Cue validity probability influences neural processing of targets

Antonio Arjona[a], Miguel Escudero[b], Carlos M. Gómez[a,*]

[a] *Human Psychobiology Lab, Experimental Psychology Department, University of Seville, C/Camilo José Cela s/n, 41018, Sevilla, Spain*
[b] *Neuroscience and Behaviour Group, Department of Physiology, University of Seville, Avda. Reina Mercedes 6, 41012, Sevilla, Spain*

ARTICLE INFO

ABSTRACT

The neural bases of the so-called Spatial Cueing Effect in a visuo-auditory version of the Central Cue Posner's Paradigm (CCPP) are analyzed by means of behavioral patterns (Reaction Times and Errors) and Event-Related Potentials (ERPs), namely the Contingent Negative Variation (CNV), N1, P2a, P2p, P3a, P3b and Negative Slow Wave (NSW). The present version consisted of three types of trial blocks with different validity/invalidity proportions: 50% valid – 50% invalid trials, 68% valid – 32% invalid trials and 86% valid − 14% invalid trials. Thus, ERPs can be analyzed as the proportion of valid trials per block increases. Behavioral (Reaction Times and Incorrect responses) and ERP (lateralized component of CNV, P2a, P3b and NSW) results showed a spatial cueing effect as the proportion of valid trials per block increased. Results suggest a brain activity modulation related to sensory-motor attention and working memory updating, in order to adapt to external unpredictable contingencies.

1. Introduction

Human beings are immersed in a world of uncertain relationships among stimuli, actions and consequences. The intensity of these relationships needs to be updated in order to improve the adaptive value of responses. Predictions about these relationships make it possible to anticipate the next stimulus and prepare actions. Also, allows to compute the prediction error, which can be considered the driver of the brain network's adaptive changes (Friston, 2009). When people perceive the consequences of their actions, the process of behavioral adaptation begins. Thus, the conduct is immersed in a continuous loop of correction based on previous experience (Fuster, 2004; Gómez & Flores, 2011). This loop can be analyzed through the Central Cue Posner's Paradigm (CCPP) (Posner, 1980). In this experimental paradigm, the subjects (i) generate hypotheses, induced by spatial cues, about the characteristics of the next event in a given context (trying to predict sensory events and prepare adequate motor responses); (ii) perceive the target-stimulus and execute the target-demanded action; and, finally, (iii) confirm or reject their hypotheses, so that their behaviors and underlying neural network connections are fortified or reassessed.

Currently, multiple theoretical approaches include ideas related to this adaptive loop. Fuster (2004) proposed the term "perception-action cycle" to refer to this continuous adaptation of human behavior. It is based on an ongoing assessment of the consequences of actions taken in order to adjust the behavior to the demands of the environment. As Fuster (2008) states, the "perception-action cycle operates at all levels of the central nervous system". Another point of view analyses these adaptive dynamics in terms of probabilities. It is a mathematical approach which considers that subjects generate *a priori* conditional probabilities about the different cues (S1) as predictors of future events (S2). Subjects would change these conditional probabilities (p (S2/S1)) based on the results of previous events (trials in experimental settings), and so the behavior would be continually adapting to the environment (Bruce & Tsotsos, 2009; Feldman & Friston, 2010; Reynolds & Heeger, 2009). In this regard, the model proposed by Friston (2009), known as the 'Bayesian Brain Model', proposes that the brain operates on similar dynamics to the Bayesian Statistics. There would be a continuous change in the conditional probabilities assigned to events based on previous experience. In this context, the concept of 'Prediction Error' would arise as the signal that causes the change in these probabilities, which would correspond, at the neural level, to changes in synaptic weights (Feldman & Friston, 2010; Friston, 2009; Gómez & Flores, 2011). In summary, this model proposes a brain that develops a representation of the world based on the incoming sensory information and the continuous computation of conditional probabilities between world states and neural representations (Knill & Pouget, 2004).

* Corresponding author at: Human Psychobiology Lab Experimental Psycholog Department, University of Seville, C/Camilo Jose Cela s/n. CP: 41018, Spain.
E-mail addresses: aarjona@us.es (A. Arjona), mescudero@us.es (M. Escudero), cgomez@us.es (C.M. Gómez).

One type of stimulus sequence that seems particularly well suited to testing the way cue-target conditional probabilities are updated is the CCPP. In this paradigm, the central cue may validly or invalidly indicate the spatial location of an upcoming target. There are studies showing that the stimuli appearing in attended locations are perceived more easily than the stimuli appearing in unattended locations (Jonides, 1981; Muller & Rabbit, 1989; Posner, Cohen, & Rafal, 1982). When the cue matches the target location (valid trials), faster and more accurate responses are obtained than when they are discordant (invalid trials); this is the so-called 'spatial cueing effect'. This effect shows a Reaction Time (RT) benefit for validly cued targets, and a RT cost for invalidly cued targets. The spatial cueing effect seems to reflect the cost produced by rearranging attentional resources from the side indicated by the cue to the opposite side (Jonides, 1983; Posner, 1980; Posner et al., 1982; Riggio & Kirsner, 1997). The present study aims to analyze this spatial cueing effect from a broader perspective taking in account that cueing not only directs attention to a given location but also defines the probability that the expected event occurs at the cued location (Summerfield & de Lange, 2014). Three types of trial blocks (200 trials per type of block), with different validity/invalidity proportions at the cue-target combination, were analyzed: (i) 50% valid trials – 50% invalid trials, (ii) 68% valid trials – 32% invalid trials and (iii) 86% valid trials – 14% invalid trials (Fig. 1). Thus, it would be possible to observe modulations in subjects' response to the targets based on the higher or lower credibility generated by the cue along each type of block.

