result of the transfer of language-related information from the LH to the RH, occurring after (i.e., beyond ~350 ms) the processing indexed by the N2pc (e.g., Roberson et al., 2008). It should be noted, however, that although the presence of CP in the ERP data for targets in the RVF (LH) could have reflected the involvement of linguistic mechanisms, it is also possible that the LH advantage for colour CP might be related to an LH specialization for the perceptual encoding of categorical representations (see Kosslyn, Koenig, Barrett, Backer Cave, Tang & Gabrieli, 1989).

*Clifford et al. (2009): Infant effects*

Clifford et al. (2009) used the ERP technique to investigate colour CP in seven-month old infants. This was the first ERP study of colour CP in infancy and so provides an insight into the development of the time course and electrophysiological markers of colour category effects. It also builds on the findings of behavioural studies of pre-linguistic CP, offering further evidence of categorical responding in the absence of language (e.g., Franklin & Davies, 2004; Franklin et al., 2008; Franklin, Pilling & Davies, 2005). Clifford and colleagues used a visual oddball task that was similar to that used by Holmes et al., but specially adapted for use with seven-month old infants. Frequent repetitions of a standard colour were shown, interspersed with infrequent presentations of two deviant colours, one of which was from the same colour category as the standard and the other from a different category. Hue separations between standard and deviants were equidistant in Munsell colour

space. Coloured stimuli were displayed in the shape of schematic faces to sustain infants' attention over many trials (e.g., Catherwood, Crassini & Freiberg, 1990).

Analysis of the ERP data (using ANOVA and pairwise comparisons with the Bonferroni correction method) revealed differences in the ERP waveforms for within- and cross-category deviant stimuli. These occurred during the time ranges relevant to the three key infant ERP components typically elicited during visual oddball tasks, which are quite different from those that occur in adults. First, the cross-category deviant evoked an Nc component with greater mean amplitude than the standard ( $d = 1.04$ ), whereas the Nc amplitude for the within-category deviant did not differ from that of the standard. The Nc is an early infant ERP component that arose in Clifford et al.'s study between 250 and 650 ms. It is thought to be a marker of attentional allocation to the stimulus (e.g., Quinn, Westerlund & Nelson, 2006). This finding therefore suggests that infants processed the cross-category deviant as if it were notably more different, allocating it more attention than the standard or the within-category deviant, which each received the same amount of attention. The category effect for the Nc indicates that infants first register the categorical status of a colour at least 250 ms after stimulus onset. Second, Clifford et al. found category differences during the time range for the negative slow wave (NSW; associated with novelty detection, Nelson & Monk, 2001) and the positive slow wave (PSW; associated with stimulus encoding and working memory updating, Nelson & Monk, 2001), which in this study occurred between 1150 and 1700 ms. Here, there were differences in the amplitude and polarity of the slow waves elicited by within- and cross-category deviants. Although there was a slightly different pattern of results across different electrode sites, the cross-category deviant was found to elicit a greater NSW than the within-category deviant and the standard (all  $d \leq 1.50$ ). Additionally, at some central

sites the standard and the within-category deviant were found to elicit equivalent PSW amplitudes. Although the within-category deviant is different from the standard, it appeared to be incorporated into the infants' representation of the standard and processed as if it were the same. Clifford and colleagues conclude that mechanisms involved in both attention, novelty detection and recognition memory play a central role in infant colour CP.

***Thierry et al. (2009): Effects of colour language***

A recent ERP investigation by Thierry et al. (2009) explored the effects of colour language on pre-attentive colour perception. Both Greek and English have one basic colour term that includes light and dark green. However, whereas English has one basic colour term that includes light and dark blue, Greek distinguishes light and dark blue with the basic terms '*ble*' and '*ghalazio*' (Androulaki, Gómez-Pestana, Mitsakis, Jover, Coventry & Davies, 2006). Thierry et al. compared ERPs elicited from English and Greek native speakers during a visual oddball task in which participants were required to detect occasional coloured squares in amongst a sequence of coloured circles. Within each experimental block, the sequence of coloured circles consisted of a standard that was presented frequently, and a deviant that was presented infrequently. The standard and the deviant were either two different shades of blue ('*ble*' and '*ghalazio*') or two different shades of green. The assignment of colour was counterbalanced so that in one block the standard was '*ble*' and in another block it was '*ghalazio*'. Similarly for green stimuli, in one block the standard was light green and in another block it was dark green. The difference in luminance between the stimuli was equated for blue and green stimulus pairs. The authors aimed to establish whether

the blue lightness difference that is marked in the Greek language, would be reflected in low-level and pre-attentive stages of perceptual processing.

