Brief report

The N-40: An electrophysiological marker of response selection

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ABSTRACT

A frontocentral electrophysiological wave occurring before the response, the N-40, has been reported in response choice situations compared to no-choice situations. This was interpreted as reflecting response selection. The gradual sensitivity of the N-40 to the demands put on response choice was tested by manipulating stimulus–response (S–R) congruence so as to influence response selection processes. After Laplacian transformation, an N-40 clearly emerged and was larger for incongruent (more demanding) than for congruent (less demanding) S–R associations. The N-40, which possibly reflects SMA activation, thus provides information about the implementation of response selection in the brain.

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1. Introduction

In choice reaction time (RT) situations, about 40 ms before the contraction of the muscle involved in the required response, a phasic negative event-related potential was evidenced (Vidal et al., 2003). It was called the N-40.[1]

On the basis of converging arguments, Vidal et al. (2011) suggested that the N-40 was an electrophysiological marker of response selection. Indeed, the N-40 (1) arises *before* the build-up of the motor command (Vidal et al., 2003), as revealed by the initial slope (Tarkka and Hallett, 1991) of the motor potential (Deecke et al., 1969); (2) the N-40 has a frontocentral topography and most likely originates from motor areas of the medial wall (Picard and Strick, 1996) whose contribution to response selection is also supported by metabolic neuroimaging in humans (see Rushworth et al., 2004, for a review); and (3) the N-40 is *present* when a choice between two alternative responses is required (in a between-hand choice RT task), but *absent* when no response choice is required (in a Go/No-go task) (Vidal et al., 2011). It is worth pointing out, as discussed by the authors, this difference could not be attributed to perceptual processes as, in the between-hand as well as in the

Go/No-go task, the nature, the number, and the probability of the imperative stimuli were the same. Moreover, in both tasks, participants had to identify the stimuli in order to react properly in both conditions.

If the N-40 is actually an electrophysiological marker of response selection, we should be able to predict that when the implementation of response selection is made more or less demanding, this should result in a modulation of the N-40.

The so-called "Simon task" provides an experimental context for manipulating the demands put on response selection (Kornblum et al., 1990; Ridderinkhof, 2002; van den Wildenberg et al., 2010). In the most common version of the Simon task, participants have to choose between a left- and a right-hand keypress according to the color of a visual stimulus presented a few degrees to either the left or the right of a fixation point. The performance expressed both in terms of error rate and RT is better when the required response corresponds spatially to the irrelevant stimulus location (congruent association) than when it does not (incongruent association). This effect is termed the "Simon effect" (Simon, 1990; Hommel, 2011). A widely accepted interpretation of the Simon effect is that the irrelevant stimulus location automatically engages a response impulse in the spatially corresponding hand while the relevant stimulus color must be translated into the required response according to the task instructions (De Jong et al., 1994; Kornblum, 1994; Proctor et al., 1995, but see Van der Lubbe et al., 2012). When the stimulus–response (S–R) association is congruent, the impulse triggered by the irrelevant stimulus location activates the required response, which facilitates response processing. In contrast, when the S–R association is incongruent, the impulse triggered by the irrelevant location activates the non-required response which must

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[1] The N-40 was evidenced by the Laplacian transformation. Indeed, acting as a highpass spatial filter, the Laplacian transformation strongly attenuates volume conduction effects (Babiloni et al., 2001) and has proven efficient in disentangling overlapping components (Vidal et al., 2003).

be suppressed and replaced by the required one. These additional operations occur at a cost and the performance is degraded.

Consequently, in the present study, we affected the response selection by using a Simon task. If the N-40 actually reflects the response selection process, we expect that the more the response selection is demanding, the larger the N-40 should be. The N-40 should, therefore, be larger for incongruent than for congruent S-R associations.

