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Onward and upward: Optimizing motor performance

Lee-Kuen Chua[a,*], Gabriele Wulf[a], Rebecca Lewthwaite[b,c]

[a] University of Nevada, Las Vegas, United States
[b] Rancho Los Amigos National Rehabilitation Center, Downey, United States
[c] University of Southern California, Los Angeles, United States

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ABSTRACT

In the OPTIMAL theory of motor learning (Wulf & Lewthwaite, 2016), three factors are postulated to facilitate motor performance and learning: Enhanced expectancies (EE) for performance, autonomy support (AS), and an external focus (EF) of attention. We examined whether EE, AS, and EF would have immediate performance benefits and whether implementing these factors consecutively would lead to incremental performance increases. Participants were assigned to the optimized or control groups and performed a maximal jump. After the first trial block (baseline), optimized group participants were provided different conditions on each of the following 3 blocks: (a) Positive social-comparative feedback (EE); (b) choice of figure on the ground from which to jump (AS); and (c) instructions to focus on a marker on their waist (EF). The order of conditions was counterbalanced. Control group participants performed all 4 blocks under the same (control) condition. The optimized group outperformed the control group on Blocks 2–4. Moreover, their jump height increased with each addition of another variable, whereas it did not change across blocks in the control group. Thus, EE, AS, and EF had additive or incremental benefits for performance. The findings corroborate the importance of key variables in the OPTIMAL theory for motor performance.

The OPTIMAL theory of motor learning (Wulf & Lewthwaite, 2016) identifies three factors key to the optimization of motor performance and learning. These three variables – enhanced expectancies (EE), autonomy support (AS), and external focus (EF) of attention – appear to make partially independent contributions to goal-action coupling or the fluidity with which the intended goal is translated into action (Wulf, Lewthwaite, Cardozo, & Chiviacowsky, 2017). The result of efficient goal-action coupling is enhanced motor performance as well as motor skill learning. Motivational and attentional factors help prime and align central cortical and subcortical and peripheral neuromuscular processes to the intended goal (e.g., Cole, Laurent, & Stocco, 2013; Kuhn, Keller, Ruffieux, & Taube, 2017; Lohse, Sherwood, & Healy, 2010; Manohar et al., 2015; Meadows, Gable, Lohse, & Miller, 2016; Wulf, 2013; Wulf & Lewthwaite, 2016) in part, through instruction and the intrinsic neuromodulatory influence of reward-related dopamine.

One of the myriad ways to *enhance expectancies*, that is, elevate a person's expectations for positive experiences or success, is the provision of normative feedback that suggests that performance is better-than-average in the context of comparison with others (Hutchinson, Sherman, Martinovic, & Tenenbaum, 2008; Lewthwaite & Wulf, 2010b; Stoate, Wulf, & Lewthwaite, 2012; Wulf, Chiviacowsky, & Lewthwaite, 2010). Positive feedback indicating that one was performing better relative to others was found to increase performers' perceived competence over and above that of participants who were provided with negative feedback or no social-comparative feedback (Lewthwaite & Wulf, 2010b). Likewise, the liberal defining of success criteria (Chiviacowsky, Wulf, &

* Corresponding author at: Department of Kinesiology and Nutrition Sciences, University of Nevada, Las Vegas, 4505 Maryland Parkway, Las Vegas, NV 89154-3034, United States.
E-mail address: lee-kuen.chua@unlv.edu (L.-K. Chua).

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Lewthwaite, 2012; Palmer, Chiviacowsky, & Wulf, 2016; Trempe, Sabourin, & Proteau, 2012) or the use of visual illusions (Chauvel, Wulf, & Maquestiaux, 2015; Marchant, Carnegie, Wood, & Ellison, 2018; Witt, Linkenauger, & Proffitt, 2012) to suggest relative ease of task can increase confidence in personal performance capabilities. The provision of simple statements that suggest to a person that peers typically perform well at the task (Hively & El-Alayli, 2014; Wulf, Chiviacowsky, & Lewthwaite, 2012), and the mindset that performance increases progressively with practice (Jourden, Bandura, & Banfield, 1991; Wulf & Lewthwaite, 2009) are other possible strategies for enhancing performers' expectancies. Enhanced performance expectancies serve a task-readying function by directing attention to the task goal and suppressing task-irrelevant or self-related thoughts (see Wulf & Lewthwaite, 2016). Further, expectations of rewarding experiences trigger a dopaminergic response that facilitates short-term performance and longer-term learning through functional and structural connectivity (Gruber, Ritchey, Wang, Doss, & Ranganath, 2016; Lappin et al., 2009; Wise, 2004).