The results (using ANOVA and follow-up pairwise comparisons) revealed that blue and green deviants elicited a negative ERP component within the time range associated with the visual mismatch negativity (vMMN) component (100-250 ms post stimulus onset). The vMMN is typically evoked in response to infrequent unattended visual events, and has been linked to unconscious pre-attentive change detection and low-level visual processing (e.g., Czigler et al., 2004). Thierry et al.'s data revealed that change detection within the vMMN time range was equivalent across the blue and green deviants for English speakers. For Greek speakers, however, change detection was greater for blue deviants than for green deviants (effect size not provided). The authors attributed this stronger change detection in the blue region of colour space to the Greek language having two basic colour terms for blue. They concluded that differences in colour language can affect early stages of colour perception and are not constrained in their effects to higher level stages of semantic categorisation.

Thierry et al.'s approach offers a novel and effective way of investigating the influence of language on colour perception. However, future studies should ensure that change detection within the vMMN time range truly reflects processes that are independent of attention. It is not entirely clear that this was achieved in Thierry et al.'s study, as a P3 component looked to be present in the grand averaged waveforms for English speakers (indicating possible attention to the colour change). It is conceivable therefore that vMMN effects may have been obscured to an extent by the presence of an overlapping N2b — a component that often arises



prior to the P3 in response to infrequent attended targets (Pazo-Alvarez, Cadaveira & Amendo, 2003). If English speakers were attending to the colour change then caution is advised when drawing conclusions based on cross-linguistic comparisons of pre-attentive colour perception. Further research is clearly needed to assess the influence of language on early pre-attentive stages of colour perception. If the findings of Thierry et al. are supported, this would suggest that even early perceptual category effects could be modulated by language (see Ting Siok et al., 2009).

### *Summary*

ERP studies have provided evidence of colour CP on visual oddball tasks in adults (Fonteneau & Davidoff, 2007; Holmes et al., 2009; Thierry et al., 2009) and infants (Clifford et al., 2009), and on visual search tasks in adults (Liu et al., 2009). Fonteneau and Davidoff found category effects in ERPs during stages of post-perceptual processing, which suggests that post-perceptual stimulus classification and target probability contribute to colour category effects. These post-perceptual stages could reflect a range of different processes, including linguistic or memorial mechanisms (e.g., McCarthy & Donchin, 1981). Holmes and colleagues' findings also implicate post-perceptual processes in colour CP, but additionally show category effects from as early as 90 ms, demonstrating that early perceptual mechanisms contribute to colour CP. These findings are compatible with those in the auditory domain, which reveal that phoneme CP occurs at a very early stage in processing (e.g., Dehaene-Lambertz, 1997). Using a visual search task, Liu et al. found that neural markers of CP were greater for targets in the RVF than the LVF, although CP was present in both visual fields. This finding provides support for laterality effects in colour CP (e.g., Gilbert et al.,

2006; Ting Siok et al., 2009), and implicates the involvement of language. Clifford and colleagues provide electrophysiological evidence of colour CP in pre-linguistic infants, attributing these category effects to mechanisms of attention and novelty detection, consistent with studies of infant category effects in other domains (e.g., Dehaene-Lambertz & Baillet, 1998; Quinn et al., 2006). Thierry et al. interpret their findings as evidence for effects of language on early pre-attentive stages of colour perception. If this is the case, it would suggest that colour discrimination is modulated by language even at a perceptual level. However, further research is needed to verify this claim.

These studies provide evidence for the involvement of a range of processes in colour CP, ruling out purely perceptual or purely linguistic explanations. They build on the findings of previous behavioural studies by presenting clearer and more detailed accounts of the mechanisms involved in colour category effects, revealing the time course of colour CP and the relative contributions of perceptual and post-perceptual processes. However, to fully understand the interplay between these mechanisms further research is necessary. For example, further investigation of early perceptual processes is required to clarify whether early colour category effects are related to pre-linguistic colour categories, or whether they reflect a process of language-mediated perceptual change. Additionally, direct exploration of whether the identified neural markers of colour CP are found in populations whose language segments colour space differently, would clarify the potential interactions of perceptual and post-perceptual processes. Future studies should investigate whether colour category effects in ERP components extend to category boundaries other than blue-green.

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*Figure Captions*

**Figure 1.** An example of an adult ERP waveform elicited in the 1200 ms interval following stimulus onset. The vertical axis represents amplitude ( $\mu\text{V}$ ) and the horizontal axis denotes time in milliseconds. The P1, N1, P2 and P3 components are indicated.

**Figure 1.**

