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Movement Efficiency Through Autonomy Support

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MOVEMENT EFFICIENCY THROUGH AUTONOMY SUPPORT

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Abstract

Supporting performer autonomy has been consistently been shown to enhance motor learning (for reviews, see Sanli, Patterson, Bray, & Lee, 2013; Wulf, 2007; Wulf & Lewthwaite, 2016). Autonomy-supportive situations are those in which learners are given control over aspects of the practice conditions or are provided with other choices, including small and incidental choices that are not necessarily related to the task at hand. Providing autonomy support also benefits immediate motor performance, as demonstrated by enhanced punching velocity and impact forces in a study involving skilled kick boxers (Halperin, Chapman, Martin, Lewthwaite, & Wulf, 2016). Autonomy support is a key factor in the OPTIMAL theory of motor learning. Having a sense of autonomy is assumed to contribute to enhanced expectancies as a precondition for goal-action coupling (Wulf & Lewthwaite, 2016). The successful coupling of movement goals and necessary action is predicted to result in effective and efficient movement production. However, experimental evidence demonstrating effects of autonomy support on motor performance or movement efficiency is still lacking.

The purpose of this dissertation was to examine effects of autonomy support on motor performance, in particular movement efficiency. Three experiments were conducted to address this issue. Experiment 1 attempted to replicate the findings of Halperin et al. (2016) and examine their generalizability to non-athletes. Experiment 2 examined whether autonomy support would increase movement efficiency by including direct measures of movement efficiency (i.e., oxygen consumption, heart rate) during a submaximal run. Experiment 3 examined whether autonomy support would increase movement efficiency as measured by the use of surface electromyography (sEMG) while performing force production tasks at 3 different intensities.

The purpose of Experiment 1 was first study to determine whether providing autonomy support would enhance performers' ability to maintain maximum force levels. Participants were asked to repeatedly produce maximum forces using a hand dynamometer under either choice or control conditions. After 2 initial trials with the dominant and non-dominant hand, choice group participants were able to choose the order of hands (dominant, non-dominant) for the remaining trials (3 per hand). For control group participants, hand order was determined by their yoked choice-group counterparts. The choice group was able to maintain the maximum forces produced on the first trial, while control group participants significantly showed a continuous decrease in force levels across trials. We interpret this finding as evidence that performers produced forces more efficiency under autonomy-supportive conditions.

A more direct measure of movement efficiency was used in the second study. Participants were asked to run at a submaximal intensity (65% of VO_2 max) for 20 minutes. In the choice group, they were able to choose 5 of 10 photos (5 city, 5 nature motifs) as well as the order in which they were shown on a computer screen during the run. Participants in a control group were shown the same photos, in the same order, chosen by their counterparts in the choice group. Throughout the run, oxygen consumption and heart rate were significantly lower in the choice group than in the control group, indicating an increase in running efficiency. Thus, providing autonomy support may result in enhanced movement efficiency.

The third study examined muscle activity as a function of autonomy support by using sEMG. Participants were asked to perform a plantar flexion task at each of the 3 target torques, 80%, 50%, and 20% of maximum voluntary contractions (MVC). In the choice condition, participants were able to choose the order of 3 target torques. In the choice condition, participants were informed about order of torques (which was determined by the order chosen by another participant). EMG activity of gastrocnemius muscle was significantly lower in the choice condition relative to the control condition, while the similar torques were produced under both conditions. Thus, the choice condition allowed participants to perform at the same target force with less neuromuscular activity, indicating an increase in movement efficiency.

Overall, the dissertation findings add to increasing evidence that providing performers choices as a form of autonomy support has an immediate impact on motor performance. Experiment 2 and 3, in particular, provide direct evidence of enhanced movement efficiency (reduced oxygen consumption, heart rate, EMG activity) resulting from autonomy support. Overall, the current findings are in line with notion that autonomy support facilitates the coupling of movement goals and actions (Wulf & Lewthwaite, 2016). Practitioners can take advantage of these effects to not only to facilitate motor learning, but also to enhance motor performance or movement efficiency.