Autonomy support, or conditions that are supportive of individuals' need for control or autonomy in their actions, are important for motivation, performance, and learning (e.g., Cordova & Lepper, 1996; Deci & Ryan, 2008; Tafarodi, Milne, & Smith, 1999). In the motor learning literature, many studies have demonstrated that learning is enhanced when learners have the opportunity to make decisions about aspects of practice conditions, including the delivery of feedback, skill demonstrations, or amount of practice (e.g., Janelle, Barba, Frehlich, Tennant, & Cauraugh, 1997; Post, Fairbrother, & Barros, 2011; Wulf, Raupach, & Pfeiffer, 2005; for a recent review, see Wulf & Lewthwaite, 2016). There is also increasing evidence that providing even small or incidental choices that do not have direct task relevance can be sufficient to enhance motor performance or learning. Examples include choosing the golf ball color for a golf putting task (Lewthwaite, Chiviacowsky, Drews, & Wulf, 2015), selecting the particular order of different types of punches in kickboxing (Halperin, Williams, Martin, & Chapman, 2016), and picking the color of a mat to be placed under a target (Wulf et al., 2017). A meta-analysis of research studies on choice effects found that incidental choices can be particularly motivating (Patall, Cooper, & Robinson, 2008). Opportunities for choice enhance expectations for positive outcomes and often result in higher self-efficacy and intrinsic motivation compared with controlling conditions (Hooyman, Wulf, & Lewthwaite, 2014; Lemos, Wulf, Lewthwaite, & Chiviacowsky, 2017; Murayama, Izuma, Aoki, & Matsumoto, 2016). They allow performers to maintain their attentional focus on the task goal, without the need to engage in self-regulatory activity, and suppress negative emotional reactions resulting from controlling environments (e.g., Reeve & Tseng, 2011).

Finally, the importance of maintaining a clear *external focus* on the task goal has been demonstrated in numerous studies. An instructed external focus of attention on the intended movement effect (e.g., implement trajectory, hitting the target, exerting force against the ground) typically results in more effective and efficient performance or learning than an internal focus on body movements (for a review, see Wulf, 2013). Since the pioneering study by Wulf, Höß, and Prinz (1998) showing that adopting an external focus resulted in more effective balance learning than the use of an internal focus or no specific focus instruction, numerous studies have corroborated this effect. Immediate performance advantages or learning benefits have been found to increase accuracy in hitting a target (e.g., Bell & Hardy, 2009; Lohse et al., 2010), enhance movement kinematics (e.g., An, Wulf, & Kim, 2013; Christina & Alpenfels, 2014), increase maximum force production (e.g., Halperin et al., 2016; Wulf & Dufek, 2009), or reduce oxygen consumption (e.g., Schücker, Hagemann, Strauss, & Völker, 2009). An external focus is an important contributor to goal-action coupling. It is assumed to facilitate functional connectivity (Kuhn et al., 2017) by maintaining attention on the task goal and preventing a detrimental internal or self-related focus. Furthermore, by producing effective performance it might also contribute to enhanced expectancies for future performance (e.g., Pascua, Wulf, & Lewthwaite, 2015; Wulf, Chiviacowsky, & Cardozo, 2014).

