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Does practicing a skill with the expectation of teaching alter motor preparatory cortical dynamics?

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ABSTRACT

Recent evidence suggests practicing a motor skill with the expectation of teaching it enhances learning by increasing information processing during motor preparation. However, the specific motor preparatory processes remain unknown. The present study sought to address this shortcoming by employing EEG to assess participants' motor preparatory processes while they completed a golf putting pretest, and then practiced putting with the expectation of (a) teaching another participant how to putt the next day (teach group, $n = 30$), or (b) being tested on their putting the next day (test group, $n = 30$). Participants' EEG during the 3-s prior to and 1-s after initiating putter movement was analyzed. All participants completed posttests 1 day after the practice session. The teach group exhibited better posttest performance (superior learning) relative to the test group, but no group differences in motor preparatory processing (EEG) emerged. However, participants in both groups exhibited linear decreases in both theta power at frontal midline and upper-alpha power over motor areas during putt initiation. These results suggest a decrease in working memory and action monitoring (frontal midline theta), and an increase in motor programming (motor upper-alpha) during putt initiation. Further, participants in both groups exhibited increased frontal midline theta from pretest to practice, but decreases in both upper motor-alpha and upper-alpha coherence between left/right temporal and motor planning regions. These results suggest participants utilized working memory and action monitoring to a greater extent during practice relative to pretest, while refining their motor programming and verbal-analytic/visuospatial involvement in motor programming.

1. Introduction

Determining practical ways to enhance people's learning is a challenge in the field of motor behavior. One way might be having people study and practice a skill with the expectation of teaching it to another person. There are several mechanisms whereby expecting to teach could enhance motor learning. First, expecting to teach may cause a learner to recognize their learning affects another person's learning. This recognition might increase the learner's motivation (Benware and Deci, 1984; Fiorella and Mayer, 2014, Experiment 1), which has been positively linked to motor learning (Lethwaite and Wulf, 2012; Wulf and Lewthwaite, 2016). Second, the learner could have elevated anxiety (pressure) by identifying their responsibility in facilitating another person's learning. This elevated anxiety may yield arousal levels that are adaptive for learning (Yerkes and Dodson, 1908). Third, expecting to teach could enhance information processing. Specifically, learners expecting to teach could engage in greater information processing while practicing, which has been positively associated with motor learning (Cross et al., 2007). For example, knowing that they have to teach another person, a learner might use working memory and verbal-analytic processes (e.g., instructional self-talk) to implement proper skill technique, more elaborate programming and parameterizing for their movements, and more attentional monitoring of their movements, all of which could lead to better skill retention.

Daou et al. (2016a) conducted the first experiment testing the hypothesis that studying and practicing a skill with the expectation of teaching it enhances motor learning. Specifically, the authors examined the skill of golf putting and tested motivation and pressure as possible mechanisms related to an effect of expecting to teach. Results from Daou, Buchanan et al. revealed that participants who were expecting to teach exhibited superior posttest putting accuracy and precision (enhanced motor learning), but not increased motivation or pressure.

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Further, participants who were expecting to teach remembered more key concepts about golf putting on a free recall test, in accord with some literature indicating expecting to teach enhances declarative memory (Bargh and Schul, 1980; Benware and Deci, 1984; Nestojko et al., 2014).

As Daou et al. (2016a) observed expecting to teach does indeed enhance motor learning, but motivation and pressure did not explain the expecting to teach effect, Daou et al. (2016b) investigated whether information processing could explain the effect. Specifically, Daou, Lohse et al. sought to index information processing during practice by quantifying the amount of time participants took preparing each putt. Results revealed that expecting to teach increased the duration participants took preparing each putt and improved motor learning, the latter replicating Daou, Buchanan et al.'s findings. Additionally, the increased putt preparation time during practice predicted superior posttest accuracy and precision (although not when controlling for group [i.e., whether participants were expecting to teach or not]). Thus, Daou, Lohse et al.'s results provide modest evidence that expecting to teach enhances motor learning by increasing information processing during motor preparation.

Daou et al. (2016b) revealed motor preparatory processing during practice may explain the expecting to teach effect, however the authors did not investigate the specific preparatory processes. Therefore, the present study sought to examine particular motor preparatory processes reflected by cortical dynamics while participants prepared to putt during practice. To assess motor preparatory cortical dynamics, electroencephalography (EEG) was employed. A number of experiments have used EEG to investigate cortical dynamics related to motor preparatory processes (for reviews, see Cooke, 2013; Hatfield et al., 2004). For instance, spectral power in the theta frequency bandwidth (4–7 Hz) at the frontal midline is a variable positively associated with attention employed for working memory and action monitoring while people are performing a task (Doppelmayr et al., 2008; Dyke et al., 2014; Gevins et al., 1997; Kao et al., 2013; Weber and Doppelmayer, 2016). For example, Weber and Doppelmayer (2016) observed participants exhibited increased frontal midline theta power during motor preparation for a dart throw after 15 sessions of mental and physical dart throwing practice, presumably because the practice required participants to engage working memory and action monitoring processes.

