ABSTRACT
In the current study, we implemented the three key factors (i.e., enhanced expectancies [EE], autonomy support [AS], and external focus [EF]) of the OPTIMAL theory [Wulf, G., & Lewthwaite, R. (2016). Optimizing performance through intrinsic motivation and attention for learning: The OPTIMAL theory of motor learning. *Psychonomic Bulletin and Review*, 23(5), 1382–1414. https://doi.org/10.3758/s13423-015-0999-9]. Following the findings in an earlier study that the simultaneous use of EE, AS, and EF during practice resulted in learning advantages, we explored whether the implementation of EE, AS, and EF in a consecutive manner during practice would be beneficial for the learning of golf putting. Optimised and control groups first completed a pre-test under neutral conditions. Optimised group participants were then provided a different condition for each of three acquisition blocks in a counterbalanced order: (a) positive feedback (EE); (b) choice of golf ball colour (AS); and (c) instructions to focus on a pendulum-like swing motion (EF). Control group participants practised under neutral conditions. The optimised group outperformed the control group during practice and on a delayed retention test, as measured by accuracy score and number of successful putts. Additionally, optimised group participants reported higher levels of confidence and positive affect after practice, and they were more confident prior to the retention test, as compared to control group participants. Our findings indicate that the key motivational (EE and AS) and attentional (EF) factors of the OPTIMAL theory can be applied individually in a sequential fashion, and in any order, throughout practice to benefit skill learning.

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Introduction
The OPTIMAL (Optimizing Performance Through Intrinsic Motivation and Attention for Learning) theory of motor learning (Wulf & Lewthwaite, 2016) identifies three key factors for optimising motor performance or learning: Enhanced expectancies (EE), autonomy support (AS), and an external focus (EF) of attention. The presence of these factors has been shown to have benefits for both immediate performance and longer-term learning. Individuals’ expectancies for future performance can be enhanced in various ways.
For instance, the provision of positive feedback has been found to enhance balance learning (e.g., Lewthwaite & Wulf, 2010), running efficiency (Stoate et al., 2012), or force production (Hutchinson et al., 2008) compared with control conditions. Also, liberal definitions of success (Ziv et al., 2019), suggestions that a task is learnable (Jourden et al., 1991), or that peers perform well on a given task (Wulf et al., 2012) can enhance performers’ self-efficacy beliefs and result in more beneficial effects for performance or learning than no such information.

Conditions that support individuals’ need for autonomy by providing them with choices can also enhance motor performance or learning. For example, allowing learners to choose when to receive feedback about their performance (e.g., Janelle et al., 1997), letting them decide when to use an assistive device (e.g., Chiviacowsky et al., 2012), or asking them to choose the amount of practice (Post et al., 2011), has been shown to facilitate learning. Even small choices or those that are incidental to the task can have immediate benefits for performance or enhance learning (e.g., Lewthwaite et al., 2015). For example, being able to choose the order of different tasks to be performed has been demonstrated to result in greater movement accuracy (An et al., 2020), balance (Wulf & Adams, 2014), and efficiency in force production relative to control conditions (Halperin et al., 2017; Iwatsuki et al., 2017, 2019).

Finally, the importance of adopting an external focus on the intended movement effect for the effectiveness and efficiency of movements has been demonstrated in numerous studies (for a review, see Wulf, 2013). An EF might be directed at the motion of an implement (e.g., racquet, ball, skis, discus, kayak) or even a sticker attached to the body (e.g., chest), a target to be hit, the force exerted against the ground, or an image such as the pendulum-like motion of a golf club. Compared with an internal focus on body movements or no directed-focus control conditions, benefits to performance and learning have been demonstrated for a wide variety of skills, levels of expertise, age, or (dis)ability. Much of this research has previously been reviewed (e.g., Lohse et al., 2012; Wulf, 2007a, 2007b, 2013; Wulf & Lewthwaite, 2010, 2016; Wulf & Prinz, 2001).