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Chapter 1

Introduction

The learning of motor skills is fundamental to every person's life. Factors that facilitate motor learning have therefore been studied extensively. One factor that has been found to be important in this regard is having a sense of autonomy. Providing learners with control over certain aspects of their practice conditions (e.g., feedback, skill demonstrations) has been demonstrated to enhance motor skill learning in numerous studies (for reviews, see Sanli, Patterson, Bray, & Lee, 2013; Wulf, 2007; Wulf & Lewthwaite, 2016). Interestingly, recent studies have demonstrated that even small choices – and those that are not necessarily task-relevant – can facilitate motor learning (Lewthwaite, Chiviacowsky, Drews, & Wulf, 2015; Wulf, Iwatsuki, Machin, Kellogg, Copeland, & Lewthwaite, 2017).

Autonomy is a fundamental psychological need (Deci & Ryan, 2000, 2008) and a biological necessity (Leotti & Delgado, 2014; Leotti, Iyengar, & Ochsner, 2010). Providing autonomy-supportive conditions has the effect of enhancing important psychological factors that lead to effective motor learning, including self-efficacy (Chiviacowsky, 2014; Hooyman, Wulf, & Lewthwaite, 2014; Ste-Marie, Vertes, Law, & Rymal, 2013), positive affect (Lemos, Wulf, Lewthwaite, & Chiviacowsky, 2017; Wulf et al., 2017), and perceived competence (Chiviacowsky, 2014; Chiviacowsky, Wulf, & Lewthwaite, 2012). The neuroscientific literature also supports the importance of personal choices to enhance motivation and performance (Murayama, Izuma, Aoki, & Matsumoto, 2016). Therefore, studying the effects of autonomy support is important from both theoretical and practical perspectives.

Autonomy support is also a critical factor in the OPTIMAL theory of motor learning (Wulf & Lewthwaite, 2016). While many studies have shown effective learning resulting from giving choices, an important question is: Does providing choice have an immediate impact on *motor performance* and *movement efficiency*? According to the theory, autonomy facilitates the coupling of goals and actions, thereby enhancing motor performance (Wulf & Lewthwaite, 2016). One study has demonstrated this point (Halperin, Chapman, Martin, Lewthwaite, & Wulf, 2016) by showing greater punching velocities and increased impact forces among skilled kick boxers under an autonomy-supportive condition. However, this is the only study examining the effect of autonomy support on motor performance at this point. More experiments are necessary to fill the gaps in understanding the effects of autonomy support on motor performance, and more specfically its effects on movement efficiency. Three experiments reported in this addressed these issues.

The first experiment examined the generalizability of autonomy support on sustained maximum force production, an indirect measure of movement efficiency. The co-authors included Reza Abdollahipour, Rudolf Psotta, Rebecca Lewthwaite, and Gabriele Wulf. The second study examined whether autonomy support would increase movement efficiency, as evaluated by more direct measures of movement efficiency (e.g., oxygen consumptions, heart rate). The co-authors associated are James W. Navalta and Gabriele Wulf. Lastly, electromyography was used to record muscular activity as a function of having a choice or not during force production. The co-authors are Hui-Ting Shin and Gabriele Wulf.

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Chapter 2

Autonomy Facilities Repeated Maximal Force Production

Significance of the Chapter

The learning of motor skills has been shown to be enhanced by autonomy-supportive conditions. In the literature, self-controlled practice – allowing participants to choose certain aspects of the practice conditions – has been found to improve motor skill learning (Sanli, Patterson, Bray, & Lee, 2013; Wulf & Lewthwaite, 2016). Even choices that are relatively small or unrelated to the learning task itself have been shown to be effective (Wulf, Iwatsuki, Machin, Kellogg, Copeland, & Lewthwaite, 2016; Lewthwaite, Chiviacosky, Drews, & Wulf, 2015). Providing autonomy support also has immediate benefits for motor performance, as demonstrated by enhanced punching velocity and impact forces involving skilled kick boxers (Halperin, Chapman, Martin, Lewthwaite, & Wulf, 2016). Being autonomous is assumed to contribute to enhanced expectancies and goal-action coupling, leading to effective and efficient performance and learning (Wulf & Lewthwaite, 2016). However, there is a lack of experimental evidence showing increased movement efficiency as a result of autonomy support. The present experiment examined the effect of autonomy support relative to a control condition on a maximal force production task. The task required repeated maximal force productions using a handgrip dynamometer. The ability to sustain force levels was used of a measure of movement efficiency.