Numerous experiments have shown that providing information to performers that enhanced their expectancies for future performance, supporting their need for autonomy, or prompting them to focus attention externally on intended movement effects enhanced performance or learning of a variety of motor tasks (for reviews, see Lewthwaite & Wulf, 2017; Wulf & Lewthwaite, 2016). Furthermore, practice conditions that included combinations of two factors – EE and AS (Wulf et al., 2014), EE and EF (Marchant et al., 2018; Pascua et al., 2015), or AS and EF (Abdollahipour, Palomo Nieto, Psotta, & Wulf, 2017; Wulf, Chiviacowsky, & Drews, 2015) – have been found to result in additional benefits relative to the presence of only one of these factors, or none, for the learning of a throwing task. That is, EE, AS, and EF seemed to have additive learning benefits. Recently, Wulf and colleagues (2017) demonstrated that combining all three factors in acquisition enhanced learning to an even greater extent than combinations of two factors. Thus, there is preliminary evidence that the learning of tasks requiring movement accuracy can be optimized by combining the three key factors in the OPTIMAL theory (Wulf & Lewthwaite, 2016). The syncing of research and methodologies to allow study of complex movement behavior with underlying neuroscience mechanisms, though advancing, is still in its infancy. However, the need is ongoing and often critical to inform instructional, coaching, and therapeutic practice in effective means to acquire skill and support high levels of performance. One relevant question concerns ways in which to invoke the factors in the OPTIMAL theory to optimally influence performance and learning. To date, no study has investigated the effects of implementing all three motivational and attentional factors in close succession in a single experimental session. It is unclear, therefore, whether the consecutive rather than combinatorial application of the three key variables of the OPTIMAL theory would have beneficial effects on the *performance* of motor skills.

Thus, the purpose of the present study was to follow up on previous findings by examining whether EE, AS, and EF would also have immediate benefits for motor performance. Importantly, we asked whether implementing all three factors consecutively, rather than simultaneously, would lead to further increases in performance. The sequential application of these three factors in successive blocks of trials provided the opportunity to glimpse behaviorally the potential sustainability of the temporal pairing of dopamine with skill execution in motor performance (Lewthwaite & Wulf, 2017). The task we chose was a countermovement jump as it requires effective whole-body coordination for maximal jump height, involving a multijoint explosive movement. Jump height is maximized by the optimal coordination of joint activation timings of the shoulders, hips, knees, and ankles (Nuzzo, McBride, Cormie, & McCaulley, 2008). We hypothesized that providing participants with either positive feedback (EE), a choice (AS), or an external focus cue (EF) would result in greater jump height relative to a “neutral” control condition. A second hypothesis was that, in the optimized condition, participants would show incremental increases in jump height across consecutive blocks of trials when introduced to additional variables (EE, AS, and EF).

1. Method

1.1. Participants

Based on a factorial design with one between-participants factor (group) and one within-participants factor (condition or block), an estimated effect size of $\eta_p^2 = .07$ (Wulf et al., 2017), an α-level set at .05, and a power value of 90%, a sample size of 30 participants was estimated via a power analysis using G*Power 3.1 (Faul, Erdfelder, Lang, & Buchner, 2007). In total, thirty-six university students (18 females, 18 males) with a mean age of 24.9 years ($SD = 6.41$) were recruited for participation in the study. All of them were naïve as to the specific purpose of the experiment. All gave written informed consent before participating in the study, which was approved by the university’s institutional review board.

1.2. Apparatus and Task

Vertical jump height (displacement) was measured with a VERT® Classic instrument (6.0 × 3.0 × 0.5 cm; Mayfonk Inc., Florida, USA). This wearable inertial measurement unit consists of a 3-axis accelerometer and a 3-axis gyroscope. Jump height data collected via the VERT device have been shown to be valid ($r = .83$ to .97) in measuring vertical jump height in relation to three-dimensional trajectory data captured by a 20-camera Vicon motion analysis system (Charlton, Kenneally-Dabrowski, Sheppard, & Spratford, 2017). The instrument was placed in the pouch of an elastic band that was worn around the waist at the navel level of each participant. The elastic band was adjustable for customization of a secure fit to ensure minimal movement of the instrument relative to the body motion of each participant. The data were sent in real-time via Bluetooth technology to an iOS tablet (Apple Inc., California, USA). Three figures of different colors and shapes (red triangle, green square, and blue pentagon), but of the same surface area of 35 cm^2, were marked out on the ground using duct tape. Participants were asked to perform maximal-height countermovement jumps within these jump figures (see Fig. 1). Finally, a spherical (reflective) marker was attached to the VERT® instrument during the block of trials for the EF condition. The marker served as an external focus cue in the respective condition.

