



Psychophysiological support of increasing attentional reserve during the development of a motor skill[☆]



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ABSTRACT

The aim of this study was to determine the relationship between motor skill and attentional reserve. Participants practiced a reaching task with the dominant upper extremity, to which a distortion of the visual feedback was applied, while a control group performed the same task without distortion. Event-related brain potentials (ERPs), elicited by auditory stimuli were recorded throughout practice. Performance, as measured by initial directional error, was initially worse relative to controls and improved over trials. Analyses of the ERPs revealed that exogenous components, N1 and P2, were undifferentiated between the groups and did not change with practice. Notably, amplitude of the novelty P3 component, an index of the involuntary orienting of attention, was initially attenuated relative to controls, but progressively increased in amplitude over trials in the learning group only. The results provide psychophysiological evidence that attentional reserve increases as a function of motor skill acquisition.

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1. Introduction

As one learns a novel motor task the effort required to execute the demands is reduced even though the requirements remain constant, resulting in efficient use of physiological resources as one becomes proficient. Efficiency is traditionally characterized by the effort required for work output and can be quantified by increased force per motor unit (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002), enhanced inter-limb coordination (Lay, Sparrow, Hughes, & O'Dwyer, 2002), streamlined neural resource allocation (Hatfield, Haufler, Hung, & Spalding, 2004; Hatfield & Hillman, 2001), and greater focus on task-relevant cues (Williams, 2002), etc. In tandem with changes in efficiency are modifications in attentional processes. Phenomenological reports and behavioral

studies suggest a positive relationship between increasing proficiency and attentional reserve (Magill, 2007). Specifically, Magill suggests that attentional demands are high during the early stage of motor learning, but then decrease as skill is acquired. Although some have investigated the neural underpinnings of this relationship (Maclin et al., 2011), psychophysiological evidence of the dynamic relationship between attention and motor learning is limited.

Attention refers to the directed allocation of cognitive resources. Attention is quantitatively limited, and the total quantity available is referred to as attentional capacity (Schmidt & Wrisberg, 2008). As one engages in a task, attentional resources are drawn from this capacity, thus reducing attentional reserve. Reserve is further consumed when additional tasks are initiated. In other words, there is an attentional 'cost' associated with each task that is being performed. Additionally, more complex tasks require greater attentional resources compared to simple tasks. If attentional resources are low, one's performance on a single, or on multiple tasks may diminish (Magill, 2007; Strayer, Drews, & Johnston, 2003). However the attentional 'cost' for a given task is not fixed. Fitts and Posner (1967) hypothesized that as one becomes skilled there is

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a shift from controlled processing during which motor sequences are held in working memory to automatic processing wherein motor sequences become routine, thus decreasing the attentional resources associated with the execution of a given task.

Supporting this notion, skilled soccer players are able to maintain dribbling performance while also attending to a visual-monitoring task whereas the dribbling performance of less skilled players declined (Smith & Chamberlin, 1992). Employing a golf putting task, Beilock, Wierenga, and Carr (2002) observed that experience enabled performers to spare attentional processes associated with primary task execution such that resources were available for additional tasks. Furthermore, experts who allocate excess attentional resources toward a task incur a performance decrement (Beilock, Carr, MacMahon, & Starkes, 2002; Grey, 2004). The effect of expertise is evident even in tasks that require minimal attention such as postural control, e.g., expert gymnasts relied less on attentional processes during a unipedal balance task (Vuilleume & Nougier, 2004). Reductions in required attentional resources as motor learning progresses are hypothesized to result from changes in the neural networks that underlie these behaviors.

Neurobiological investigations of motor learning suggest that skill acquisition is marked by refinements in cortical dynamics (Bell & Fox, 1996; Busk & Galbraith, 1975; Gentili, Bradberry, Hatfield, & Contreras-Vidal, 2009; Haier et al., 1992; Hatfield et al., 2004; Kerick, Douglass, & Hatfield, 2004). A likely outcome of this “streamlining” is an increase in the neural resources available for attentional demands beyond those associated with the primary motor task, i.e., an increase in attentional reserve (Weissman, Roberts, Visscher, & Woldorff, 2006). However, the physiological processes associated with this shift have not been unambiguously investigated during the execution of a single task. Dual-task studies have revealed behavioral and psychophysiological changes in attention with learning (Maclin et al., 2011). However, Kramer, Wickens, & Donchin, 1985, advanced the notion that dual-task investigations characteristically confound measurement of primary task (i.e., the task of interest) outcomes as the two tasks compete for neural resources.¹

The probing of attention across the process of motor learning has not been investigated using psychophysiological measures of attentional dynamics during a single-task paradigm. This approach would provide a means to confirm the assumption that the demand on attentional resources reduces as one becomes proficient at a given task. In this regard, psychophysiological methods have been employed successfully to assess other cognitive processes (Humphrey & Kramer, 1994; Kerick, Hatfield, & Allender, 2007; Parasuraman, 1980; Senkowski & Herrmann, 2002). Specifically, components of the event related potential (ERP), derived from electroencephalography (EEG), have been used to infer the amount of cognitive resources consumed by a given task (Miller, Rietschel, McDonald, & Hatfield, 2011).