2. Methods

2.1. Participants

Twelve participants (six males; mean age: 26; range: 21–37; right-handed; normal vision) volunteered. They performed the task in standard conditions (reported), and for another purpose, after a 26 h period of wakefulness (not reported). The order of the two sessions was counterbalanced across participants. They were paid 200 euros. Informed written consent was obtained according to the declaration of Helsinki and the local ethics committee approved the experiment.

2.2. Design and procedure

Participants were seated in a sound attenuated Faraday cage in front of a faradised screen. They had to press a left or right key with the left or right thumb, respectively, as soon and accurately as possible after a response signal (RS). RSs were the digits 1, 2, 3, 4, 5 and 6 (.62° visual angle). Participants had to respond right or left depending on the digit parity (this was counterbalanced across participants). RSs were randomly presented to the right or to the left of a fixation cross (1.24° visual angle). In the congruent condition, responses were required ipsilaterally to stimuli; in the incongruent condition, responses were required contralaterally. There were 16 blocks of 145 trials each. Between each block, there were short rest breaks during which participants were asked to be more accurate, if they had committed more than 10% of errors. Before recordings, participants performed one training block.

Trials began with RS onset. The RS was turned off after a key press or after 800 ms if no presses occurred. The next RS was displayed 500 ms later.

2.3. Electrophysiological recordings

Electroencephalogram (EEG), electromyogram (EMG), and electro-oculogram (EOG) were recorded continuously from preamplified Ag/AgCl electrodes (BIOSEMI Active-Two electrodes, Amsterdam). The signal was filtered and digitized online (bandwidth: 0–268 Hz, 3 db/octave, sampling rate: 1024 Hz).

For EEG, 64 recording electrodes were disposed according to the 10/20 system with CMS–DRL as reference and ground (specific to the Biosemi acquisition system). A 65th electrode on the left mastoid served to reference the signal offline.

Electrodes for vertical and horizontal EOG were at the Fp1 and below the left eye, and at the outer canthus of the left and right eyes, respectively.

For EMG, two electrodes were pasted onto the skin of the thenar eminence over the *flexor pollicis brevis* of each thumb, about two centimeters apart.

2.4. Data processing

Trials with RTs (measured from stimulus presentation to button press) shorter than 100 ms (anticipations), longer than 800 ms (omissions), errors and partial errors (correct key presses preceded by a subthreshold EMG burst on the incorrect response side: 9.5% of the trials) were excluded from analyses.

Electrophysiological data were numerically filtered offline (EEG, EOG: high-pass = .02 Hz, EMG: high-pass = 10 Hz). Bipolar derivations were performed for vertical and horizontal EOGs. Then, ocular artifacts were subtracted (Gratton et al., 1983). A trial-by-trial visual inspection of monopolar recordings allowed us to reject unsatisfactory subtractions and other artifacts.

Bipolar derivations were performed over each *flexor pollicis brevis*. Then, EMG onset was detected by visual inspection of each trial (Van Boxtel et al., 1993).

The data were segmented from −500 to 500 ms with the EMG onset as zero of time and averaged, time-locked to the EMG onset. No additional filtering was performed on the segmented data. The Laplacian transformation was applied to the monopolar averages, after spherical spline interpolation with 3 as the degree of spline and a maximum of 15 degrees for the Legendre polynomial (Perrin et al., 1987).

We sought the generator of the N-40 (so far not localized) with the standardized Low Resolution Electromagnetic Tomography (sLORETA) method, which implements a normalized form of the minimum norm constraint (see Pascual-Marqui, 2002 for technical details). Source localization was performed at a single time point (35 ms before EMG onset) on the monopolar grand average for the incongruent condition in which the N-40 was the largest with a −200 to −100 ms baseline.

