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Research report

Context-dependent neuroelectric responses during motor control

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HIGHLIGHTS

- Combined measures of grasping kinematics and EEG.
- Simulated everyday-like grasping in contrast to laboratory grasping.
- Brain responses are context-dependent.
- N200 and P300 are differently affected by the behavioral context.
- Restricted transfer of laboratory to everyday-life brain responses.

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ABSTRACT

Research on brain responses during motor control is usually performed under typical laboratory settings. However, everyday life and the laboratory differ in many aspects, such as purposeful and motivated behavior; and there's no awareness of "being measured" in everyday life. In the laboratory, movements are usually explicitly instructed, overtly measured and follow no intrinsic motivated purpose. Therefore, here we present a new method to measure and reliably analyze neuroelectric brain responses by EEG, as well as kinematics during the performance of grasping movements in two different behavioral contexts. One context (L) simulates a typical laboratory task and another context (E) uses selected features of everyday behavior. However, in both tasks the mechanical constraints and stimuli for the movement are exactly the same. Amplitudes of event-related N200 and P300 measured at the brain's midline were differentially affected by the two contexts. P300 was increased in L compared to E. N200 was distinct at anterior electrode sites (Fz, Cz) in context E, while it was elevated at posterior electrode sites (Pz, Oz) in context L. For the first time, kinematic and electrophysiological recordings are combined to analyze identical movements, performed in varied behavioral contexts. The results indicate that brain responses measured under typical laboratory context may not be necessarily transferred to everyday life; thus, the present approach offers a wide range of new questions to analyze context-dependent brain responses.

1. Introduction

One of the most striking characteristics of human beings is their ability to perform precision grips with their hands in order to manipulate their surrounding environment. This trait distinguishes humans as the only species where tool use is an essential and universal characteristic [1]; and where use requires an enormous sensory-motor-processing ability [2,3]. The ability to perform fine motor skills in today's highly developed society is still important, since human spend over half of their time each day grasping and manipulating objects [4]. Therefore, it is obvious that many studies have investigated fine motor skills from several perspectives using different methodological approaches, which were successful in advancing the understanding of sensory-motor control mechanisms in animals as well as in humans (cf. [5]).

However, most of the studies that focused on characteristics of motor skills were conducted in the laboratory, and not directly in everyday life or natural settings. Existing studies

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investigating human behavior in natural settings most often concentrated on studies on the visual system during everyday activities (see [5] for a comprehensive review). Those studies investigated eye movements in car driving [6], in food preparation in the kitchen (e.g. [7]) and others in sport activities such as table tennis [8] or squash [9]. Studies of hand movements laid the focus on hand's digit independence in everyday activities [10]. However, none of the above-mentioned studies directly compared a movement performed under typical laboratory conditions with exactly the same movement performed in a more natural setting. Therefore, it remains still an open question whether motor skills such as precise grasping movements observed in the laboratory reflect everyday life behavior, since everyday life and laboratory behavior differ in many aspects [11,12]. In the laboratory test situation, the setting is arranged, the test is highly controlled, and it is usually held in a quiet location; few distractions exist, movements are explicitly instructed, performed in isolation, repetitive, and purposeless. In contrast, everyday life is full of task-irrelevant and distracting information, has varying noise levels, movements are not instructed, are self-chosen and are usually embedded in other purposeful behavior, so that attention is often divided between tasks [13].

It has been documented in a series of experiments that grasping in a typical laboratory context (L) substantially differs from that in a more everyday-like context (E). Participants were asked to perform a grasp from the same starting point to the same object in the same location, moved it in the same way, and returned their hand to the same starting point. The behavioral context varied in which this grasp was conducted: In L the movement was visually triggered, repetitive, purposeless, and explicitly instructed, while in context E movements were part of a captivating computer game and served to acquire a reward. These movements were implicitly instructed and covertly measured. Kinematics and dynamics differed between the contexts, and factor analysis indicated that the differences cannot be traced back to one single cause [14,15]. Further experiments showed that context differences varied in dependence of an individual's cognitive abilities [15], the gravito-inertial environment [16], old age [17], handedness [18], and can even be modified by the motivational state [19]. The view of multiple context-dependent functional modules in generating grasping movements is supported by the fact that the variation of attention, movement speed and movement sequence can affect the underlying factorial structure [20]. This is in line with studies indicating that goal-directed grasping movements involve an interconnected and large cortical network localized in parietal and frontal brain areas, which is differentially activated in dependence of task demands [21–25].