Not only has each factor (EE, AS, or EF) individually been shown to augment performance and learning relative to control conditions, but in a recent series of studies it was found that these factors can have additive benefits. Conditions that included combinations of two factors resulted in greater advantages for performance (Abdollahipour et al., 2017 [AS and EF]; Marchant et al., 2018 [EE and EF]) or learning (Pascua et al., 2015 [EE and EF]; Wulf et al., 2015 [AS and EF]; Wulf et al., 2014 [EE and AS]) than did those that included only one of these factors, or none. Furthermore, the presence of all three factors enhanced learning to an even greater extent than did combinations of two factors (Wulf et al., 2018).

Recent studies addressed the question of whether motor performance could be immediately enhanced by implementing all three factors in succession (Abdollahipour et al., 2019; Chua et al., 2018; Singh et al., 2020, Experiment 1). Abdollahipour et al. (2019) found that children’s bowling performance was enhanced by each of the three factors. After a baseline test, one group was provided EE, AS, and EF on three consecutive blocks of trials, in a counterbalanced order. Relative to a control group that performed all blocks under neutral conditions, that group demonstrated greater bowling accuracy (more pins knocked down) on all three blocks. Utilising similar designs, Singh et al. (2020, Experiment 1) found enhanced maximum handgrip strength, and Chua et al.
(2018) demonstrated greater maximum vertical jump height on blocks for which the so-called optimised group received one of the three factors. Moreover, in Chua et al.’s (2018) study, with each addition of a variable on successive blocks of trials, jump height increased further whereas it did not change in a control group.

The present study followed up on previous findings in various ways. First, we wanted to examine whether the successive implementation of the three factors (EE, AS, and EF) throughout the practice phase, rather than a simultaneous introduction of these factors at the beginning of practice (Wulf et al., 2018), would enhance learning, as measured by a delayed retention test. Previous studies that introduced the factors successively (Abdollahipour et al., 2019; Chua et al., 2018; Singh et al., 2020, Experiment 1) only examined immediate effects on performance. Those findings suggested that the sequential application of the three factors in successive trial blocks had a sustained influence on motor performance for the duration of the experimental session. We deemed it important to also examine possible longer-term influences on learning. In the present study, we used a golf putting task and investigated whether implementing EE, AS, and EF consecutively (in a counterbalanced order) in one group (optimised) would lead to increases in putting performance across practice, relative to a control group. Importantly, we hypothesised that the optimised practice condition would lead to superior learning. Second, unlike previous studies that examined the effects of all three factors only on motor outcomes (Abdollahipour et al., 2019; Chua et al., 2018; Singh et al., 2020; Wulf et al., 2018), we included measures of confidence and positive affect. Receiving positive feedback (EE), having a sense of autonomy (AS), and effective performance with an EF would all be expected to enhance performers’ confidence (e.g., Ávila et al., 2012; Pascua et al., 2015). Furthermore, perceptions of successful performance resulting from EE, AS, and EF may also increase positive affect (e.g., Clark & Ste-Marie, 2007; Stoate et al., 2012; Wulf et al., 2018). Positive affect is associated with phasic increases in dopamine discharge that strengthen neural connections (Ashby et al., 2010) and is believed to play a role in memory consolidation (Trempe et al., 2012). We expected the optimised group to show greater confidence immediately after practice and perhaps before the retention test (Ghorbani, 2019; Pascua et al., 2015) compared with participants practising under the non-optimised (control) condition. We further expected optimised group participants to experience greater positive affect than control group participants at the conclusion of the practice session.

Methods

Participants

A sample size of 30 participants was estimated via a power analysis using G*Power 3.1, with an estimated $\eta^2_p$ value of .07 (Wulf et al., 2018), an $\alpha$ value of .05, and a power value of .90 (Chua et al., 2018). Thirty-six undergraduate students (30 males, 6 females), with a mean age of 23.1 years ($SD$: 2.01) participated in this study. None of the participants had prior experience in golf putting, and all were naïve as to the specific purpose of the experiment. Also, no participant had taken a class in which material related to the OPTIMAL theory was discussed. They signed an informed consent form before participation. The study was approved by the university’s institutional review board.
**Apparatus and task**

Participants were asked to perform 2 m putts to a circular target (hole cup), with a standard-hole diameter of 10.8 cm. The putting task was performed on a level artificial-turf indoor green (700 × 550 cm). The green speed, as measured by a stimpmeter, was of 8.5 feet, which corresponded to a medium-high speed. To determine the putting accuracy, four increasingly larger concentric circles were drawn around the hole cup with diameters of 30, 50, 70, and 90 cm, respectively. Five points were awarded if the putt was made successfully. Four-, three-, two-, and one-point scores were recorded for balls stopping in one of the other farther zones, respectively. A score of zero points was given for any ball coming to rest outside the largest circle. Whenever the ball stopped on any line of the concentric circles, the higher score of the two adjacent zones was given for the trial. All participants used the same putter (Odyssey Hot 2-Ball Blade).