1.3. Procedure

Participants watched a standard demonstration video that showed them how to perform a countermovement jump, which involved the lowering of the body while swinging both arms back, from a standing upright position, before immediately jumping up as

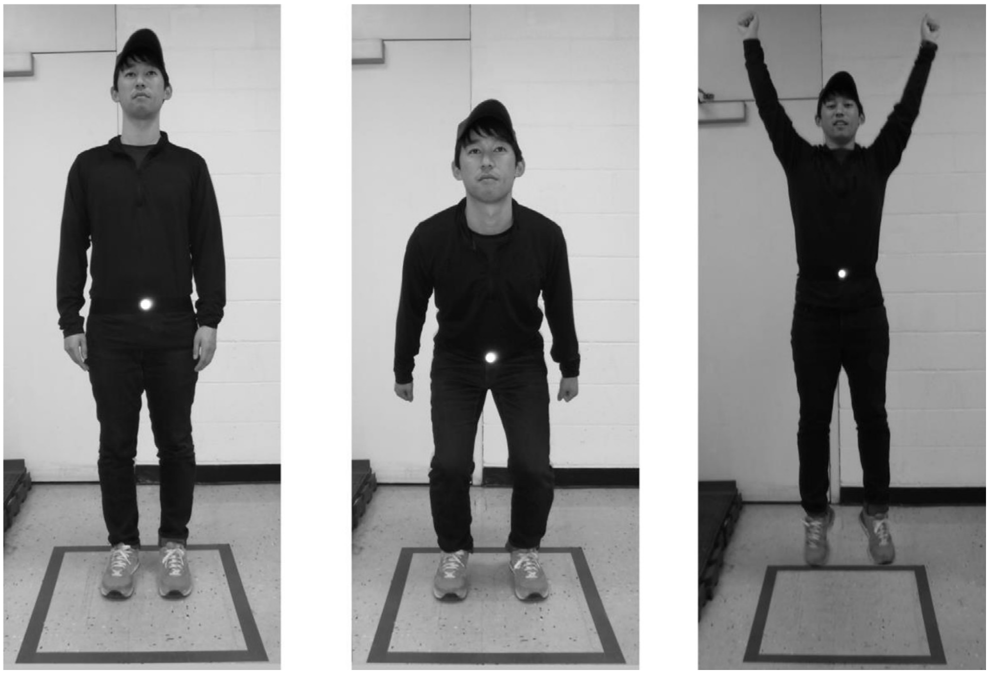

Fig. 1. Front view of countermovement jump performance. Spherical marker at waist is consistent with the optimized group's external focus condition.

high as possible while swinging both arms upward and thereafter landing back on the support surface with both feet (Morris, 2016). Participants were then asked to perform warm-up stretching exercises at their own discretion, as well as three submaximal-height countermovement practice jumps at moderate effort. Participants were pseudo-randomly assigned, based on gender, to one of two groups: the optimized group and the control group.

Each participant performed a total of four blocks of five trials with the general instruction to jump as high as possible. The first block was considered a baseline block, and all participants performed the jump within the green square. On the following three five-trial blocks, participants in the optimized group were given different instructions that were specific to one condition assigned for each block. Specifically, in the EE condition, they were told, prior to the start of the block, that the average of the jump heights they achieved in the previous block of five trials was "better than average" in comparison to other participants. In the AS condition, participants were informed that they could choose the jump figure (red triangle, green square, or blue pentagon) for each trial and were asked by the experimenter to make a choice before each trial in the block. In the EF condition, they were asked before each trial to focus on bringing the spherical marker to as high a vertical position as possible. Participants were instructed not to look at the marker but simply to concentrate on it. Thus, with the exception of the AS condition, in which participants could choose the jump figure, all jumps were performed from the green square. The order of the EE, AS, and EF conditions was counterbalanced across participants (i.e., all six possible orders were used) to control for possible order effects. Control group participants performed all four blocks under the same (control) condition. Before each trial, they were asked to jump as high as possible. With respect to the jump figures in one of the blocks (AS), each control group participant was yoked to a participant in the optimized group. That is, the control group participants (unbeknownst to them) were asked to jump from the same figure that their respective counterparts in the optimized group had chosen for each trial. Participants were given a two-minute rest between trial blocks. Instructions, 20 jumps, and rest periods were completed within 10 minutes, on average.