Abstract

Performer autonomy (or self-control) has consistently been shown to enhance motor learning, and it can also provide immediate benefits for motor performance. Autonomy is also a key variable in the OPTIMAL theory of motor learning (Wulf & Lewthwaite, 2016). It is assumed to contribute to enhanced expectancies and goal-action coupling, affecting performance effectiveness and efficiency. The purpose of the present study was to examine whether providing autonomy support by giving performers choices would enhance their ability to maintain maximum force levels. Participants were asked to repeatedly produce maximum forces using a handgrip dynamometer. After 2 initial trials with the dominant and non-dominant hand, stratified randomization was used to assign participants with the same average maximum force to one of two groups, choice or yoked control groups. Choice group participants were able to choose the order of hands (dominant, non-dominant) on the remaining trials (3 per hand). For control group participants, hand order was determined by choice-group counterparts. Maximum forces decreased significantly across trials in the control group, whereas choice group participants were able to maintain the maximum forces produced on the first trial. We interpret these findings as evidence that performer autonomy promotes movement efficiency. The results are in line with the view that autonomy facilitates the coupling of goals and actions (Wulf & Lewthwaite, 2016).

Key words: Choice, self-control, handgrip dynamometer

Introduction

Autonomy, or being able to make one's own decisions, is considered to be a fundamental psychological need (Deci & Ryan, 2000, 2008) or even biological need (Leotti, Iyengar, & Ochsner, 2010). Like humans, other animals prefer to have choices. Removing opportunities for choice may cause negative responses such as increased stress-related behavior (Owen, Swaisgood, Czekala, & Lindburg, 2005) and cortisol release (Glavin, Paré, Sandbak, Bakke, & Murison, 1994). In contrast, having choices is inherently rewarding (Leotti & Delgado, 2011). Supporting individuals' need for autonomy is critical for performance and well-being in many situations. Autonomy-supportive climates have been associated with persistence in activity engagement and adherence over longer courses of participation (Hagger, Sultan, Hardcastle, & Chatzisarantis, 2015; Yu, Rouse, Veldhuijzen, Van Zanten, Metsios, Ntoumanis, Kitas, & Duda, 2015). It has also been shown to be important for motor performance and learning.

In the motor learning literature, numerous studies have shown that allowing learners to make their own decision about aspects of the practice conditions, so-called self-controlled practice, benefits learning relative to yoked control conditions. For instance, learning advantages have been found when learners were allowed to have control over practice variables, including the amount of practice (Lessa & Chiviacowsky, 2015; Post, Fairbrother, & Barros, 2011), timing of performance feedback (Ali, Fawver, Kim, Fairbrother, & Janelle, 2012; Janelle, Barba, Frehlich, Tennant, & Cauraugh, 1997; Lim, Ali, Kim, Kim, Choi, & Radlo, 2015), or use of assistive devices (Chiviacowsky, Wulf, Lewthwaite, & Campos, 2012; Hartman, 2007; Wulf & Toole, 1999).

Furthermore, several studies have shown that even incidental choices, or those not directly related to the task, can enhance learning (e.g., Wulf, Iwatsuki, Machin, Kellogg, Copeland, & Lewthwaite, 2017). For example, choice of golf ball color led to enhanced learning of a golf putting task (Lewthwaite, Chiviacowsky, Drews, & Wulf, 2015, Experiment 1). Also, being able to choose the order of balance exercises resulted in more effective balance learning than did an assigned order of the same exercises (Wulf & Adams, 2014). Even choices that are completely unrelated to the task (e.g., choosing a picture to be hung on a wall) have been found to facilitate motor learning (Lewthwaite et al., 2015, Experiment 2). Moreover, in one recent study, involving the learning of a novel motor skill (throwing a lasso), task-relevant (video demonstration) and task-irrelevant (color of mat placed under the target) choices resulted in the same learning benefits relative to a control condition without choice (Wulf et al., 2017). The fact that learning is facilitated when performers are given choices, regardless of the type of choice, suggests that the underlying mechanisms of this effect are motivational in nature (Lewthwaite & Wulf, 2012; Wulf & Lewthwaite, 2016).

Autonomy is a key variable in the OPTIMAL theory of motor learning (Wulf & Lewthwaite, 2016). It is assumed to contribute to enhanced expectancies and goal-action coupling, thereby affecting effective and efficient performance. Anticipation to act autonomously has been shown to be related to activation in brain regions associated with a sense of agency (Lee & Reeve, 2013), a state associated with dopamine release (Aarts, Bijleveld, Custers, Dogge, Deelder, Schutter, & Haren, 2012). Thus, a sense of autonomy would be expected to result not only in longer-term learning benefits but also in immediate enhanced performance. Indeed, in a recent study, letting kick boxers choose the order of different punches led to greater punching velocity and higher impact forces than did an assigned order of punches (Halperin, Chapman, Martin, Lewthwaite, & Wulf, 2016). That is, a relatively incidental choice shortly before task execution produced greater maximal forces compared with those seen in a standard test protocol (with no choice).