**Procedure**

Participants were quasi-randomly assigned to one of two groups in the order of appearance, the optimised and control groups, stratified by gender (15 males and 3 females per group). At the beginning of the experiment, a demonstration of the basic putting technique was provided to each participant. All participants received the same instructions from the experimenter, a professional golfer, regarding grip, posture, ball position, and alignment. They were asked to perform the putts as accurately as possible. After watching the demonstration and receiving the basic instructions, each participant completed a 20-trial pre-test. Subsequently, both groups performed the practice phase which consisted of 60 trials (i.e., three blocks of 20 trials). In the optimised group, one factor (EE, AS, or EF) was implemented in each block, with the order of factors counterbalanced across participants, using all six possible orders (EE-AS-EF, EE-EF-AS, AS-EE-EF, AS-EF-EE, EF-EE-AS, and EF-AS-EE). For the EE condition, positive feedback, in combination with (false) social-comparative feedback (“You are doing well, better than average.”), was provided after every fifth trial (see Figure 1a). In the AS condition, participants were able to choose the colour of the golf ball (white, orange, or yellow) for each putt (see Figure 1b). In the EF condition, they were asked to focus on a pendulum-like motion of the putter by producing a similar swing distance for the backswing and forward swing (see Figure 1c); a reminder was 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

![Figure 1. Feedback (EE) and instructions (AS, EF) for participants in the optimised group.](image)
optimised group and had to use the same colour schedule of golf balls that their counterpart had used in their corresponding AS block. One day after the practice phase, all participants performed a retention test consisting of 20 trials without positive feedback, choice, or focus instructions. During the pre-test, practice phase (with the exception of the AS block), and retention test, white golf balls were used by both groups. Between blocks, participants were given short breaks (one to two minutes).

Participants were asked to complete confidence questionnaires after the pre-test (before the first practice trial), after the practice phase, and prior to the retention test. Specifically, participants were asked to rate three statements (“I feel confident about my putting performance”; “I expect to get a higher score on each putt”; and “I trust my ability to achieve a higher average score in practice” or “I trust my ability to achieve a higher average score on the retention test”), on a scale from 1 (not confident at all) to 10 (extremely confident). The statements were adapted from the perceived competence subscale of the Intrinsic Motivation Inventory (McAuley et al., 1989). Cronbach’s alpha values were .92 (before practice), .95. (after practice), and .97 (before retention). Furthermore, a brief set of three items (i.e., happy, interested, strong), excerpted from the Positive and Negative Affect Schedule – Expanded Form (PANAS-X; Watson & Clark, 1994), was used to measure positive affect at the conclusion of the practice session. Participants were asked to rate each word in terms of how they felt at the present moment on a scale from 1 (very slightly or not at all) to 5 (extremely). Cronbach’s alpha for positive affect was .92.

Data analysis

Our main measure of putting performance was the total accuracy score on each block of 20 trials. In addition, we determined the number of holed putts (i.e., the ball ending up in the target hole) for each block. To analyse pre-test and retention test performance, one-way analyses of variance (ANOVA) were used. For the practice phase, we used a 2 (groups: optimised, control) × 3 (blocks: 1, 2, 3) mixed ANOVA with repeated measures on the last factor. To follow up on interaction effects, one-way ANOVAs were used. Ratings of confidence and positive affect were each averaged across three statements for each timepoint. Confidence ratings were analysed using a 2 (groups: optimised, control) × 2 (time: before practice, after practice) mixed ANOVA with repeated measures for the second factor for the practice phase, and a one-way ANOVA for the retention test. Positive affect after the practice phase was analysed using a one-way ANOVA. The alpha level was set to a value of .05, and partial eta squared ($\eta^2_p$) was used to determine effect size. Greenhouse-Geisser adjustments were used in instances when sphericity was violated. For post-hoc analysis, the Bonferroni correction was applied for multiple pairwise comparisons.

