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RESEARCH NOTE

Optimizing Bowling Performance

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The present study examined the influence on motor performance of key variables described in the OPTIMAL (Optimizing Performance Through Intrinsic Motivation and Attention for Learning) theory of motor learning: enhanced expectancies for future performance, autonomy support, and an external focus. Participants performed a nine-pin bowling task. In the optimized group, enhanced expectancies, autonomy support, and an external focus were implemented on three successive blocks of 12 trials. In the control group, participants performed all trials under "neutral" conditions. The optimized group outperformed the control group on all blocks. The findings corroborate the importance of key variables in the OPTIMAL theory by demonstrating immediate benefits of their implementation for motor performance.

Keywords*:* autonomy support, enhanced expectancies, external focus, motor performance

According to the OPTIMAL (Optimizing Performance Through Intrinsic Motivation and Attention for Learning) theory of motor learning (Wulf & Lewthwaite, 2016), three factors are key to optimal motor performance and learning. Two of these factors are motivational in nature (enhanced expectancies, autonomy support) and one is related to the performer's focus of attention (external focus). Each factor independently has been shown to enhance the performance and learning of various types of motor skills (e.g., Lewthwaite, Chiviacowsky, Drews, & Wulf, 2015; Stoate, Wulf, & Lewthwaite, 2012; Wulf, Höß, & Prinz, 1998; for reviews, see Lewthwaite & Wulf, 2017; Wulf & Lewthwaite, 2016).

Conditions that enhance an individual's expectancies for future performance include, for example, feedback highlighting good performance (e.g., Badami, VaezMousavi, Wulf, & Namazizadeh, 2011), positive social-comparative feedback (e.g., Montes, Wulf, & Navalta, 2018), information that a skill is learnable (e.g., Wulf & Lewthwaite, 2009), or liberal definitions of success (Palmer, Chiviacowsky, & Wulf, 2016). Enhanced expectancies increase perceptions of

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competence (Gonçalves, Cardozo, Valentini, & Chiviacowsky, 2018), self-confidence (Badami, VaezMousavi, Wulf, & Namazizadeh, 2012), and self-efficacy (e.g., Saemi, Porter, Ghotbi-Varzaneh, Zarghami, & Maleki, 2012). Heightened confidence in their ability allows performers to direct their attention to the task goal, which in turn results in enhanced movement outcomes (Wulf & Lewthwaite, 2016).

Practice or performance conditions that support an individual's need for autonomy typically involve the opportunity to make choices (Cordova & Lepper, 1996; Deci & Ryan, 2008; Tafarodi, Milne, & Smith, 1999). Numerous studies have demonstrated that allowing performers to make task-related choices or decisions, such as those concerning the delivery of feedback (Janelle, Barba, Frehlich, Tennant, & Cauraugh, 1997), demonstrations of the skill (Wulf, Raupach, & Pfeiffer, 2005), amount of practice (Post, Fairbrother, & Barros, 2011), or the order of tasks (Halperin, Williams, Martin, & Chapman, 2016; Iwatsuki, Abdollahipour, Psotta, Lewthwaite, & Wulf, 2017) facilitates learning. Recent studies have found that even small or incidental choices, such as color of implements (e.g., Lewthwaite et al., 2015) or other task-irrelevant choices (Iwatsuki, Navalta, & Wulf, 2019; Wulf, Iwatsuki, et al., 2018), enhance motivation, performance, and learning.

Finally, an external focus of attention, or concentration, on the intended movement effect or outcome has consistently been shown to be a prerequisite for optimal performance and learning (e.g., Wulf et al., 1998). Relative to instructions or feedback that induce an attentional focus on body movements (internal focus) or control conditions, those that promote an external focus generally result in greater fluidity and automaticity (Wulf, McNevin, & Shea, 2001), and superior movement effectiveness and efficiency (for a review, see Wulf, 2013). Aside from directing attention with clarity to the task goal, an external focus has the benefit of preventing disruptive body or self-related attentional distractions from the movement goal (Abdollahipour, Palomo Nieto, Psotta, & Wulf, 2017).

While each factor independently has been shown to benefit performance and learning, a series of studies has shown that combinations of two or three factors can be even more beneficial. Conditions that included both enhanced expectancies and autonomy support (Wulf, Chiviacowsky, & Cardozo, 2014), enhanced expectancies and external focus (Marchant, Carnegie, Wood, & Ellison, 2018; Pascua, Wulf, & Lewthwaite, 2015), or autonomy support and external focus (Abdollahipour et al., 2017; Wulf, Chiviacowsky, & Drews, 2015) resulted in more effective performance or learning than those that included only one factor or none. Combining all three factors during practice has been found to be even more beneficial than any combination of two factors (Wulf, Lewthwaite, Cardozo, & Chiviacowsky, 2018). These findings suggest that the advantages for performance or learning provided by three key factors in the OPTIMAL theory (Wulf & Lewthwaite, 2016) are additive in nature, presumably by utilizing (partially) different mechanisms.