Another important variable is spectral power in the upper-alpha bandwidth (10–12 Hz) overlying motor cortex, which is *negatively* associated with cortical resource allocation to accurate motor programming (Babiloni et al., 2008; Cooke et al., 2014; Cooke et al., 2015). For instance, Cooke et al. (2014) observed participants exhibited decreased upper-alpha power over motor cortex during motor preparation for successful (holed) versus unsuccessful (missed) putts, suggesting decreased upper-alpha was associated with more accurate motor programming.

Further, another variable related to motor preparatory processes is upper-alpha T7-Fz coherence, which is positively associated with the degree of communication between left temporal lobe and premotor cortex, with more communication indicating greater verbal-analytic information being processed in order to translate the information into motor planning (Buszard et al., 2016; Cheng et al., 2017; Deeny et al., 2003; Deeny et al., 2009; Gallicchio et al., 2016; Gallicchio et al., 2017; Gentili et al., 2015; Rietschel et al., 2012; Zhu et al., 2010; Zhu et al., 2011a, 2011b; Zhu et al., 2011a). For example, Zhu et al. (2011a, 2011b) observed participants predisposed to use verbal-analytic processes during movement exhibited elevated left temporal-premotor coherence during motor preparation for golf putts relative to counterparts not predisposed to use verbal-analytic processes during movement, suggesting the coherence differences were due to variation in participants' tendency to use verbal-analytic processes during movement.

Finally, another variable related to motor preparatory processes is the readiness potential (RP). Unlike the aforementioned variables, the RP is a time-domain variable, in particular a negative-going wave with a central scalp distribution that precedes movement execution (Brunia et al., 2012). The RP can be divided into early (~between 2000 ms and 1500 ms preceding movement) and late (~between 500 ms and 400 ms preceding movement) subcomponents. According to Brunia et al. (2012), the early-RP reflects motor program selection, with greater early-RP amplitude reflecting more cortical resources devoted to program selection. Conversely, the late-RP reflects the specification of movement parameters required for accuracy and precision, with greater late-RP amplitude indicating more cortical resources allocated to parameterization. Brunia et al.'s opinion is based on a review of studies showing early-RP is modulated by factors such as movement selection, whereas late-RP is altered by variables such as movement precision (also see Shibasaki and Hallett (2006)'s review). Notably, Daou, Lohse et al. concluded that expecting to teach did not increase the elaborateness of the motor program used for putting, but this conclusion was inferred from reaction times recorded during pretest and posttest (Henry and Rogers, 1960). Thus, Daou, Lohse et al. concluded expecting to teach likely improves the specification of motor program parameters, but does not affect motor program selection.

Based on Daou et al. (2016b), we predicted participants expecting to teach would exhibit greater motor preparatory processing while practicing a skill, and this increased processing would be reflected in the aforementioned EEG variables. Specifically, we predicted participants expecting to teach would exhibit: (1) greater frontal midline theta (attempt to keep more skill information in mind and monitor their actions to greater extent); (2) less motor upper-alpha (allocate more cortical resources to motor programming); (3) higher T7-Fz coherence (show more verbal-analytic information being translated into motor planning); and (4) greater late-RP amplitude (engaging in more deliberate movement parameter specification).

2. Methods

Prior to beginning data collection, the experimental design and analyses were registered and made public on AsPredicted.org (https://aspredicted.org/dt4gj.pdf).

2.1. Participants

Sixty right-handed young adults (28 females), ages between 18 and 35 years ($M_{\text{age}} = 21.1$ years, $SD = 1.53$ years), participated in the study after consenting to a protocol approved by the Auburn University Institutional Review Board (#16-484 EP 1612). Participants were recruited from university courses and by word-of-mouth, and were compensated with course credit and/or entry into a raffle for a monetary award. Sample size was determined with an a priori power calculation providing 80% power ($\alpha \leq 0.05$) to detect a moderate-sized effect ($f^2 = 0.15$) when adding a practice phase EEG variable (e.g., frontal midline theta or motor-upper alpha) to the multiple regression model predicting posttest performance (accuracy/precision) controlling for group, pretest performance, and the pretest EEG variable (i.e., one variable being tested with four total predictors; Faul et al., 2007). The power calculation yielded N of 55, but it was decided to include 60 participants because past studies in our lab recording EEG from participants putting excluded about 8% of participants due to poor EEG recording (Dyke et al., 2014).

2.1.1. Task

All participants used a standard, right-handed golf putter to putt a standard golf ball from a starting position indicated by a 5 cm line painted in white washable paint on an artificial grass surface to a target cross (+) comprised of two 10.8 cm lines painted in white washable paint. Participants' objective was to make the ball stop as close to the center of the target as possible.