Results

Putting accuracy

Accuracy scores

Total scores on each 20-trial block for each group are shown in Figure 2. While the optimised group (40.72) and the control group (42.28) performed similarly on the pre-test $F(1, 34) = 0.82, p = .373, \eta^2_p = .023$, the optimised group (Block 1: 49.22, Block 2: 57.83; Block 3:
61.22) outperformed the control group (Block 1: 45.44, Block 2: 52.17, Block 3: 51.00) throughout practice. For the practice phase, the main effect of group was significant, $F(1, 34) = 12.40, p = .001, \eta^2_p = .267$. Both groups increased their putting accuracy, with the main effect of block being significant, $F(2, 68) = 30.66, p < .001, \eta^2_p = .474$. The interaction of group and block was also significant, $F(2, 68) = 3.68, p = .030, \eta^2_p = .098$. Follow-up ANOVAs showed that while the optimised and control groups did not differ significantly on Block 2 ($M_{diff} = 5.67, SE = 2.92$), $F(1, 34) = 3.76, p = .061, \eta^2_p = .100$, the optimised group outperformed the control group on Block 1 ($M_{diff} = 3.78, SE = 1.83$), $F(1, 34) = 4.24, p = .047, \eta^2_p = .111$, and Block 3 ($M_{diff} = 10.22, SE = 2.11$), $F(1, 34) = 23.42, p < .001, \eta^2_p = .408$. On the retention test conducted one day later, the optimised group (59.39) had significantly higher accuracy scores than the control group (53.61), $F(1, 34) = 8.65, p = .006, \eta^2_p = .203$. From the pre-test to the retention test, scores increased by 46% in the optimised group and 27% in the control group.

**Number of holed putts**

Both the optimised group (3.00) and the control group (3.39) had a similar number of holed putts on the pre-test, $F(1, 34) = 1.35, p = .253, \eta^2_p = .038$ (see Figure 3). Over the course of the practice phase, the optimised group (Block 1: 4.33, Block 2: 5.50, Block 3: 6.89) outperformed the control group overall and showed a greater increase across blocks than did the control group (Block 1: 2.94, Block 2: 4.28, Block 3: 4.28). The main effects of group, $F(1, 34) = 22.92, p < .001, \eta^2_p = .403$, and block, $F(1.66, 56.37) = 27.94, p < .001, \eta^2_p = .451$, were significant. The interaction of group and block was also significant, $F(1.66, 56.37) = 4.14, p = .027, \eta^2_p = .108$. Follow-up ANOVAs showed that, while the optimised group had higher numbers of holed putts than the control group on all blocks, that performance advantage was greatest on the last practice block [Block 1 ($M_{diff} = 1.39, SE = 0.41$): $F(1, 34) = 11.59, p = .002, \eta^2_p = .254$; Block 2 ($M_{diff} = 1.22, SE = 0.51$): $F(1, 34) = 5.71, p = .023, \eta^2_p = .144$; Block 3 ($M_{diff} = 2.61, SE = 0.50$): $F(1, 34) = 27.67, p < .001, \eta^2_p = .449$]. On the retention test one day later, the optimised group (6.11) had a significantly higher number of holed putts than the control group (4.11), $F(1, 34) = 17.60, p < .001, \eta^2_p = .341$. The increase in the number of holed putts...
putts from the pre-test to the retention test was 104% in the optimised group versus 21% in the control group.