According to the OPTIMAL theory, the three factors contribute to successful movement outcomes by strengthening the coupling of performers' goals and their movement actions. The benefits of enhanced expectancies and autonomy support are presumably the result of reward-related dopaminergic responses. When paired with skill practice, dopamine helps strengthen memory and learning (Wise, 2004) by facilitating functional and structural neural connectivity. An external focus directly contributes to goal-action coupling by helping the performer direct attention to the task goal and preventing disruptive body or self-related distractions from the task goal. In addition, by producing successful movement outcomes, an external focus likely enhances expectancies for future performance. Thus, the presence of enhanced expectancies, autonomy support, and external focus results in enhanced motor performance and learning. In fact, one prediction of the OPTIMAL theory is that conditions that optimize performance facilitate learning.

Most previous studies that examined combined effects of enhanced expectancies, autonomy support, and/or external focus were concerned with motor *learning*, as measured by retention or transfer performance of groups that practiced under the respective conditions (Schmidt, Lee, Winstein, Wulf, & Zelaznik, 2019). Immediate effects on motor *performance* resulting from combinations of enhanced expectancies, autonomy support, or external focus have been investigated in very few studies (Abdollahipour et al., 2017; Marchant et al., 2018), and only one study compared the influence of all three factors to a neutral control condition (Chua, Wulf, & Lewthwaite, 2018). That study examined immediate effects of enhanced expectancies, autonomy support, and external focus on the performance of a maximum countermovement jump and demonstrated increasing jump heights when the three factors were implemented on successive blocks of trials. In contrast, jump height did not change across blocks in a control condition. Given the theoretical significance of these findings and their potential practical implications, the current study sought to replicate and extend these findings. While Chua et al.'s (2018) study required maximum force production, we wanted to examine effects of consecutively introducing enhanced expectancies, autonomy support, and external focus on a task requiring movement accuracy (i.e., nine-pin bowling). Within a single experimental session, enhanced expectancies (positive social-comparative feedback), autonomy support (choice of ball color), and external focus (focus on the path of the ball) were implemented on successive trial blocks, in a counterbalanced order, in the optimized group. The control group performed all blocks under the same "neutral" conditions. We hypothesized that bowling performance would be enhanced (i.e., greater number of pins knocked down) in the optimized relative to the control group, irrespective of the order in which the three factors were implemented. We also wanted to examine potential incremental effects of the three variables, as seen in the study by Chua et al. (2018).

Methods

Participants

Thirty-six undergraduate university students (18 males, 18 females) with a mean age of 21.4 ± 1.6 years participated in the study. A priori power analysis with G*Power 3.1 indicated that 36 participants would be sufficient to identify significant group differences in a two-way between-within-participants design with a power (1 – β) of .90, an effect size f of .25 ($\eta_p^2 = .06$), and an α level of .05 (Faul, Erdfelder, Lang, & Buchner, 2007). Ethical approval was obtained from the university's review board. All participants provided informed consent before data collection began. Participants were not aware of the specific purpose of the study. No participant had prior experience with the bowling task.

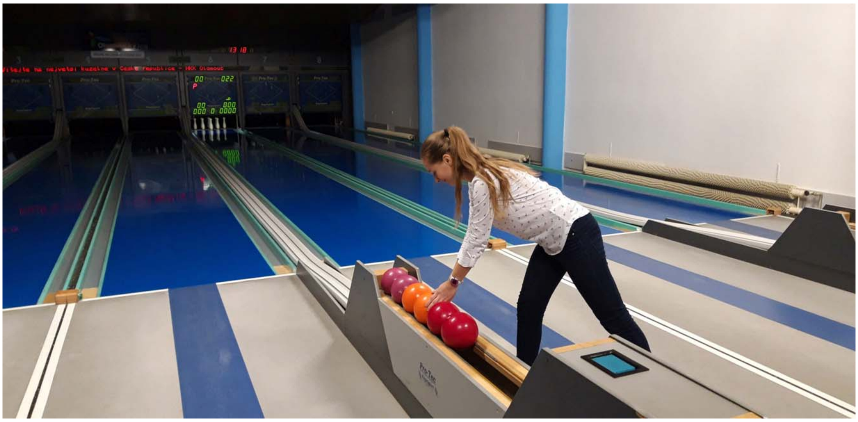

Figure 1 — A participant choosing the color of the bowling ball in the autonomy support condition.

