Clinical Neurophysiology 115 (2004) 2014–2020
www.elsevier.com/locate/clinph

Response monitoring without sensory feedback☆

S. Allain[a,b,*], T. Hasbroucq[a,b], B. Burle[b], J. Grapperon[c], F. Vidal[a,b]

[a]*Institut de Médecine Navale du Service de Santé des Armées, BP 610, 83800 Toulon Naval, France*
[b]*Laboratoire de Neurobiologie de la Cognition, Centre National de la Recherche, Scientifique et Université de Provence, Marseille, France*
[c]*Hôpital d'Instruction des Armées, Toulon, France*

Accepted 17 April 2004
Available online 26 June 2004

Abstract

Objective: The elicitation of an evoked potential, the 'error negativity' (Ne) when subjects commit errors in speeded tasks, is often taken as an index of response monitoring processes. The presence of a Ne-like wave on purely correct trials challenges the current conceptions about the nature of such a monitoring system. Here, we evaluate the possibility that the Ne-like wave on correct trials is merely due to reafferences, and at the same time, we test directly the general opinion according to which the Ne is generated by an internal signal.

Methods: We studied the presence of a Ne-like wave in a completely deafferented patient. The patient performed two reaction time (RT) tasks: a two-responses RT task and a go/no-go task.

Results: In this patient, a Ne occurs on errors, on incorrect EMG activations, and on purely correct responses. On errors, the Ne was clearly followed by an error positivity (Pe).

Conclusions: The Ne and the Ne-like wave are not generated by reafferences. This similarity is a further argument to consider that these two waves are of same nature.

Significance: The present data demonstrate that sensory information is not mandatory for the brain to monitor and correct ongoing responses.

Keywords: Error; Ne/ERN; Supervisory system; Reafferences; Laplacian

1. Introduction

It is often considered that a supervisory system evaluates the ongoing information processing to detect failures, and to activate adjustment processes (Logan, 1985). Evidence for such a supervisory system stems from reaction time (RT) studies, where sequential effects such as post-error slowing (Rabbitt, 1966) are observed. These sequential effects have been interpreted as revealing strategic 'between-trials' adjustments, suggesting that the supervisory system uses the outcome of actions in order to adjust performance on the following trials.

Another index of the existence of a supervisory system comes from event-related potentials. In RT tasks, when subjects commit errors, a fronto-central negativity peaking around 100 ms after electromyogram (EMG) onset, the 'error negativity' (Ne) (Falkenstein et al., 1991) or 'error-related negativity' (ERN) (Gehring et al., 1993), is observed. Incorrect EMG activations (i.e. although the correct response is given, a subthreshold EMG activation corresponding to the inadequate response sometimes precedes the correct one) evoke a smaller Ne (Scheffers et al., 1996; Vidal et al., 2000). On the basis of an indirect chronometrical argument, it is generally admitted that the Ne is elicited by an internal (central) signal. Among the hypotheses proposed to account for its functional significance, two are dominant: (1) the Ne reflects the outcome of the comparison between the representation of the actual response and of the required response (mismatch hypothesis; Coles et al., 2001); (2) the Ne is an index of response conflict monitoring (conflict hypothesis; Carter et al., 1998). Recently, a Ne-like wave has been described on correct responses (Vidal et al., 2000). Would this Ne-like wave be the same component as the Ne, this would have important consequences for the functional significance of the Ne, and for cognitive control theories. The possibility that

☆ The work was done at the Institut de Médecine Navale du Service de Santé des Armées.

* Corresponding author. Tel.: +33-49-4099617; fax: +33-49-4099132.
E-mail address: allain@lnf.cnrs-mrs.fr (S. Allain).

1388-2457/$30.00 © 2004 International Federation of Clinical Neurophysiology. Published by Elsevier Ireland Ltd. All rights reserved.
doi:10.1016/j.clinph.2004.04.013

the Ne-like wave was due to uncontrolled artifacts (Coles et al., 2001) has been discarded (Vidal et al., 2003). Here, we evaluate the possibility that a 'mandatory' negative component, not necessarily related to the supervisory process, is present on all trials (correct and incorrect; Vidal et al., 2003). Indeed, during voluntary self-paced and RT movements, Tarkka and Hallett (1991a) described a fronto-central negativity peaking about 100 ms after EMG onset: the frontal peak of motor potential (fpMP). A fpMP-like wave has also been recorded during passive movements, leading to interpret the fpMP as a component evoked by proprioceptive feedback (Tarkka and Hallett, 1991b). The fpMP sharing the same latency and scalp topography as the Ne-like wave, it remains possible that the Ne-like wave is related to proprioceptive reafferences. Therefore, on correct trials, the Ne-like wave would correspond to such a mandatory component, whereas on incorrect trials, the 'true' Ne would be added on the mandatory component.