1.4. Data Analysis

Jump height was averaged across all five trials in each block. To account for possible baseline differences (Block 1) between groups, we determined changes in jump height for each block relative to Block 1. Subsequently, we performed two different analyses. First, to determine the effects of each condition (EE, AS, EF) relative to the control condition/group, we compared the two groups' relative jump height (i.e., jump height differences relative to Block 1) in a 2 (groups) × 3 (conditions) mixed-factor analysis of variance (ANOVA) with repeated measures on the second factor. Because participants in the optimized group performed the three conditions in (six) different orders, the blocks of their respective counterparts in the control group were organized accordingly for this analysis. Second, we wanted to determine whether the addition of other variables (e.g., AS then EF then EE) would result in additional increases in jump height. Therefore, we compared the two groups' relative jump height in a 2 (groups) × 3 (blocks) ANOVA that included a chronological order of blocks. For all post-hoc tests, pairwise comparisons with Bonferroni adjustments of alpha level for multiple comparisons were used. Mauchly's test revealed that the assumption of sphericity was not violated ($p > .05$); thus no adjustment to the degrees of freedom was made. Effect sizes were expressed as partial eta squared values. Statistical analyses were performed with $p < .05$ as the criterion for identifying statistically significant results.

2. Results

As can be seen in Fig. 2 (left), average jump performance at baseline (i.e., absolute jump height in Block 1) was similar for the control ($M = 43.1$ cm, $SD = 2.61$) and optimized ($M = 42.5$ cm, $SD = 2.61$) groups. Fig. 2 (right) also shows jump height relative to baseline (Block 1) for the optimized and control group as a function of AS, EE, and EF. As can be seen, all three conditions enhanced

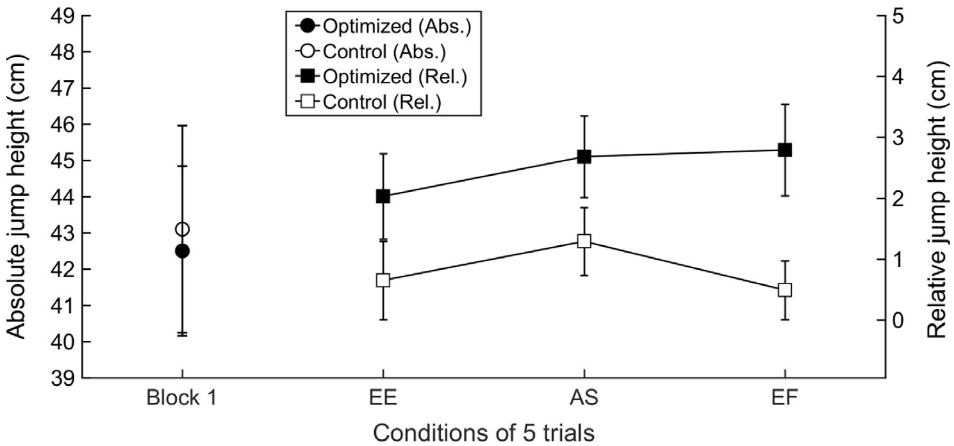

Fig. 2. Jump performance by condition showing the absolute jump heights (y-axis on left side for Block 1) and relative jump heights (y-axis on right side for EE, AS, and EF conditions) of the optimized and control groups. Error bars represent standard errors.

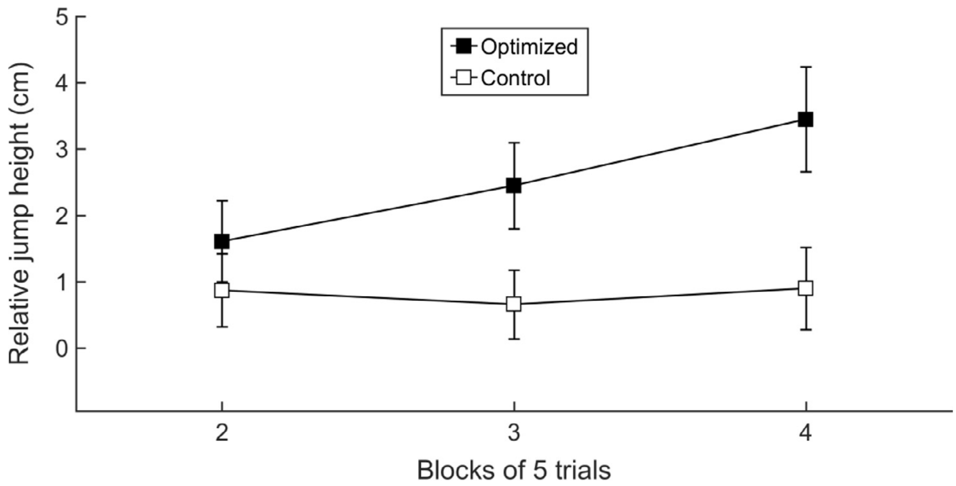

Fig. 3. Jump performance by block showing the relative jump heights of the optimized and control groups. Error bars represent standard errors.

performance. The main effect of group was significant, F (1, 34) = 4.61, p = .039, η_p^2 = .12. There was no significant main effect of condition, F (2, 68) = 1.41, p = .250, η_p^2 = .04, or interaction of group and condition, $F < 1$.