For a convergent and complementary approach, we used the Rap-Music algorithm (Mosher and Leahy, 1999) as implemented by Brain Electrical Source Analysis (BESA) in the −250 to 330 ms EMG-locked interval. Shortly, a principal component analysis (PCA) was first performed on the monopolar grand average of incongruent trials (largest N-40). We kept the first six dimensions for the signal space in which the sources would be identified. Within this subspace, we chose to identify four sources iteratively. It is worth pointing out that (1) we kept a rather large number of dimensions in the signal subspace to avoid missing any small activity and that (2) the choice of the number of sources does not influence, in any way, the amplitude or the time course of the source since this method is iterative: the method first identifies the strongest source, next discards the remaining signal (hence removing the contribution of this first source) and then identifies the second strongest source and so on.

3. Results

3.1. Behavior

RTs of correct trials and error rates were submitted to a repeated measures analysis of variance with Congruence (congruent vs. incongruent) as the within participants' factor and Order (standard session *before* sleep deprivation session vs. standard session *after* sleep deprivation session) as the between participants' factor.

There was no Order effect, $Fs(1,10) < 1$, both for RTs, $\eta_p^2 = .01$, and for error rates, $\eta_p^2 = .03$, and no interaction between Order and Congruence, RTs: $F(1, 10) < 1$, $\eta_p^2 = .01$, error rates: $F(1, 10) = 1.26$; $p = .29$, $\eta_p^2 = .11$. Error rates did not differ between congruent (.074) and incongruent (.076) conditions, $F(1, 10) = 2.38$; $p = .15$, $\eta_p^2 = .19$. RT was longer in the incongruent (429 ms) than in the congruent condition (421 ms), $F(1, 10) = 10.45$, $p = .009$, $\eta_p^2 = .51$.

3.2. Electrophysiology

At the FCz electrode, the N-40 (Fig. 1) begins to develop about 100 ms and peaks about 35 ms before EMG onset. The slopes of the linear regression of this wave were computed for each participant from −100 to −35 ms and compared to zero, and between the congruent and incongruent conditions with a unilateral paired Student *t*-test. With response-locked data, slope analysis has certain advantages over amplitude analysis: slopes are independent of the baseline, they give morphological information on the polarity of the curves in delimited time windows and are less variable than amplitude measures (Vidal et al., 2003).

To verify the Order effect, slopes of the N-40 were submitted to a repeated measure analysis of variance with Congruence (congruent vs. incongruent) as within participants' factor and Order (standard condition *before* sleep deprivation condition vs. standard condition *after* sleep deprivation condition) as between participants' factor. There was no Order effect, $F(1, 10) = 1.64$, $p = .23$, $\eta_p^2 = .14$, and no interaction between Order and Congruence, $F(1, 10) < 1$, $\eta_p^2 = .03$. The slope was steeper in the incongruent than in the congruent condition, $F(1, 10) = 3.36$, $p < .05$[3], $\eta_p^2 = .25$. The slope of the N-40 was negative and different from zero, both in the incongruent condition ($-18 \ \mu V \ cm^{-2} \ s^{-1}$), $t(11) = 2.94$, $p < .01$, Cohen's $d = 1.21$ and

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[2] The Spatial-Numerical Association of Response Codes (SNARC) effect does not interact with the Simon effect (Mapelli et al., 2003). Moreover, we checked this effect in the present study using an ANOVA with Simon (congruent vs. incongruent) and SNARC (congruent vs. incongruent) as within participants' factors. There was no SNARC effect, $F(1, 11) < 1$, $\eta_p^2 = .04$, there was a Simon effect $F(1, 11) = 10.94$; $p < .01$, $\eta_p^2 = .50$. and no interaction between SNARC and Simon, $F(1, 11) = 1.77$; $p = .21$, $\eta_p^2 = .14$.

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[3] If there is only one degree of freedom in the numerator, the ANOVA *F* will be exactly equal to the square of the *t* computed on the same means and the *F*'s will be absolutely equivalent to the *t*'s two-tailed *p*. So to test a directional hypothesis with ANOVA *F* and only two means, the ANOVA *F*'s *p* should be divided by two corresponding exactly to the same *p* one would obtain with a one-tailed *p* from *t* (Ley, 1979).