Given the potential theoretical and practical implications of those findings, we wanted to replicate them and examine their generalizability. In the present study, participants (non-athletes) were asked to repeatedly produce maximal forces using a handgrip dynamometer. In one group (choice), participants were able to choose the order of hands (dominant, non-dominant), whereas in another group (control) hand order was determined by the participant's counterpart in the choice group. In contrast to Halperin et al., we used a between-participant design. Thus, participants in one group (choice or control) were not aware of the experimental condition of the other group. We used the perceived choice scale of the Intrinsic Motivation Inventory (IMI; Ryan, 1982) as a manipulation check. We hypothesized that participants in the choice group would have higher ratings of perceived choice and be able to maintain force levels across trials to a greater extent than would control group participants.

Method

Participants

Participants were 30 college students (18 males, 12 females) with an average age of 25.7 years (*SD* = 5.78). Informed consent was obtained from all the participants before the beginning of the experiment. Participants were not aware of the specific purpose of the study, but were informed that maximum forces would be assessed. The university's institutional review board approved the study.

Apparatus and Task

A handgrip dynamometer (MG-4800, Marsden, England) was used to measure the maximum forces produced with the dominant and non-dominant hand. The participant was seated in a chair without armrest. The hand grasping the dynamometer was held in a "hand-shake" position with the elbow flexed at 90 degrees. The display of the dynamometer was turned away from the participant so that they did not receive feedback about the forces produced.

Procedure

Each participant was first asked to perform a maximum effort trial with the dominant hand, followed by the non-dominant hand. Based on the average force produced on the first 2 trials, a stratified randomization procedure was used to assign participants to one of two groups with similar initial force, the choice or yoked control groups. Participants in the choice group were then asked in which order they wanted to complete the remaining 6 trials. Specifically, they were asked before each trial which hand they wanted to use, with the understanding that they were to perform 3 trials with each hand. Control group participants also understood that they had to perform 3 trials with each hand, but they were informed before each trial which hand to use (determined by their choice-group counterpart). There were 20-s rest periods between trials.

Subsequently, participants filled out the perceived choice sub-scale of the IMI (Ryan, 1982). It consisted of 8 statements (e.g., I believe I had some choice regarding this activity) that were rated on a 7-point Likert scale with response options ranging from 1 (*not at all true*) to 7 (*very true*). Participants were then debriefed, provided with performance feedback, and thanked for their time.

Data Analysis

Maximum forces were analyzed in a 2 (group: choice vs. control) x 2 (hand: dominant vs. non-dominant) x 4 (trials) analysis of variance with the repeated measures on the last two factors. Mauchly's test was utilized to assess the sphericity assumption, and it showed that the assumption was violated. Therefore, Greenhouse-Geisser epsilon values were used to adjust the degrees of freedom. Bonferroni corrections were performed for all adjustments and pairwise post-hoc tests. Estimates of effect size were quantified by two measures. First, partial eta squared (ηp^2) was employed, where ηp^2 = .01, .06 and .14 were estimates for a small, moderate and large effect, respectively (Larson-Hall, 2009). Cohen's *d* was utilized as a measure of the difference between group means using the repeated-measures version of Cohen's *d* that factors in the correlation between time points (Morris & DeShon, 2002). To examine the difference between the choice and control groups with regard to perceived choice, a t-test was used. Cohen's *d* for t-test was calculated for independent groups. The evaluation of Cohen's *d* corresponded to a low (d = 0.2), medium (d = 0.5), and large (d = 0.8) effect (Cohen, 1988). The level of significance was set at .05.

Results

Hand Usage

Participants tended to switch hands after the first 2 trials with the dominant (first) and non-dominant hands. The percentage of dominant-hand use was 93.3% on Trial 3, 26.7% on Trial 4, 73.4% on Trial 5, 13.3% on Trial 6, 66.7% on Trial 7, and 26.7% on Trial 8.