Apparatus and Task

A nine-pin bowling task was used. Participants' goal was to knock down as many pins as possible. They were asked to begin each trial by standing behind a line that was placed three meters behind the throwing line. Participants held the ball with their dominant hand, took three steps, and then rolled the ball towards the pins (see Figure 1). The specifications of the lane, ball, and pins were in accordance with the official World Nine-Pin Bowling Association's technical requirements (World Ninepin Bowling Association, 2017). Each pin was 40 cm tall and weighed 1.6 kg. Nine pins were positioned by a setter machine in which the lead pin was placed at a distance of 19.5 m from the throwing line. All balls had a weight of 2.8 kg and a diameter of 16 cm. The number of pins knocked down was displayed on a scoreboard.[1]

Procedure

Participants were asked to wear their own athletic clothing and shoes. They completed a five-minute warm up outside the bowling hall. The warm up was administrated by a research assistant and involved a two-minute run and three minutes of dynamic stretching exercises. Upon entering the bowling hall, the experimenter explained the task to participants, including a) beginning a trial behind the start line, b) holding the ball with dominant hand, c) taking three steps forwards, and d) bowling the ball toward the pins. The experimenter also demonstrated the task and explained that the goal was to knock down as many pins as possible. Next, each participant performed two baseline trials.

Participants were pseudo-randomly assigned to the optimized or control group, with the constraint that there be an equal number of females and males in each group. Participants performed a total of 36 trials (i.e., three blocks of 12 trials). There were 30-sec rest intervals between trials and a five-min rest interval between trial blocks. In the optimized group, participants received different instructions before each block. In the enhanced expectancies condition/block, they received (false) positive social-comparative feedback. That is, they were informed that the average of their previous trials was "better than average" in comparison to other participants. In the autonomy support condition, participants were told that they could choose the color of the ball (red, purple, or orange) before each trial in this block. On all other blocks, the purple ball was used. In the external focus condition, participants were asked to focus on the path of the ball, and reminders were given after every third trial. The order of the enhanced expectancies, autonomy support, and external focus conditions was counterbalanced across optimized group participants. Control group participants performed all three blocks under the same conditions, that is, without additional instructions or feedback. However, each control group participant was yoked to one participant in the optimized group and was assigned the same ball color that participant had chosen in her/his respective autonomy-support block.

Data Analysis

The average number of pins knocked down on baseline trials and in each 12-trial block served as the dependent variable. Baseline performances of the two groups were compared in a univariate analysis of variance (ANOVA). To compare group differences on the three experimental trial blocks, two different analyses were performed. First, we used a 2 (group: optimized vs. control) × 3 (condition: enhanced expectancies, autonomy support, external focus) mixed-factor ANOVA with repeated measures on the second factor to compare the effects of enhanced expectancies, autonomy support, and external focus in the optimized group to the control condition. As participants in the optimized group performed the three conditions in six different orders, the blocks of their respective control group counterparts were organized accordingly for this analysis (similar to Chua et al., 2018). Second, to determine potential cumulative effects of the independent variables (enhanced expectancies, autonomy support, external focus), we compared the two groups' performances in a 2 (groups) × 3 (blocks) ANOVA that included a chronological order of blocks. For post-hoc tests, Bonferroni adjustments were used when appropriate. Effect sizes are reported as partial eta squared values (η_p^2), where η_p^2 = .01, .06, and .14 correspond to small, moderate, or large effects, respectively (Cohen, 1988; Lakens, 2013). To compare the effect sizes between blocks, the repeated-measures version of Cohen's *d* was utilized. Cohen's *d* values correspond to low ($d = 0.2$), medium ($d = 0.5$), or large ($d = 0.8$) effects (Cohen, 1988).

Results

The average number of pins knocked down on baseline trials was similar for the control ($M = 2.05$, $SD = 2.10$) and optimized ($M = 2.11$ cm, $SD = 1.40$) groups (see Figure 2). There was no significant group difference, $F(1, 34) = 0.009$, $p = .926$, $\eta_p^2 = .001$.