Fig. 3 shows relative jump height across Blocks 2-4. Across consecutive trial blocks, participants in the optimized group consistently increased their absolute jump heights, whereas no increase was seen for the control group. The Group main effect was again significant, F (1, 34) = 4.61, p = .039, η_p^2 = .12. Also, the interaction of group and block was significant, F (2, 68) = 3.16, p = .049, η_p^2 = .09. Post-hoc tests showed that, while the optimized and control groups did not differ significantly on Block 2, p = .381, η_p^2 = .02, the optimized group outperformed the control group on Block 3, p = .039, η_p^2 = .12, and Block 4, p = .016, η_p^2 = .16. The main effect of block, F (2, 68) = 3.44, p = .038, η_p^2 = .09, was also significant.

3. Discussion

We investigated whether motor performance could be enhanced (incrementally) by motivational (EE, AS) and attentional (EF) variables that are key to motor performance and learning according to the OPTIMAL theory (Wulf & Lewthwaite, 2016). The maximal vertical jump task used in the present study requires whole-body coordination and was therefore deemed sufficiently challenging and sensitive to the influence of those variables. Vertical jump tests are often considered reliable measures of lower limb strength (Aragón-Vargas, 2000; Bosco, Luhtanen, & Komi, 1983). Yet, as previous studies have demonstrated, maximum or sustained force production can be increased by EE (e.g., Hutchinson et al., 2008; Tod, Hardy, & Oliver, 2011), AS (e.g., Iwatsuki, Abdollahipour, Psotta, Lewthwaite, & Wulf, 2017), or EF (e.g., Wulf & Dufek, 2009) relative to control conditions. In the present study, we combined all three of these factors and provided them in successive order. Results supported additive or incremental benefits for performance. Relative to baseline performance (Block 1), the optimized group showed generally greater jump height than did the control group on Blocks 2-4. Importantly, the optimized group's jump height increased across blocks with each addition of a variable (EE, AS, or EF), whereas jump height did not change across blocks in the control group. Thus, "maximum" performance was enhanced by each variable in an incremental fashion.

The present results are consistent with previous studies in various regards. First, studies comparing motor performance on standard tests (or control conditions) to that under EE, AS, or EF conditions have demonstrated that performance can be increased immediately by the addition of one of these variables. For example, Montes, Wulf, and Navalta (2018) found that, on tests measuring aerobic capacity, maximum oxygen consumption (VO_2max) was enhanced in trained runners when they were led to believe that their VO_2max on a previous test was above the average of their peers. That is, enhancing their performance expectancies (EE) in this way increased maximum VO_2 consumption, indicating a higher physical working capacity, relative to their own previous values and relative to control group participants. In another study (Halperin, Chapman, Martin, Lewthwaite, & Wulf, 2017), maximum force production was measured. High-level professional and amateur boxers performed a standard punching test with a prescribed order of punches. When the same boxers were allowed to choose the order of punches (AS) on another test, both impact forces and punching velocities were significantly higher than they were on the standard test. Finally, using a vertical jump-and-reach test, Wulf, Zachry, Granados, and Dufek (2007) found greater maximum jump heights with an instructed EF compared with a standard (control) condition. Thus, each factor (EE, AS, EF) individually has been shown to increase what was considered maximum performance. The current results are consistent with these findings by showing that each factor (EE, AS, EF) was able to enhance maximum performance. The fact that simple conditions promoting EE, AS, or an EF can enhance performance suggests that performance under "neutral" conditions does not necessarily represent the individual's optimal or maximal performance. Rather, the findings are consistent with an integrative perspective on motor performance that reflects its social-cognitive–affective–motor nature (Lewthwaite & Wulf, 2010a). What is seen, even with maximal effort instructions, is not necessarily all that can be produced—if the conditions have not been optimized.