Maximum Force Production

Maximum forces, averaged across hands, produced by the choice and control groups can be seen in Figure 1. While maximal force levels were similar for both groups on Trial 1, the control group showed a consistent decrease across trials, whereas the choice group was able to maintain the initial force level. The interaction of group and trial was significant, F (2.13, 59.74) = 3.28, p = .041, η_ρ^2 = .105. Post-hoc tests confirmed that force production in the control group was significantly lower on the last trial (M = 37.93 ± 8.97 kg) relative to the first trial (M = 40.66 ± 10.08 kg), p = .005, d = .856, whereas there was no significant change for the choice group from the first (M = 40.58 ± 10.40 kg) to the last trial (M = 40.51 ± 10.06 kg), p > .05, d = .011. The main effect of hand was significant, F (1, 28) = 30.77, p < .001, η_ρ^2 = .524, as forces produced with the dominant (M = 41.06 ± 9.64 kg) were greater relative to the non-dominant hand (M = 38.59 ± 9.56 kg), p = .000, d = .025. The main effect of trial was significant, F (2.13, 59.74) = 3.44, p < .05, η_ρ^2 = .109. The main effect of group, F (1, 28) = .17, p = .678, η_ρ^2 = .006, was not significant. There were no other significant interaction effects.

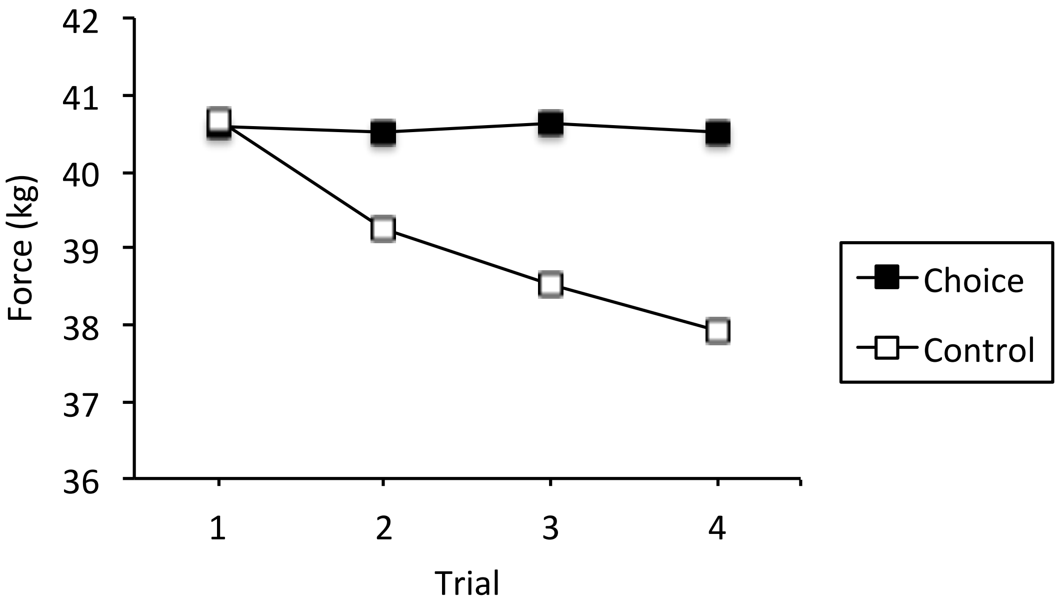

Figure 1. Maximum forces produced by the choice and control groups across trials (average of right and left hands).

Perceived Choice

The choice group ($M = 43.67 \pm 4.85$) had significantly higher ratings of perceived choice than the yoked group ($M = 38.60 \pm 6.41$), $p = .021$, $d = .892$.

Discussion

The present results support our hypothesis that providing performers the opportunity for a small choice (order of hands) would help them sustain forces across repeated maximum effort attempts. Relative to a control group without that choice, but with a yoked order of hand usage, the choice group's force levels remained unchanged whereas the control group showed a consistent drop in force across trials. The manipulation check confirmed that the degree of perceived choice differed between groups. Thus, it appears that the increased sense of autonomy facilitated sustained force production, consistent with other recent findings from within-participant comparisons (Halperin et al., 2016). The present results complement the findings of Halperin et al. (2016) showing that maximum force production (e.g., impact forces) in kick boxers was increased by giving them an incidental choice (i.e., order of punches). Relative to a prescribed order of punches, the same boxers produced greater forces when they could choose the order. In the present study, a different group of (yoked) participants showed effects of choice in sustained force relative to their no-choice counterparts.

