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Research Article

Optimizing Motor Learning in Older Adults

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Abstract

Objectives: According to the Optimizing Performance Through Intrinsic Motivation and Attention for Learning (OPTIMAL) theory of Wulf and Lewthwaite, enhanced expectancies (EE), autonomy support (AS), and an external focus (EF) of attention facilitate motor performance and learning. The present study examined whether consecutive implementation of EE, AS, and EF during practice would enhance the learning of a square-stepping task in older adults.

Methods: Participants were randomly assigned to optimized and control groups. After the pretest, 1 of the 3 factors was implemented during each of the three 12-trial practice blocks, in a counterbalanced order, in the optimized group: positive feedback (EE), choice of mat color (AS), and instructions to focus on the squares (EF). Control group participants practiced without any of these factors.

Results: Results indicated that the optimized group had faster movement times than the control group during the practice phase and on 24-hr retention and transfer tests.

Discussion: The key variables in the OPTIMAL theory can be applied sequentially in order to facilitate motor performance and learning in older adults.

Keywords: Autonomy support, Enhanced expectancies, External focus of attention, OPTIMAL theory

Older adults face challenges due to changing physical and mental capacities, as well as age-related stereotype threats, that can further compromise their performance (e.g., Hess, 2006). The OPTIMAL (Optimizing Performance Through Intrinsic Motivation and Attention for Learning) theory of motor learning (Lewthwaite & Wulf, 2017) specifies three essential variables for effective motor performance or learning. Two of these variables are motivational in nature: enhanced expectancies (EE) and autonomy support (AS). The third variable is an external focus (EF) of attention. Each factor independently has been shown to enhance the performance and learning of various types of motor skills (for reviews, see Lewthwaite & Wulf, 2017; Wulf & Lewthwaite, 2021). In the present study, we sought to extend this framework to motor-cognitive performance in the older adult population, who may experience declines in motor performance for a variety of reasons, including lowered expectations (e.g., Levy et al., 2014).

Among the many ways in which learners' expectancies for future performance have been enhanced in previous studies is the use of social-comparative feedback suggesting to participants that their performance is above average when compared to that of other participants (Hutchinson et al., 2008; Lewthwaite & Wulf, 2010; Stoate et al., 2012; Wulf et al., 2010). This type of positive feedback has been shown to result in an increase in perceived competence, as well as enhanced performance or learning, relative to performers who received negative or no social-comparative feedback (e.g., Lewthwaite & Wulf, 2010). Also, information suggesting improvements relative to learners' own previous performance (temporal-comparative feedback) can benefit learning. In one study (Chiviacowsky et al., 2019), young adults who were provided with positive temporal-comparative feedback demonstrated not only greater perceived competence at the end of practice, but also more effective learning of golf putting task relative to participants without such feedback.

Supporting performers' need for autonomy has also been found to positively influence the acquisition of motor skills (for reviews, see Sanli et al., 2013; Wulf & Lewthwaite, 2016). Numerous studies have demonstrated that participants who are given choices outperform those with no choice (Lewthwaite et al., 2015; Wulf, Iwatsuki, et al., 2018). Allowing learners to choose the delivery of feedback (e.g., Janelle et al., 1997), amount of practice (e.g., Post et al., 2011), or use of an assistive device (e.g., Chiviacowsky et al., 2012), for example, has been demonstrated to result in more effective learning than not being able to choose. Even small or incidental choices, such as ball color, pictures to be viewed during performance, or the order of practice tasks (An et al., 2020), have been found to enhance learning. Opportunities

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for choice enhance expectations for movement success and often result in higher self-efficacy and intrinsic motivation compared with controlling conditions (Hooyman et al., 2014; Lemos et al., 2017).