Furthermore, our results are in line with, and extend, previous findings showing that combinations of EE, AS, or EF can result in greater benefits than any of these factors alone (Abdollahipour et al., 2017; Marchant et al., 2018; Pascua et al., 2015; Wulf et al., 2014, 2015, 2017). There are several differences between previous studies and the present one, however. In most of the previous studies, different groups were provided with one or more, or none, of the three factors during a practice phase, and skill learning was assessed by delayed retention and transfer tests. In contrast, in the present study, we examined immediate effects on motor performance (see also Abdollahipour et al., 2017). Moreover, we successively added EE, AS, or EF in the same group of participants and found that they led to incremental gains in performance. Even though conditions from prior blocks (i.e., feedback about better-than-average performance, choice regarding jump figure, external focus instruction) were not repeated, it seems likely that participants either remembered them and deployed them again and/or that there was a sufficiently lasting effect from their direct instantiations. For example, if participants were informed at the end of a given block that their performance was above average, it may have enhanced their expectancies on subsequent blocks as well. This would be not unlike other studies in which a single EE instruction (Wulf et al., 2012), AS provided once before the practice phase (Lewthwaite et al., 2015, Experiment 2), or EF instructions given at the beginning of a trial block (Pascua et al., 2015) had long-term effects on learning. Together the existing findings support the notion that the three variables – whether they are applied simultaneously or successively – make at least partially independent contributions to enhanced performance or learning. Just as Wulf et al. (2017) demonstrated that conditions with EE, AS, and EF can have additive contributions to the optimization of motor performance and learning, possibly through the effects of separate dopaminergic responses to a motivational (EE or AS) factor or of more efficient goal-action coupling (e.g., Kuhn, Keller, Lauber, & Taube, 2018; Kuhn et al., 2017; Meadows et al., 2016; Themanson & Rosen, 2015) when any two of the three variables or all three variables were applied in combination during the skill acquisition phase, our findings provided the empirical evidence that it is possible to incrementally improve motor performance by applying the three variables in turn, regardless of the order, shortly one after another. The absence of a threshold effect after the application of any of these three variables implies that they acted through non-interfering mechanisms to optimize the performance of a motor task. The availability of extracellular dopamine following burst stimulation of dopaminergic neurons in the ventral tegmental area has been found in rats in the prefrontal cortex and nucleus accumbens for more than 20 minutes (Lohani et al., 2017). The spatial (neurogeographic) and temporal nature of dopamine dynamics, especially related to optimization of behavioral conditions, deserves further study. Our study found that the performance enhancement effects of a temporally separated application of the three key factors of the OPTIMAL theory lasted for approximately 10 minutes. It may be interesting for future studies to examine whether these effects could be sustained for a longer time duration using the same or another task. Along the same line, future studies could investigate the consecutive application of the three key factors of the OPTIMAL theory on motor learning outcomes. The efficient application of insights gained from the findings of such research may enhance the success of diverse performance and learning efforts.

Vertical jumping is considered a fundamental skill that is presumed to exist in the repertoire of most physically active, healthy adults. Adult-like characteristics of the vertical jump can be observed in children who are as young as two years of age (Poe, 1976) and jump performance indexes lower-body strength (Bosco et al., 1983). Yet, the findings of our study and others (e.g., Tod, Thatcher, McGuigan, & Thatcher, 2009) verify that psychological and attentional factors can additionally influence a person's supposedly stable jump height. Performance of a whole-body, maximum-effort motor (coordination) skill such as the countermovement jump can be enhanced in terms of outcome effectiveness by a simple change in the individual's motivational state or attentional focus. Specifically, interventional strategies that enhanced expectancies, provided autonomy support, and induced an external focus of attention produced additional performance advantages above and beyond control conditions in which performers did not perform optimally when left to their own devices. This provides further evidence that practitioners should provide instructions and ensure a training environment that affirmatively enhances expectations for future success, supports the need for autonomy, and induces an external focus of attention on intended movement effects. Doing this may promote an increase in self-efficacy and/or encourage automatic processing to develop in untrained individuals, which directly facilitates the improvement of their motor performance.

A good coach or instructor ought to understand these practical implications and carefully structure interventions to facilitate motor performance based on a principled understanding of the motivational and attentional needs of the performer. To this end, the OPTIMAL theory of motor learning is a timely addition to the armamentarium of instructors, coaches, and clinicians and may change the way conditions around motor performance are organized.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.humov.2018.05.006.

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