Maximum force production typically decreases somewhat over repeated trials as a result of peripheral and central fatigue (Kennedy, Hug, Sveistrup, & Guével, 2013; Smith, Martin, Gandevia, & Taylor, 2007). In the current study, effects of fatigue were seen in the control group, even though there were only 4 maximum effort trials per hand, and in most cases the rest period between trials with a given hand was at least 40 seconds (because participants switched hands on successive trials). It is also possible that participants in this more controlled condition felt less compelled to keep effort high. In contrast to the control group, no change in force production was seen in the choice group.

What may explain the benefit of having an opportunity for choice on force production? Anticipation of choice is related to greater activity in brain regions involved in reward, affective, and motivational processes, and is associated with dopamine release (Aarts et al., 2012; Lee & Reeve, 2013; Leotti & Delgado, 2011). Consistent with these activations, kinematic and kinetic advantages in rapid force production movements have been found in Parkinson disease when dopamine agonists are administered (Foreman, Singer, Addison, Marcus, LaStayo, & Dibble, 2014). Indirect effects of having a sense of autonomy include the opportunity to enhance expectations for performance, which in turn prepare the individual for successful movement (Wulf & Lewthwaite, 2016). Reward expectations, for instance, have been demonstrated to suppress electroencephalographic (EEG) activity in the beta-frequency range, which inhibits spinal motor activity (Meadows, Gable, Lohse, & Miller, 2016). Suppression of beta activity, which is enhanced by dopamine (Jenkinson & Brown, 2011), readies the motor system for action as indicated, for example, by reduced pre-motor reaction times (Meadows et al., 2016).

Future studies might seek more direct evidence for optimized mechanisms for motor activity, such as motor unit recruitment and greater neuromuscular efficiency resulting from being autonomous – similar to what is seen when performers' expectancies are directly enhanced (Hutchinson, Sherman, Martinovic, & Tenenbaum, 2008) or their attentional focus is directed to the movement goal (e.g., Lohse, Sherwood, & Healy, 2011; Vance, Wulf, Töllner, McNevin, & Mercer, 2004). Future studies should follow up on these findings by including measures of movement efficiency, such as electromyographic measures in force production tasks or oxygen consumption in endurance tasks. In addition, brain imaging studies examining functional connectivity as a result of performer autonomy are desirable as they might yield more direct evidence for the role of autonomy in goal-action coupling (Wulf & Lewthwaite, 2016).

The present findings add to increasing evidence that small or even incidental choices can be sufficient to enhance motor performance and learning. In fact, in their meta-analysis, Patall, Cooper, and Robinson (2008) found that incidental choices, or those that are not directly task-relevant, seem to be particularly motivating. Thus, the range of beneficial choices that practitioners can take advantage of to facilitate skill learning and immediate performance appears to be greater than clearly task-relevant ones.

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Chapter 3

Autonomy Enhances Running Efficiency

Significance of the Chapter

The findings of the first experiment showed that performer autonomy enabled participants in a choice group to sustain maximum force levels to a greater extent than a control group without choice. The second experiment examined the effect of autonomy support on movement efficiency by including direct measures of movement efficiency (e.g., oxygen consumption, heart rate). Participants were asked to run at submaximal intensity for 20 minutes on a treadmill under choice or control conditions. It was hypothesized that the choice group (selection of photos shown on a screen) would show increased running efficiency compared with the control group.

Abstract

Performer autonomy has been shown to contribute to effective motor performance and learning. Autonomy support is therefore a key factor in the OPTIMAL theory of motor learning (Wulf & Lewthwaite, 2016). The purpose of the present study was to examine whether supporting individuals' need for autonomy by giving them choices would increase movement efficiency. Such a finding would be consistent with the OPTIMAL theory prediction that autonomy facilitates the coupling of goals and actions. Participants (N = 32) first completed a graded exhaustive exercise test to determine their VO_2 max. One week later, they were asked to run at a submaximal intensity (65% of VO_2 max) for 20 minutes. Before the run, participants in a choice group were able to choose 5 of 10 photos as well as the order in which they would be shown to them on a computer screen during the run. Control group participants were shown the same photos, in the same order, chosen by their counterparts in the choice group. Throughout the run, oxygen consumption and heart rate were significantly lower in the choice group than the control group. Thus, providing autonomy support resulted in enhanced running efficiency. The present findings are in line with the notion that autonomy facilitates the goal-action coupling (Wulf & Lewthwaite, 2016).