The third key factor in the OPTIMAL theory (Wulf & Lewthwaite, 2016) is an EF of attention. An EF, or a concentration on the intended movement effect, has consistently been shown to result in more effective motor performance and learning than an internal focus on body movements (for reviews, see Wulf, 2013; Wulf & Lewthwaite, 2010). Since the first demonstration of the learning benefits of an external relative to an internal focus (Wulf et al., 1998), numerous studies have followed and replicated the findings. Recent comprehensive meta-analyses (Chua et al., 2021) have confirmed that an EF is more effective than an internal focus for both immediate performance and longer-term learning, regardless of age, health condition, and level of expertise. The effective performance with an EF can also enhance learners' self-efficacy (e.g., Pascua et al., 2015).

Although each factor (EE, AS, EF) individually has been found to benefit performance and learning, a number of studies have demonstrated that having two factors present during practice—EE and AS (Wulf et al., 2014), AS and EF (Wulf et al., 2015), or EE and EF (Pascua et al., 2015)—resulted in even more effective learning than one factor alone or none. For instance, participants who had an opportunity to choose the color of the ball to be used (AS) on a throwing task and received positive feedback (EE) outperformed those who received one of the two interventions (AS or EE) or no intervention (control group; Wulf et al., 2014). Moreover, practice conditions that included all three factors (EE, AS, EF) have been found to result in more effective learning than combinations of the two factors (Wulf, Lewthwaite, et al., 2018). Thus, the three factors seem to have additive advantages for skill learning. More recent studies examined immediate effects on performance and found that under "optimized" conditions, in which EE, AS, and EF were implemented either on consecutive trial blocks or simultaneously, performance was enhanced. Specifically, maximum jump height (Chua et al., 2018), maximal force production (Singh et al., 2020, Exp.1), bowling performance (Abdollahipour et al., 2019), balance (Chua et al., 2020), and golf putting (An et al., 2021) were found to be enhanced under optimized relative to control conditions. Taken together, implementing key factors in the OPTIMAL theory has been found to enhance both motor skill learning and immediate performance.

Previous studies have used mainly young adults (university students) as participants. Only a few studies have examined the learning of motor skills in older adults by implementing OPTIMAL factors (EE, AS, or EF). In one of those studies (Wulf et al., 2012), a group of older participants (60–74 years) learning a challenging balance task was informed that "active people like you, with your experience, usually perform well on this task" (EE). This statement enhanced EE group participants' self-efficacy (before retention testing) and facilitated their learning compared with a control group. In another study (Chiviacowsky et al., 2012), participants with Parkinson's disease and an average age of 67 years were given the opportunity to choose the timing of using a balance pole (AS) while practicing a balance task. The results showed that this choice enhanced their motivation to learn the task, reduced nervousness, and enhanced their learning, relative to participants without a choice (yoked control group). Finally, EF instructions have been shown to help older adults (with an average age of 69 years) acquire a balance task relative to internal focus instructions (Chiviacowsky et al., 2010).

Given the relatively small number of studies with older participants, we sought to extend and broaden OPTIMAL theory applications to motor-cognitive learning in older adults. Older individuals face a variety of challenges. In addition to actual declines in physical and cognitive capabilities, negative age-related stereotypes may affect their memory or motor performance (e.g., Hess, 2006). Older people's expectations—whether they are internalized or assumed to be present in others—can influence their performance, self-perceptions, and even physiological responses (Levy et al., 2014; Weiss, 2018). The implementation of OPTIMAL factors would be expected to mitigate possible negative age-related expectations. Moreover, it has the potential to enhance the performance and learning of motor and cognitive tasks (Wulf & Lewthwaite, 2021). EEs, for example, have been found to benefit not only motor but also cognitive task performance (e.g., Damisch et al., 2010), and autonomy support has been shown to enhance task engagement, persistence, and well-being (Jaquess et al., 2020; Langer & Rodin, 1976; Ryan & Deci, 2000). In the present study, we incorporated all three factors, EE, AS, and EF, in the practice conditions of one group (optimized group). We used a motor-cognitive task, square-stepping, that was originally used as an exercise for improving lower-extremity functional fitness in older participants (Shigematsu & Okura, 2006). The task involves recalling memorized step sequences and executing them, with the goal of minimizing the time needed to complete the sequence. In the optimized group, EE, AS, and EF were implemented (in a counterbalanced order) on different trial blocks during practice. We hypothesized that the optimized group would show superior learning relative to a control group, as measured by delayed retention and transfer tests.