Therefore, the aim of this study was twofold: (1) to check the general opinion according to which the Ne is elicited by an internal signal, and overall (2) to examine if the Ne-like wave on correct responses could be related to proprioceptive reafferences, and hence is a fpMP.

Given the theoretical importance of these questions, they deserve a specific analysis. We examined whether a completely deafferented patient (G.L.) presents a Ne on errors and a Ne-like wave on correct responses. If the Ne-like wave is generated by reafferences, this patient will present no Ne-like wave, whereas if the Ne-like wave is generated by an internal signal, this patient will present a Ne-like wave. These predictions were tested in two RT tasks known to generate a Ne and a Ne-like wave.

2. Methods

2.1. Patient

One deafferented patient (G.L.), a right-handed 54-year-old woman with normal vision, participated in the study. Her written informed consent was obtained and the rights of the patient were protected according to the declaration of Helsinki. Patient G.L. (Cooke et al., 1985; Forget and Lamarre, 1987) has been functionally deafferented following a Guillain-Barré and a second episode of polyneuropathy affecting selectively the large myelinated sensory fibers. This patient is unique as far as her case has sufficiently been explored and documented ensuring that she is completely deafferented. Clinically she has a total loss of touch, vibration, pressure and kinesthetic senses and no tendon reflexes in the 4 limbs. Pain and temperature sensations are present, which indicates selective impairment of the large diameter peripheral sensory myelinated fibers. The motor fibers are not affected and the results of electrophysiological tests confirmed the above clinical findings. Motor nerve conduction velocity was normal, while no sensory potential could be registered in the 4 limbs. The H-reflex was absent in the legs and there was no cortical response evoked by electrical stimulation of peripheral nerves of either arms. The results of a sural nerve biopsy revealed a severe demyelination affecting particularly the large fibers: the percentage of myelinated fibers larger than 9 μm in diameter was very small (0.31%) as compared to normal values (more than 18%) (more information can be found on http://deafferented.apinc.org).

2.2. Apparatus and procedure

The patient was comfortably seated in an armchair equipped with a headrest (to minimize the contamination of the electroencephalogram (EEG) recordings by the EMG activity of the neck muscles). The experiment took place in a Faraday cage, within a sound attenuated room.

The first experiment was a RT task involving the left and the right thumbs. Depending on the nature of a visual response signal (RS: the French words 'droite'-right- or 'gauche'-left), G.L. had to respond as soon and accurately as possible by pressing the left or the right button of a response pad (Neuroscan©), respectively. Note that the stimulus-response mapping was incompatible (this mapping is known to induce a larger error rate than a compatible one). The RS were equiprobable. In half of the trials, a visual preparatory signal (PS) precued which thumb to be used. In this case the PS was always identical to the RS. In the other half, the PS did not provide any advance information regarding the response side. In this case, the PS was the French word 'neutre' (neutral). Nine percent of 'catch' trials (the RS was the French word 'piège'-trap-, G.L. was asked not to respond) were included to encourage G.L. to identify, and not simply detect the RS in the precued condition.

Each word written in white was presented at the center of a faradized video monitor (Stim System of Neuroscan©; total of visual angle 1.5°). The PS was displayed for 1 s. The RS appeared 2 s after the PS onset. The RS was displayed until G.L. responded, within a time limit of 800 ms. If G.L. did not respond, the RS was displayed for the full 800 ms. The inter trials interval was 500 ms. Before the experimental session, G.L. performed a training block (110 trials). The experimental session comprised 6 blocks of 110 trials. After each block, G.L. had a few minutes rest (see Carbonnell et al. (2002) for further details relative to the design).

In the second experiment, G.L. had to respond as soon and accurately as possible by pressing the right button of a response pad with her right thumb when the imperative signal was the digit 8 or 9 (go situation). When the imperative signal was the digit 2 or 3, G.L. had not to respond (no-go situation). The go and no-go signals were equiprobable. The imperative signal was displayed until the response, or during 800 ms if G.L. failed or had not to respond. Then, 500 ms after the imperative signal extinction, the next imperative signal was presented. The inter trials interval was 500 ms. Before the experimental session,