**Confidence**

After the pre-test, confidence ratings were similar for the optimised (4.20) and yoked groups (4.42) (Figure 4a). However, the optimised group (6.19) had higher confidence than the control group (5.28) at the end of practice. The interaction of group and time was significant, $F(1, 34) = 8.58, p < .01, \eta^2_p = .202$. The main effect of time was also significant, $F(1, 34) = 54.00, p < .001, \eta^2_p = .614$, whereas the Group main effect was not significant $F(1, 34) < 1$. Follow-up tests on the interaction effect indicated that confidence before practice did not differ between groups, $F(1, 34) = 0.56, p = .460, \eta^2_p = .016$, but was significantly higher for the optimised group at the end of practice, $F(1, 34) = 8.31, p = .007, \eta^2_p = .196$. Before the retention test, confidence was also higher in the optimised (6.31) relative to the control group (5.20), $F(1, 34) = 12.18, p = .001, \eta^2_p = .264$.

**Positive affect**

At the end of the practice phase, the optimised group had higher positive affect than the control group as shown in Figure 4b. Optimised group participants’ average positive affect rating was 4.01 ($SD = 0.72$), while control group participants’ rating was 3.14 ($SD = 0.85$). This group difference was significant, $F(1, 28) = 10.79, p < .01, \eta^2_p = .241$.

**Discussion**

In the current investigation, we followed up on the findings of earlier studies that showed immediate beneficial effects on motor performance of using EE, AS, and EF (Abdollahi-pour et al., 2019; Chua et al., 2018, 2020; Singh et al., 2020) relative to control conditions. In some of those studies, the three factors were implemented in consecutive trial blocks.

**Figure 3.** Numbers of holed putts for the optimised and control groups during the pre-test, practice phase, and retention test. Error bars represent standard errors.
The main purpose of the present study was to examine whether a consecutive implementation could also have more permanent advantages for skill learning. We examined the combined influences of providing positive social-comparative feedback (EE), giving learners a small choice (AS), and providing external focus instructions (EF). The results showed that optimised group participants who practiced golf putting with EE, AS, and EF – applied one after another (counterbalanced across all participants in the optimised group) in three blocks of practice trials – outperformed control group participants. Specifically, the optimised group showed a greater increase in putting accuracy and number of holed putts across practice than did the control group. Most importantly, the optimised group also showed superior performance on both measures of accuracy on a delayed retention test. Thus, the consecutive implementation of each of these three key factors of the OPTIMAL theory, in any order, enhanced motor skill learning. Moreover, learners who received practice conditions that included EE, AS, and EF reported greater confidence at the end of practice and prior to taking the retention test than did control group participants. In addition, optimised group participants provided higher ratings for positive affect before the retention test.

It might be argued that the optimised group benefited from the additional interaction with the experimenter relative to the control group. That is, rather than the content of the instructions (e.g., positive feedback, external focus) leading to learning differences between groups, the instructions or communications per se could have facilitated learning. With the methods we used in the present study, this explanation cannot be ruled out. Yet, it is unlikely. Previous studies that included groups who received additional instructions, albeit negative feedback (e.g., Lewthwaite & Wulf, 2010; Wulf et al., 2010) or internal focus instructions (see Wulf, 2013), demonstrated that the content matters. Only if the content was positive or promoted an external focus was learning enhanced relative to control conditions.
Wulf and Lewthwaite (2016) suggested that practice conditions that include the three key factors in the OPTIMAL theory contribute to goal-action coupling, or the fluidity with which movement intent is translated into neuromuscular activation. Increases in movement efficiency as a result of any of the three factors – EE (e.g., Hutchinson et al., 2008), AS (e.g., Iwatsuki et al., 2019), or EF (e.g., Lohse et al., 2011) – may reflect the relative ease of making large-scale and well-timed linkages (i.e., functional connectivity) among task-relevant motor networks (Menon & Uddin, 2010). All factors individually, and in combination (Wulf et al., 2018), have also been shown to enhance not only performance but also learning, which involves gaining facility over functional connections (Giboin et al., 2019; Milton et al., 2007), in addition to more permanent structural brain changes (e.g., Taubert et al., 2010) that underlie the translation of goals into actions. Dopamine release resulting from rewarding positive experiences strengthens neural connections (Ashby et al., 2010) and is believed to be a mechanism underlying motor learning (Abe et al., 2011). Successful performance would be expected to enhance expectations, as would autonomy support (Leotti & Delgado, 2011; Murayama et al., 2016). These positive experiences are often rewarding. Moreover, an external focus appears to clarify neuromuscular coordination by suppressing unnecessary neural activity (Kuhn et al., 2017, 2018) and muscular co-contractions (e.g., Lohse et al., 2011). The resulting ease of movement and effective performance likely increase learners’ performance expectancies (e.g., Pascua et al., 2015) and facilitate successful (i.e., rewarding) future performance.