Method

Participants

To estimate the sample size, power analysis software, G*Power 3.1, was used with the α-level set at 0.05, effect size (*f*) of 0.25, and the power value set at 0.80. According to the analysis, a sample size of 28 participants was needed to detect an effect. Of the 28 women, members of a retirement association, who originally participated in the study, four tested positive for coronavirus disease 2019 (COVID-19) and were not able to complete the study. The remaining 24 participants had an average age of 67.12 years (standard deviation [*SD*] 3.61). All participants were right footed and were selected based on the following criteria: (a) absence of cognitive impairment or dementia based on the Mini-Mental State Exam (Folstein et al., 1975; Foroughan et al., 2008) and (b) having normal movement ability based on the Timed-Up-and-Go test (Podsiadlo & Richardson, 1991; Steffen et al., 2002). All participants were asked to sign an informed consent form. They were not informed about the purpose of the experiment, and none of them had any experience with the task. The university's institutional review board approved the study.

Apparatus and Task

Participants performed a task used in a fall prevention program for older adults, the square-stepping exercise

(Shigematsu & Okura, 2006). This task was completed on a thin mat (250 × 100 cm) that was divided into 40 squares (25 × 25 cm). Participants were instructed to walk as fast as they could from one end of the mat to the other following a predetermined step sequence. After the participants became familiar with each of these step patterns, they stepped on the mat. Figure 1 shows the three different sequences/patterns used in this study. Patterns A and B were alternatively used on the pretest, during the practice phase, and retention test. Pattern C was used on the transfer test (see Figure 1). The time to complete each trial (i.e., movement times) was recorded by a stopwatch.

Procedure

Participants were randomly assigned to either the optimized (*M*: 67.3 years, *SD*: 3.57) or control groups (*M*: 67.0 years, *SD*: 3.81). Each participant was first shown the upcoming step sequence on paper and asked to memorize it. Next, the experimenter demonstrated the task twice. Subsequently, the participant performed the same sequence. Specifically, before the pretest, the participant was first shown, and then asked to reproduce, Pattern A and then Pattern B. If a participant touched the border of the correct square with her foot while walking, the step was considered correct if most of the foot was placed in the appropriate square. If the participant stepped into an incorrect square, she was asked to correct the mistake and continue. Thus, mistakes were reflected in the overall movement time. Participants then performed a pretest consisting of 12 trials. The practice phase consisted of three blocks of 12 trials. In the optimized group, participants received one of the three manipulations (EE, AS, EF) in each block. The order of the factors was counterbalanced across participants, and all six possible orders were used (EE-AS-EF, EE-EF-AS, AS-EE-EF, AS-EF-EE, EF-EE-AS, and EF-AS-EE). In the EE block, the experimenter gave positive feedback (“You are doing well, better than average.”) after every four trials. In the AS block, participants had the opportunity to choose the color of the mat (green, red, or blue). The mat color was white on the other blocks. In the EF block, participants were instructed to focus on the squares and stay within them. Reminders were given before each trial. None of these feedback statements or instructions were provided to the control group. However, each control group participant was yoked to one participant in the optimized group (unbeknownst to them) and was assigned the same mat color that their counterpart had chosen for each trial in their AS block. The retention and transfer tests were administered 24 hr after the practice phase. The respective patterns (A and B for retention; C for transfer) were shown to participants only on paper, before they were asked to produce them. Both the optimized and control groups performed under the same condition (e.g., no positive feedback, choice, or attentional focus instructions) on the retention and transfer tests, which consisted of 12 trials each. During the pretest, retention, and transfer tests, the white mat was used for both groups. Between blocks, participants took a 1-min break.

