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Measurement of functional task difficulty during motor learning: What level of difficulty corresponds to the optimal challenge point?

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ABSTRACT

The relationship between task difficulty and learning benefit was examined, as was the measurability of task difficulty. Participants were required to learn a postural control task on an unstable surface at one of four different task difficulty levels. Results from the retention test showed an inverted-U relationship between task difficulty during acquisition and motor learning. The second-highest level of task difficulty was the most effective for motor learning, while learning was delayed at the most and least difficult levels. Additionally, the results indicate that salivary α-amylase and the performance dimension of the National Aeronautics and Space Administration-Task Load Index (NASA-TLX) are useful indices of task difficulty. Our findings suggested that instructors may be able to adjust task difficulty based on salivary α-amylase and the performance dimension of the NASA-TLX to enhance learning.

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1. Introduction

The *challenge point framework* has been proposed to explain the optimal practice conditions based on the learner's skill level and task complexity (Guadagnoli & Lee, 2004). This framework classifies task difficulty into two categories: nominal task difficulty and functional task difficulty. The nominal difficulty of a task reflects the constant amount of difficulty, regardless of who is performing the task and under what conditions it is being performed. Task complexity is one of the factors affecting nominal task difficulty. On the other hand, functional task difficulty refers to how challenging the task is relative to the skill level of the individual performing the task and to the conditions under which it is being performed. According to the challenge point framework, learning is directly related to functional task difficulty, which is tied to the information that is available to and interpretable by the performer in a performance situation. The amount of available information increases with increasing task complexity, whereas the amount of interpretable information does not necessarily do so, because the learner has a limited capacity for information processing (Marteniuk, 1976; Miller, 1956). If there is too little information available, the result is a deterioration of the efficiency of information processing, while too much information causes a collapse of the information processing system. When the amount of information available in the performance of the task and the learner's information processing capabilities match, motor learning is most efficient. In this framework, the optimal task difficulty for motor learning, i.e., the task difficulty that promotes the most effective motor learning, is called the *optimal*

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challenge point. Based on this framework, motor learning is expected to be most accelerated if the functional task difficulty is adjusted to the optimal challenge point by manipulating the nominal task difficulty and practice conditions as a function of the learner's skill level. However, the method for measuring functional task difficulty remains to be established. In the present study, we empirically examined whether the optimal challenge point proposed in the challenge point framework (Guadagnoli & Lee, 2004) exists.

We focused on attentional demands to measure functional task difficulty considering the properties of information processing. Attentional demands can be measured using various indices, including behavioral, physiological, and subjective indices. In particular, a dual-task procedure is a behavioral index that has previously been used in many studies examining the amount of information available for the performance of a variety of perceptual motor tasks (Abernethy, 1988; Ells, 1973; Glencross & Gould, 1979; Kerr, 1975). Probe reaction time is a method that is very commonly used to measure attentional demands during the execution of a motor task in the dual-task procedure (Li & Wright, 2000; Salmoni, Sullivan, & Starkes, 1976). The attentional demands of the primary task are assumed to be inversely related to probe reaction time. That is, a longer reaction time is interpreted to indicate that the primary task requires considerable attention. For example, Li and Wright (2000) studied the attentional demands associated with random and blocked practice schedules using a probe choice reaction time task. They found that random practice was associated with a significantly greater choice reaction time. That is, a random practice schedule required more attention than a blocked practice schedule. However, several studies have pointed out a problem that must be taken into consideration in the method of measuring attentional demands using a dual-task procedure (Abernethy, 1988; Guttentag, 1989). Goh, Gordon, Sullivan, and Winstein (2014) noted that there were three methodological issues that needed to be considered and rigorously controlled. The first was the fact that the probe task itself required learning. The second issue was the primary-secondary task trade-off effects. The final issue was compliance with the task priority instructions. The authors recommended the use of multiple baseline measurements to diminish the effect of learning of the probe task, and the examination of primary-secondary task trade-off effects and compliance with task priority instructions. While these approaches make it possible to determine, after examination, whether trade-off effects or switching of task priority occurs, they cannot inhibit these phenomena during task execution. Moreover, Wickens (1984, 1992) described experiments in which two tasks were perfectly time-shared (i.e., performed concurrently), even when the difficulty of one task was manipulated. Considering these issues, the use of probe reaction time is not an optimal way to measure attentional demands in the present study. Therefore, we investigated an alternative method of measuring attentional demand.