Participants’ confidence and positive affect ratings are in line with these assumptions. Differences in confidence emerged by the end of practice, with the optimised group reporting higher confidence ratings than the control group, and this group difference was still seen before the retention test. Given that optimised group participants achieved progressively better performance across practice, their enhanced confidence may be the direct or indirect result of the optimised practice conditions. The increase in positive affect demonstrated by the optimised group relative to the control group is also consistent with the enhanced expectations and, in general, the positive experience associated with the three factors.

The present study is the first to demonstrate that implementing the three key factors of the OPTIMAL theory in a successive fashion, in any order, enhanced skill learning. While the presence of EE, AS, and EF seems to be necessary for optimal motor learning (Wulf et al., 2018), it does not appear to be necessary that they be applied at the same time. Thus, practitioners interested in enhancing learning outcomes would have some flexibility in terms of how they deploy conditions associated with key OPTIMAL factors during skill practice. Furthermore, there are many different ways in which each factor can be operationalised. While false social-comparative feedback is not recommended for practical settings due to its deceptive nature, feedback highlighting good performance (e.g., Chiviacowsky & Wulf, 2007; Saemi et al., 2012), simple encouraging comments (Wulf et al., 2012), or liberal definitions of success (Palmer et al., 2016; Ziv et al., 2019) can serve as a means for enhancing expectancies. It should be noted that success with challenge (Wulf & Lewthwaite, 2016, p. 1392) appears to be critical for enhancing motivation and learning. In a few studies (e.g., Ong, Hawke, & Hodges, 2019; Ong, Lohse, & Hodges, 2015), the failure to boost learner’s motivation – perhaps due to large target sizes (i.e., lack of challenge) – resulted in a lack of learning enhancements. To increase performers’ expectancies and motivation, practitioners should therefore seek to balance challenging practice conditions with success experience.
Learner autonomy can be supported not only by task-relevant choices such as deciding when to receive feedback (e.g., Janelle et al., 1997) or watch a skill demonstration (e.g., Wulf et al., 2005), but also by small or even incidental choices (e.g., Lewthwaite et al., 2015). The opportunity for choice is rewarding (Leotti & Delgado, 2011), independent of the type of choice – as long as the choice is at least somewhat meaningful to the performer and delivered in a respectful manner (see Lewthwaite et al., 2015). It should also be pointed out that the value of a given choice might be specific to a given context and dependent on a match with performer characteristics (e.g., age, skill level). Occasional failures to find beneficial influences of choice on motivation and learning (e.g., Grand et al., 2017) might be due to the specific operationalisation of choice, the manner in which choices are provided, or the language and tone with which they are administered (see Hooyman et al., 2014). Thus, instructors can facilitate performance and learning by creating an autonomy-supportive atmosphere that includes performers’ choices over practice conditions as well as respectful communication.

Finally, external focus feedback or instructions are important for effective performance and learning, as numerous studies have consistently shown over the past two decades (for reviews, see Wulf, 2013; Wulf & Lewthwaite, 2016). However, the optimal external focus can vary, depending on the level of expertise. While a technique-related proximal external focus such as the “platform” in volleyball (Singh & Wulf, 2020) or the pendulum-type motion of the golf club (Wulf et al., 2000) is effective for novices, a more distal external focus on the task goal (e.g., hitting a target) has been shown to be more effective at higher skill levels (Bell & Hardy, 2009; Singh & Wulf, 2020).

OPTIMAL theory is, of course, agnostic as to which forms expectancy enhancement, autonomy support, and an external focus of attention might take, not to mention the ways in which experimenters or practitioners attempt to operationalise or apply these forms. Overall, it appears that practitioners (and learners themselves) have considerable freedom as to how and when they implement OPTIMAL factors to facilitate skill learning. They can use their creativity and expertise to determine how to best utilise them.

**Disclosure statement**

No potential conflict of interest was reported by the author(s).

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