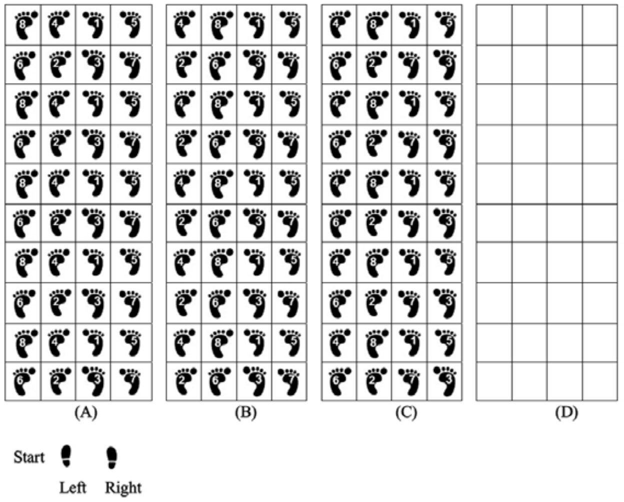

Figure 1. The square-stepping task patterns on the pretest, during the practice phase, and on the retention test (A and B) and transfer test (C). The panel on the right (D) shows the blank mat participants saw and used during all phases of the experiment. As can be seen, each pattern began with a step with the right foot into the respective cell, followed by the left foot, right foot, and so forth, until the left foot was placed into Cell 8. The same sequence was repeated four times to complete one trial.

Data Analysis

Movement time was averaged across 12 trials in each block (pretest, practice phase, retention test, and transfer test). To analyze pretest, retention, and transfer test performance, one-way analyses of variance (ANOVAs) were used. To compare group differences during the practice phase, two different analyses were performed (similar to Abdollahipour et al., 2019). First, we used a 2 (group: optimized vs control) × 3 (manipulations: EE, AS, EF) mixed-factor ANOVA with repeated measures on the last factor to compare group differences for each manipulation. Because there were six different orders in which optimized group participants performed the three conditions, the respective blocks of their control group counterparts were organized accordingly for this analysis. Second, we compared the two groups in a 2 (groups) × 3 (blocks) ANOVA in chronological order of blocks to examine the changes across practice. Partial eta squared (η^2) was used to determine effect size. Bonferroni post hoc tests were performed where the ANOVA results were significant. The level of significance was set to .05.

Results

Pretest

The optimized group ($M = 2{:}57$ min, $SD = 0{:}10$) and control group ($M = 2{:}56$ min, $SD = 0{:}11$) performed similarly on the pretest (Figure 2, left). No significant difference was found between the two groups, $F(1, 22) = 0.034$, $p = .854$, $\eta_p^2 = 0.002$.

Practice

As shown in Figure 2, performance under EE, AS, and EF conditions was significantly better in the optimized group (EE = 1:03 min, AS = 1:06 min, EF = 1:12 min) relative to the control group’s performance on the respective blocks (1:59 min, 1:54 min, 1:48 min). The main effect of group was significant, $F(1, 22) = 116.07$, $p < .001$, $\eta_p^2 = 0.841$. There was no significant main effect of condition, $F(2, 44) = 0.003$, $p = .997$, $\eta_p^2 = 0.001$, or interaction of group and condition, $F(2, 44) = 0.556$, $p = .578$, $\eta_p^2 = 0.025$.

Figure 3 shows movement time across practice blocks 1–3. Across consecutive trial blocks, participants in the optimized group (Block 1 = 1:32 min, Block 2 = 1:08 min, Block 3 = 0:48 min) outperformed the control group (Block 1 = 2:31 min, Block 2 = 1:57 min, Block 3 = 1:17 min) throughout practice. The main effect of group was significant, $F(1, 22) = 131.83$, $p < .001$, $\eta_{\rho}^2 = 0.857$. Both groups decreased their movement time, with the main effect of block being significant, $F(2, 44) = 305.904$, $p < .001$, $\eta_{\rho}^2 = 0.933$. The interaction of group and block $F(2, 44) = 20.865$, $p < .001$, $\eta_{\rho}^2 = 0.487$, was also significant. Post hoc tests indicated that the optimized group outperformed the control group on Block 1 ($M_{\text{diff}} = 00{:}59$, $SE = 00{:}05$), $p < .001$, Block 2 ($M_{\text{diff}} = 00{:}49$, $SE = 00{:}04$), $p < .001$, and Block 3 ($M_{\text{diff}} = 00{:}29$, $SE = 00{:}04$), $p < .001$.