Performance under enhanced expectancies, autonomy support, and external focus conditions was significantly higher in the optimized ($M = 3.67$, $SD = 0.85$) relative to the control ($M = 3.14$, $SD = 0.90$) group. The main effect of group was

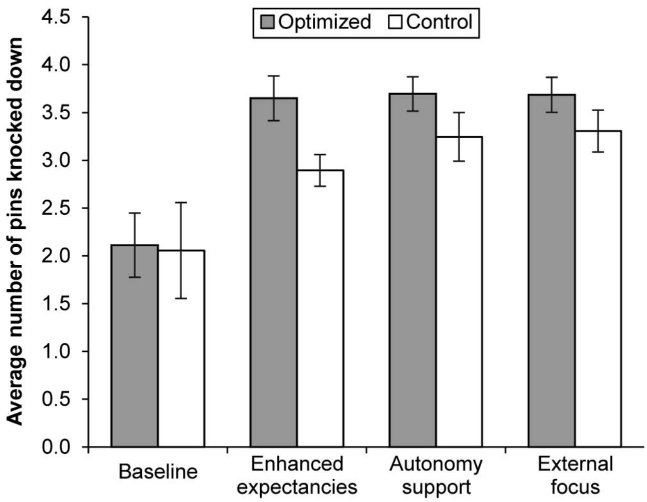

Figure 2 — Average number of pins knocked down for the optimized and control groups as a function of condition (enhanced expectancies, autonomy support, and external focus). Error bars represent standard errors.

significant, $F(1, 34) = 5.597$, $p = .024$, $\eta_p^2 = .141$. There was no significant main effect of condition, $F(2, 68) = 1.141$, $p = .326$, $\eta_p^2 = .032$, or interaction of group and condition, $F(2, 68) = 0.751$, $p = .476$, $\eta_p^2 = .022$.

Figure 3 shows the average number of pins knocked down across blocks for the optimized and control groups. Again, the optimized group outperformed the control group. The main effect of group was significant, $F(1, 34) = 5.388$, $p = .026$, $\eta_p^2 = .137$. Performance generally increased across blocks. The main effect of block was significant, $F(2, 68) = 3.529$, $p = .035$, $\eta_p^2 = .094$. There was no interaction of group and block, $F(2, 68) = 1.991$, $p = .144$, $\eta_p^2 = .055$.

Discussion

The present study followed up on Chua et al.'s (2018) study in which the three key variables in the OPTIMAL theory (Wulf & Lewthwaite, 2016), enhanced expectancies, autonomy support, and external focus, were found to enhance maximal vertical jump height. We used an accuracy task in our attempt to replicate the immediate benefits of these variables for motor performance. Similar to the design used by Chua and colleagues, the three factors were implemented on successive trial blocks for one group (optimized). Relative to the control group that performed all blocks under the same conditions, the optimized group showed significantly greater bowling accuracy. That is, all factors (enhanced expectancies, autonomy support, and external focus) resulted in enhanced performance. This finding replicated that of Chua and colleagues. It is also in line with other studies showing immediate performance benefits resulting from any of the three factors alone (for reviews, see Schmidt et al., 2019; Wulf & Lewthwaite, 2016).

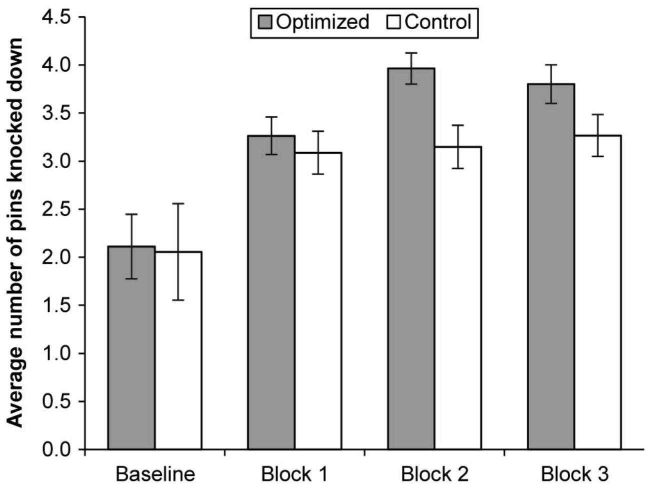

Figure 3 — Average number of pins knocked down for the optimized and control groups as a function of block. Error bars represent standard errors.