However, until now, the observation of different cortical involvement in dependence of task and/or object characteristics are based on typical laboratory studies. Moreover, the interpretation of differences between L and E were based on behavioral data only, so that the responses and potential differences on the cortical level remained unclear. One way to analyze the cortical involvement in dependence of task demands is by the use of electrophysiological responses, which have often been characterized by event-related potentials extrapolated from the EEG. Those studies, that investigated kinematics and event-related potentials of movements in laboratory contexts, often focused on well-accepted midline electrode sites [26–29].

Therefore, here we present a new, advancing method, along with first results to study brain responses to one and the same grasping movements that are performed in varied behavioral contexts by combined measures of kinematics and electrophysiology. In this approach, the focus is laid on the well-studied event-related potentials N200 and P300. Based on the proposed functional differences between the N200 and the P300 in cognitive processing [30], and the suggested differences in cognitive processing that are involved in grasping in L and in E [15,19,20], we hypothesized that the two components are differently affected by the two contexts, even though the same grasping act is performed, and the same visual stimulus is presented for movement initialization. Differences in those components in L versus in E should help to identify possible reasons on the neural basis for clarifying the behavioral differences between E and L with respect to the functions associated with the N200 and P300.

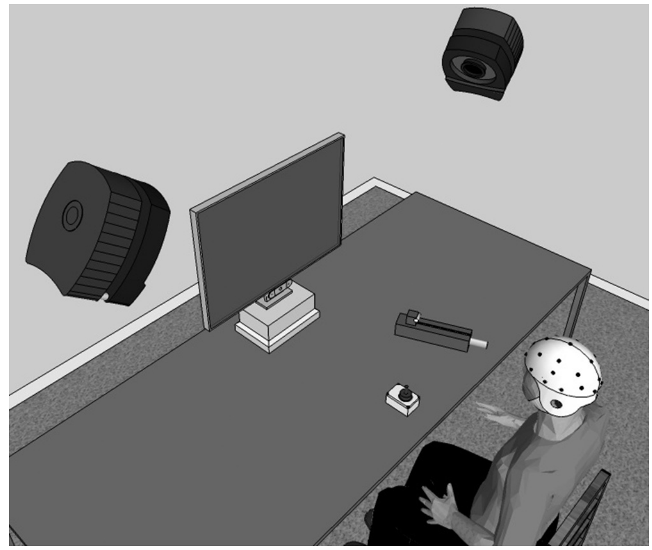

Fig. 1. Experimental setup. Details are explained in the text (see Section 2.2).

2. Materials and methods

2.1. Participants

Twenty two right-handed participants took part in this study. However, data for one participant included a high-amplitude noise component during almost all of the grasping in the recorded EEG signals, and was therefore excluded from further analysis. Subsequently, participants were 13 males and 8 females ($n = 21$; 22.5 ± 2.25 years) considered as healthy with no known history of neuromuscular or central nervous disorders. None of the participants reported to have participated in studies on motor control or in other physiological studies within the last six months. All signed informed consent prior to participation. The university's ethic committee approved this study.

2.2. Measurement of grasping kinematics

As depicted in Fig. 1, participants sat 70 cm in front of a 17″ screen. A cylindrical lever of 4 cm length and 1.5 cm diameter was located 35 cm away from the front edge and 16 cm above the surface of the table and 10 cm to the right of the screen. It was covered by a hood from behind and above to ensure that it can only be grasped with a pinch grip by the thumb and index fingertips. Therefore, instructions to use a pinch grip were not necessary. The lever could be moved 3.5 cm along a rail until to a mechanical stop. Lever position was registered by a displacement sensor (Burster® 8740) and the forces applied by the pinch grip to the lever by a 6 degree of freedoms force transducer (ATI® Nano 17), both with a sampling rate of 250 Hz.

A joystick was placed 41 cm in front of the screen with its tip 12 cm above the table's surface, such that its distance from the lever was 32 cm horizontally and 4 cm vertically. Six reflecting markers of 6 mm diameter were attached by double-sided adhesive tape to the