Retention

Results of the retention test showed a significant difference between groups, $F(1, 22) = 305.531$, $p = <.001$, $\eta_{\rho}^2 = 0.933$. The optimized group ($M = 0{:}47$ min, $SD = 0{:}05$) outperformed the control group ($M = 1{:}15$ min, $SD = 0{:}01$).

Transfer

Results of the transfer test also indicated a significant difference between the optimized and control groups, $F(1, 22) = 350.791$, $p = <.001$, $\eta_{\rho}^2 = 0.941$. Similar to the retention phase, the optimized group ($M = 1{:}04$ min, $SD = 0{:}11$) had a significantly shorter movement time than the control group ($M = 2{:}12$ min, $SD = 0{:}05$).

Discussion

The three variables used in the present study, EE, AS, and EE, are considered key factors in the OPTIMAL theory (Wulf & Lewthwaite, 2016) based on the evidence for their effectiveness in enhancing motor skill performance and learning. Previous research, including studies with older adults, has demonstrated that each factor individually facilitates learning. Specifically, providing EE has been shown to result in more effective learning of timed walking (Lessa et al., 2018) and throwing (Chiviacowsky et al., 2009) in 66-year-olds, and balance learning (stabilometer) in 61–81-year-old participants (Wulf et al., 2012). The same balance task was learned more effectively by participants with Parkinson's disease (46–88 years) who were given the opportunity to choose an assistive device (AS; Chiviacowsky et al., 2012; see also Lessa & Chiviacowsky, 2015). Finally, an EF has been shown to help older adults (69 years) acquire a balance task relative to internal focus instructions (Chiviacowsky et al., 2010). Given this previous evidence, it may not be too surprising that the combination of all three factors (optimized group) in the present study resulted in superior learning of the square-stepping task compared to the absence of these factors (control group) during practice. However, the large effect sizes and numerical differences between groups on the retention (61% faster walking speed in the optimized group) and transfer tests (52% faster walking speed) highlight the potency of the effects. It is also noteworthy that the OPTIMAL factors were able to positively impact task learning despite the drawback of having a smaller number of participants (24) than determined by the power analysis (28). Overall, the current study adds another piece of evidence to support the notion that practice under neutral conditions does not result in optimal learning; rather, it requires the inclusion of conditions that boost learners' confidence in their ability to do well (EE), gives them at least small choices (AS), and directs their attention externally (EF; Chua et al., 2018).

EE, AS, and EF are assumed to contribute to goal-action coupling (Wulf & Lewthwaite, 2016), or the relative ease with which movement goals are translated into the actions necessary to achieve those goals. Goal-action coupling involves functional connectivity among motor networks that are relevant to the task and the suppression of irrelevant (off-task or self-related) networks, as well as structural brain changes associated with learning (Dayan & Cohen, 2011). Increases in movement efficiency, including reduced muscular activity, that have been found for each of the three factors (e.g., Iwatsuki et al., 2021; Kuhn et al., 2017; Stoate et al., 2012) seem to reflect the optimization of neuromuscular activation under those conditions.