The present findings also corroborate the notion that performance under control conditions tends to be non-optimal, and that certain conditions are necessary to optimize performance (e.g., Abdollahipour et al., 2017; Marchant et al., 2018; Pascua et al., 2015; Wulf et al., 2015; Wulf, Lewthwaite, et al., 2018). The reasons for participants' less-than-optimal performance under control conditions is consistent with the view that motor performance is a blend of social-cognitive–affective–motor influences (Lewthwaite & Wulf, 2010). Cognitive, affective, or socio-cultural influences, including those that result from the presence of an experimenter or audience (Wallace, Baumeister, & Vohs, 2005), tend to promote a self-focus, or possibly other distracting thoughts, that disrupt movement fluidity and degrade performance (McKay, Wulf, Lewthwaite, & Nordin, 2015). Self-referential processing, which is related to activation of the brain's default mode (e.g., Buckner, Andrews-Hanna, & Schacter, 2008), interferes with effective task performance. Optimal performance requires functional connectivity of task-related neural networks (e.g., Di & Biswal, 2015), or an efficient coupling of goals and actions.

The notion of*goal-action coupling* is central to the OPTIMAL theory (Wulf & Lewthwaite, 2016). It is facilitated by conditions that allow the performer to direct attention to the task while suppressing self-related or task-irrelevant thoughts. Those conditions are met when enhanced expectancies, autonomy support, and external focus are present. Moreover, enhanced expectancies are thought to trigger dopaminergic responses that facilitate functional connectivity (Wise, 2004). Autonomy support conditions also enable performers to maintain their focus on the task goal by enhancing performer confidence or self-efficacy (e.g., Lemos, Wulf, Lewthwaite, & Chiviacowsky, 2017). A sense of autonomy can additionally promote positive affect and associated dopaminergic activity, in contrast to the negative emotions resulting from controlling environments (e.g., Hooyman, Wulf, & Lewthwaite, 2014; Reeve & Tseng, 2011). Finally, the benefits of adopting an external focus on the intended movement effect or task goal have been demonstrated in numerous studies (Wulf, 2013). By preventing a detrimental internal (or self) focus, it is assumed to directly promote functional connectivity for task performance (Kuhn, Keller, Ruffieux, & Taube, 2017). The presence of all three factors (enhanced expectancies, autonomy support, and external focus) presumably results in a stronger linkage between goal and action in comparison to one or two factors, although the present study was not designed to test that notion.

In contrast to Chua et al.'s study, in which enhanced expectancies, autonomy support, and external focus (independent of their order) enhanced jump height in an incremental fashion, we did not see an additive effect in the present study. That is, the optimized group did not show greater improvement across blocks than did the control group, as indicated by a lack of interaction between group and block. It should be pointed out that the OPTIMAL theory (Wulf & Lewthwaite, 2016) does not predict incremental effects of the three variables. It appears that cumulative effects may or may not be present, perhaps as a function of the overall duration of a trial block (condition). In Chua et al.'s (2018) study, all experimental trials were completed within 10 minutes. Thus, all factors were applied within this timeframe. In the present study, one trial block lasted about 15 minutes, including rest periods between trials and blocks, and the total duration of the experimental session was about 40 minutes. Thus, the intervals between implementations of additional factors were considerably longer and may have exceeded the duration during which a certain variable (e.g., positive feedback in the enhanced expectancies condition) exerted its influence. While the temporal nature of dopamine dynamics needs further study, Lohani et al. (2018) demonstrated that a phasic burst stimulation of dopamine neurons in rats resulted in sustained elevation of extracellular dopamine that lasted for about 20 minutes. According to the authors, the continued elevation of dopamine levels after stimulation might serve to maintain motivational states, stabilize active neural networks, and is likely important for memory consolidation. This timescale of tonic dopamine neurotransmission might explain why enhanced expectancies, autonomy support, and external focus yield additive benefits when they are applied in close temporal proximity (Chua et al., 2018) or even at the same time (e.g., Abdollahipour et al., 2017; Wulf, Lewthwaite, et al., 2018). Outside of this timeframe, and after dopamine levels return to baseline, the introduction of another variable may no longer result in additional performance advantages (as in the present study). Clearly, more research is needed to further examine these issues.

The present findings add to the growing evidence showing that the performance of motor skills can be enhanced almost instantaneously by conditions that boost performers' confidence (enhanced expectancies), support their need for autonomy (autonomy support) by providing them with (small) choices, and direct their attention to the intended movement effect (external focus). Practitioners, such as coaches, physical therapists, or music teachers, have many options to creatively design appropriate motivational and attentional focus interventions to facilitate immediate performance or longer-term learning (for discussions, see Lewthwaite & Wulf, 2017; Schmidt et al., 2019; Wulf & Lewthwaite, 2016).

Note

1. The top 80 nine-pin bowlers in Czechia and Slovakia knocked down between 6 and 7 pins per ball ($M = 6.42$, $SD = 0.15$) in the season 2018–2019 (http://interliga.kuzelky.cz/jednotlivci.php).

Acknowledgments

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