For example, to investigate cognitive workload as a function of task workload, Allison and Polich (2008) challenged participants with a video game (first-person shooter) under different levels of difficulty (i.e., view, easy, and hard) while recording the cortical response to an auditory probe. Notably, they employed a modified oddball, which relative to the standard oddball, replaces common tones with silence eliminating the need for the participant to engage in tone discrimination or any need to respond. Most importantly, this modified oddball provided a means to assess cognitive processes during single-task execution (i.e., without confounds

¹ However, there are scenarios in which dual task approaches are desirable. For example, such an approach would be useful if one were specifically interested in evaluating how neurocognitive resources are distributed between tasks when multi-tasking (see Maclin et al., 2011).

associated with dual tasks). Allison and Polich observed a reduction in both exogenous and endogenous ERP components elicited by the tone as workload (game difficulty) increased, suggesting that task difficulty was positively related to cognitive workload. Similarly, Miller et al. (2011) incrementally varied the difficulty of a visuomotor task (Tetris®) by manipulating game speed, while employing the modified oddball task. However, they presented novel sounds (e.g., dog bark) instead of pure tones. This approach was advantageous as such sounds have been shown to be more specific to attentional reserve. Such sounds elicit many of the same ERP components as the traditional oddball (Polich & Margala, 1997) even when ignored (Mertens & Polich, 1997), while being more robust to any habituation effects associated with repetitious stimuli (Wetter, Polich, & Murphy, 2004). Moreover, novel sounds elicit the novelty P3 component; its amplitude reflects the magnitude of attentional resources available for the compulsory orienting response (Friedman, Cycowicz, & Gatea, 2001; McDonald, Gabbay, Rietschel, & Duncan, 2010; SanMiguel, Morgan, Klein, Linden, & Escera, 2010). Miller et al. observed an inverse relationship between amplitude of the novelty P3 and task difficulty positing this as a viable method to assess attention reserve during single-task execution. However, both of these studies examined the role of task difficulty, rather than investigating the impact of skill acquisition (i.e., motor learning), on attentional processes.

Thus, the purpose of this study was to provide confirmatory psychophysiological evidence of the positive relationship between motor skill acquisition and attentional reserve, as noted above, using the modified oddball task while employing novel sounds. In the present study, participants were challenged to become proficient on a novel visuomotor task through the employment of many trials. The visuomotor task involved center-out reaching movements that required resolution of a distortion between visual and proprioceptive feedback, a method commonly employed to study motor skill acquisition (see Krakauer, 2009 for review). We predicted that the novelty P3 amplitude would initially be attenuated (suggesting reduced attentional reserve), but would progressively increase in amplitude throughout the task (suggesting increases in attentional reserve).

2. Methods

2.1. Participants

Participants included 26 individuals, however five were excluded due to excessive EEG artifact resulting in a final sample of 21 (9 women, mean age of 25.00 (2.70), ranged 21–30). All participants reported being free of neurological disorders and hearing impairment as determined by a health status questionnaire (HSQ). Additionally, all participants were right-handed as determined by the Edinburgh handedness inventory (EHI). Finally, all participants provided informed consent on a form approved by an Institutional Review Board and were compensated \$60 for being enrolled in the study.

Participants were randomly assigned to one of two groups, control ($n = 10$) or learning ($n = 11$), described below. An independent t-test confirmed that the two groups did not differ with regard to age, $t(19) = .240, p > .05$, Control Group, $M = 24.80$ (2.66), Learning Group, $M = 25.18$ (2.86).

2.2. Instrumentation

2.2.1. Experimental setup

Participants were seated directly in front of a visuomotor research apparatus (Wang & Sainburg, 2005) with both their hands resting on a flat horizontal surface. Approximately 13" above the surface upon which their hands rested was a horizontal mirror that occluded the participants' view of their hands. Additionally, the mirror displayed the visual stimuli associated with the visuomotor task (i.e., start circle, target, and cursor representing hand position). The mirror reflected images displayed on 50" LCD television (Panasonic) which was suspended above the mirror. Thus, visual stimuli were displayed on the television and the reflection was viewed by the participants on the mirror while their hand location was blocked from their visual field. Therefore, the visual feedback available to the participants regarding their movements was limited to the display on the mirror.

The participants' non-dominant hand (left) was placed in an adjustable brace that immobilizes all joint movement distal to the elbow. This brace was supported

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