Each factor appears to make somewhat unique contributions to motor learning (Chua et al., 2018; Wulf, Lewthwaite, et al., 2018). The expectation of positive or rewarding experience (EE) triggers a dopaminergic response that strengthens neural connections (Aarts et al., 2012; Leotti & Delgado, 2011). Dopamine facilitates short-term performance and longer-term learning (Lappin et al., 2009; Wise, 2004). The opportunity to choose (AS) also results in

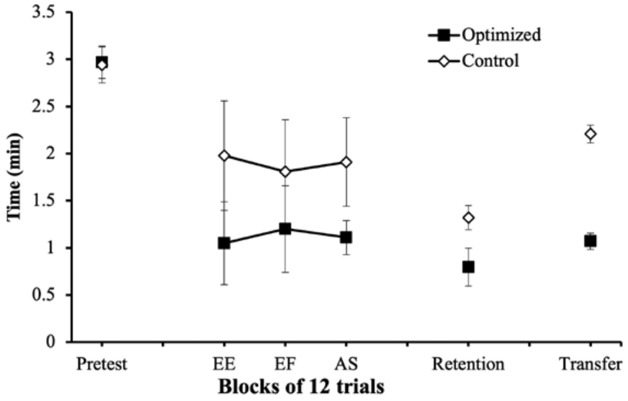

Figure 2. Task time of the optimized and control groups during the pretest, practice phase, retention, and transfer tests as a function of condition (EE, AS, and, EF). AS = autonomy support; EE = enhanced expectancies; EF = external focus.

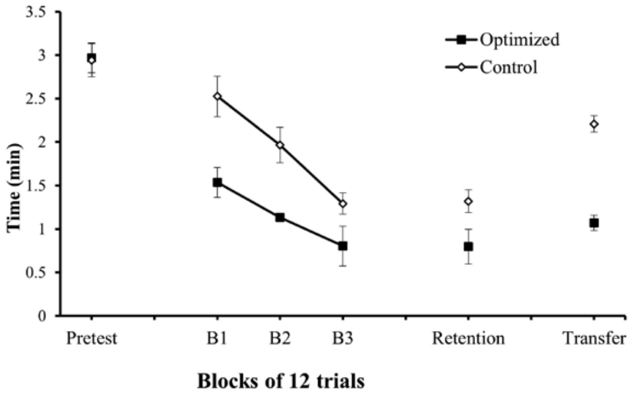

Figure 3. Task time of the optimized and control groups during the pretest, practice phase, retention, and transfer tests as a function of block.

higher self-efficacy and intrinsic motivation and is associated with dopamine release. The neurotransmitter dopamine supports efficiencies in brain connectivity and contributes to the consolidation of motor memories (e.g., Sugawara et al., 2012; Wise, 2004). Finally, an EF promotes movement automaticity (Wulf et al., 2001) and suppresses unnecessary neural activity (Kuhn et al., 2018) and muscular co-contractions (e.g., Zachry et al., 2005). The presence of EE, AS, and EF allows performers to maintain their attentional focus on the task goal, without the need to engage in more extensive self-regulatory activity (e.g., tamping negative-affect and thoughts). Movement effectiveness and efficiency resulting from performing under optimized conditions likely further increase learners' performance expectancies and facilitate future movement success in a virtuous cycle (Wulf & Lewthwaite, 2016).

The square-stepping task (Shigematsu & Okura, 2006) requires quick, multidirectional (forward, backward, lateral, oblique) movements, and smooth transfers of weight. It was designed to help improve balance, agility, and walking speed. Shigematsu et al. (2008) found a relationship between improvement in these parameters and a decrease in the number of falls (Shigematsu et al., 2008). The present study shows that the incorporation of motivational and attentional factors can further enhance the effectiveness of training on this task relative to the typical standardized practice—with potentially further benefits for older adults performing daily activities that require mobility. In fact, it is worth noting that all three OPTIMAL factors have been shown to have immediate benefits for performance (see Wulf & Lewthwaite, 2016), in contrast to typical training programs designed to enhance physical functioning in older adults over the longer term. The present findings have practical implications for institutions, communities, or programs that promote physical activities for the older adults, such as clinical rehabilitation centers, physical therapy clinics, and various exercise-related programs. Instructors can design interventions that optimize motor skills by including OPTIMAL factors. Aging populations are a global concern and regular exercise is key to preventing chronic diseases associated with age-related physical declines (Ciolac, 2013). Therefore, it is essential for practitioners to include such conditions for enhancing skills, physical activity, health, and quality of life.

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Conflict of Interest

None.

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