In our previous study, salivary α-amylase was proposed as an alternative method for measuring attentional demands (Akizuki & Ohashi, 2014). Salivary α-amylase, one of the most important enzymes in saliva, has been reported to be controlled by the sympathetic-adrenal medullary system (Chatterton, Vogelsong, Lu, Ellman, & Hudgens, 1996; Nater & Rohleder, 2009; Rohleder, Nater, Wolf, Ehlert, & Kirschbaum, 2004). Chatterton et al. (1996) investigated the correlation between salivary α-amylase and plasma catecholamine, and showed significant correlations between them ($r = 0.64$ for norepinephrine and $r = 0.49$ for epinephrine). This result directly indicates that salivary α-amylase reflects the activity of the sympathetic nervous system. Furthermore, several studies suggest that sympathetic activation was caused by increasing task difficulty (Backs, 1995; Backs, Lenneman, & Sicard, 1999; Backs, Ryan, & Wilson, 1994). For instance, Richter, Friedrich, and Gendolla (2008) demonstrated that task difficulty determines pre-ejection period reactivity and systolic blood pressure reactivity, which are indices of activity of the sympathetic nervous system, during task performance as long as task difficulty is not at an impossible level. Therefore, salivary α-amylase, which reflects sympathetic nervous system activity, might reflect changes in task difficulty. In fact, we investigated the relationship between probe reaction time and salivary α-amylase during a postural control task, and showed that probe reaction time and salivary α-amylase equally reflect task performance ($r = .62$ and $r = .64$ respectively) and there is a significant correlation between them ($r = .58$) (Akizuki & Ohashi, 2014). In our study, the rate of increase of salivary α-amylase from baseline varied from 109.1% to 166.7%. This result indicated that salivary α-amylase, as well as probe reaction time, was a valid measurement indicator of attentional demand during postural control.

Additionally, we focused on the National Aeronautics and Space Administration-Task Load Index (NASA-TLX), which is a subjective measure of each learner's mental workload (Hart & Staveland, 1988). Kantowitz (1988) defined mental workload as an intervening variable, similar to attention, which modulates the tuning between the demands of the environment and the capacity of the organism, and he advocated the concept of mental workload as a subset of attention (Kantowitz, 2000). Many subjective procedures have been developed for measuring mental workload. In particular, the Cooper–Harper Scale (Cooper & Harper, 1969), the Subjective Workload Assessment Technique (Reid & Nygren, 1988), and the NASA-TLX are widely used (Hart, 2006; Hill et al., 1992; Rubio, Díaz, Martín, & Puente, 2004). Eggemeier (1988) noted that workload assessment techniques should possess the following properties: sensitivity, diagnosticity, selectivity, validity, intrusiveness, reliability, implementation requirements, and subject acceptability. The NASA-TLX has been shown to reach an acceptable level in terms of these criteria (Battiste & Bortolussi, 1988; Rubio et al., 2004). The NASA-TLX consists of six dimensions to assess mental workload: mental demand, physical demand, temporal demand, performance, effort, and frustration. Three of the subscales (mental demand, physical demand, and temporal demand) are task-related scales, two of the subscales (performance and effort) are behavior-related scales, and the other (frustration) is a subject-related scale (Hart & Staveland, 1988). Rendell, Masters, Farrow, and Morris (2011) used the NASA-TLX as a subjective measure of learner's cognitive effort. In their study, learners assigned to random practice had higher scores than learners assigned to blocked practice on the measures of mental demand, effort, and frustration. The results indicated that some subscales of the NASA-TLX could

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