From a neural perspective, the objective of the present study was to analyze the ERP amplitude (by means of CNV, lateralized component of CNV, N1, P2 anterior (P2a) and posterior (P2p), P3a/P3b and NSW components) as a result of the credibility generated by the cue along each type of block (50%, 68% and 86% of valid trials). RTs and Errors were also analyzed.

The CNV is a negative slow wave generated by the expectancy of an incoming stimulus (Rockstroh, Elbert, Birbaumer, & Lutzenberge, 1982; Walter, Cooper, Aldridge, & McCallum, 1964). This component has been related to maintenance of attention and/or preparation of motor responses not only for spatial expectancy (Eimer, 1993; Gómez et al., 2004), but also for exogenous (Correa, Lupiáñez, Tudela, & Milliken, 2004, Correa, Lupiáñez, Madrid, & Tudela, 2006; Mento, 2013; Mento, Tarantino, Sarlo, & Bisiacchi, 2013) and endogenous temporal orienting tasks (Mento, 2013; Mento, Tarantino, Vallesi, & Bisiacchi, 2015). Different ERP studies have localized this negativity in fronto-central and posterior sensory areas (Cui et al., 2000; Gómez et al., 2001; Rockstroh et al., 1982; Walter et al., 1964; Zappoli, Versari, & Zappoli, 2000;). Moreover, hemispheric asymmetry of this slow wave has been reported under conditions of motor preparation, anticipation and in sensorial tasks (Butler & Glass, 1974; Kutas & Donchin, 1980; Lutzenberger, Elbert, Rockstroh, & Birbaumer, 1985; McCarthy & Donchin, 1978).

Previous studies, using similar tasks to present report, have observed sensory-motor pre-activation indexed by the CNV, which would reflect the build-up of the resources necessary for the adequate performance of the task (Butler & Glass, 1974; Brunia & Van Boxtel, 2001; Flores, Digiacomo, Meneres, Trigo, & Gómez, 2009; Gómez et al., 2001, 2003; Kutas & Donchin, 1980; Mento, 2013; Mento et al., 2013). The sensory-motor pre-activation produces a benefit in perceiving and responding to the targets in valid trials, and it would be influenced by the processing of S1–S2 probabilities in previous trials (Arjona & Gómez, 2013). This idea fits the Bayesian model of learning as the modulation of associative weights between cues and targets (Feldman & Friston, 2010; Friston, 2009; Gómez & Flores, 2011; Waldmann & Martignon, 1998). With regard to the hypotheses of present report, if CNV is related to expectation, its amplitude must increase in the contralateral side to the cued location as a function of cue validity, and would reflect baseline shifts to the expected stimulus (Summerfield & de Lange, 2014). In this sense, the relationship of CNV with expectation of global sequences (Chennu et al., 2013), and with targets in CCPP (Arjona et al., 2014), has been previously reported.

In CCPP, the target stimulus is followed by a series of ERPs. The 'predictive coding hypotheses' propose that ERP amplitudes to validly cued stimuli must be smaller in comparison to invalidly cued stimuli, not only because expected stimuli would not produce the prediction error generated by invalidly cued stimuli, but also because validly cued stimuli would benefit the sharpening of the tuning curves of sensory neurons, similarly to the suppression repetition effect (Summerfield & de Lange, 2014). In the context of present report, previous hypothesis would predict that the neural response difference between invalidly and validly cued targets must increase (invalid > valid) with the increase of the block cue-validity, given that invalid targets would produce a higher prediction error as the valid proportion of trials per block increases. In this line, with regard to early ERP components (N1 and P2), there may be also an influence in the opposite direction (valid > invalid), given that increased predictability should increase attention to the cued location and would produce the increase of activity to attended stimuli (Hillyard, Hink, Schwent, & Picton, 1973). Therefore, it is possible that, at least for early ERP components, a weighing of the opposite effects of prediction and attention is occurring (Lange, 2013). Instead, in late ERP components (P3a, P3b and NSW), attentional effects should be synergistic with prediction effects (Chennu et al., 2013), and the assessment of adequacy between predicted and current target location would induce increased amplitude in invalid trials with respect to valid trials.
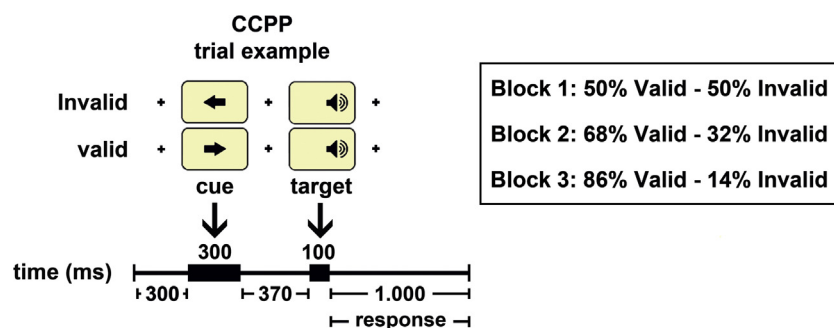
Fig. 1. Experimental paradigm. Trial example (valid and invalid) used in the experiment. The temporal sequence for stimulus presentation appears in the lower part. The central arrow (cue) was presented at the center of the screen, and the auditory stimulus (target) was monaurally emitted through the headphones. On the right side a box appears with the validity/invalidity proportion of trials for each block.