Key words: Choice, oxygen consumption, heart rate, movement economy

Introduction

Conditions that support individuals' need for autonomy (e.g., Deci & Ryan, 2000; 2008; Leotti & Delgado, 2011) are vital to well-being and quality of life (e.g., Langer & Rodin, 1976; Ryan & Deci, 2017). Autonomy support is taken here to mean contextual and interpersonal circumstances surrounding task practice that contribute to the performer's feeling of having a say or being in control in his or her actions or behaviors. Autonomy-supportive conditions would include offering control over aspects of practice conditions, providing choices or encouraging expressions of preferences in what is to be performed or how it might be approached. They also include language that conveys some freedom of choice and other opportunities for the performer to derive a sense of agency in task engagement. Autonomy support has also been shown to be important for motivation, performance, and learning (e.g., Chiviacowsky, Wulf, Lewthwaite, & Campos, 2012; Cordova & Lepper, 1996; Tafarodi, Milne, & Smith, 1999; Wulf, Iwatsuki, Machin, Kellogg, Copeland, & Lewthwaite, 2017). Even seemingly inconsequential choices may benefit learning (e.g., Cordova & Lepper, 1996; Tafarodi, Milne, & Smith, 1999). Interestingly, incidental choices, or those that are not directly task-relevant, seem to be particularly motivating (Patall, Cooper, & Robinson, 2008).

As numerous studies have demonstrated, the learning of motor skills, including sports skills, is enhanced when learners are given the opportunity to make certain decisions themselves (for a recent review, see Wulf & Lewthwaite, 2016). Since the 1990s, when Janelle and colleagues (Janelle, Kim, & Singer, 1995; Janelle, Barba, Frehlich, Tennant, & Cauraugh, 1997) first demonstrated that learner-controlled (or self-controlled) feedback facilitated learning of throwing tasks relative to yoked control conditions, many studies have replicated their findings. Aside from learner-controlled feedback (e.g., Aiken, Fairbrother, & Post, 2012; Chiviacowsky &

Wulf, 2002, 2005; Chiviacowsky, Wulf, De Medeiros, Kaefer, & Tani, 2008), letting learners determine when to use assistive devices has been shown to be advantageous for learning (Chiviacowsky et al., 2012; Hartman, 2007; Wulf & Toole, 1999). Also, the opportunity to view video demonstrations of a basketball jump shot led to a more effective learning of movement form compared with a yoked group, as measured after a 7-day retention interval (Wulf, Raupach, & Pfeiffer, 2005). Similarly, video feedback enhanced the learning of trampoline skills to a greater extent when it was requested by the learner, as compared with a condition in which learners had no control over the delivery of feedback (Ste-Marie, Vertest, Law, & Rymal, 2013). Even choosing the amount of practice can lead to superior learning, as shown in a study by Post, Fairbrother, and Barros (2011). In that study, both movement form and shooting accuracy were enhanced by letting participants decide how many practice shots they wanted to do. On a delayed retention test, the self-control group outperformed a yoked control group. In addition to the learning-enhancing effects of autonomy support, a few recent studies have demonstrated immediate benefits of choice for motor performance (Halperin, Chapman, Martin, Lewthwaite, & Wulf, 2016; Iwatsuki, Abdollahipour, Psotta, Lewthwaite, & Wulf, 2017). In those studies, allowing participants to choose the order of tasks enhanced force production.

Aside from task-relevant choices (e.g., feedback, assistive devices), even small or incidental choices can benefit motor performance and learning – underscoring the motivational nature of having a choice. For instance, in one study (Lewthwaite, Chiviacowsky, Drews, & Wulf, 2015, Experiment 1), providing participants with a small choice, namely, allowing them to choose the color of golf balls (white, orange, or yellow) to be used on a putting task enhanced learning, as measured by a delayed retention test that involved white balls. In a subsequent experiment (Lewthwaite et al., Experiment 2), the learning of the balance task was enhanced by giving learners two choices ostensibly unrelated to the task at hand (i.e., which of two tasks, involving handgrip force or coincidence timing, they wanted to perform after practicing the balance task, and which of two pictures they thought should be hung on the wall). In addition to replicating the effectiveness of task-irrelevant choices, Wulf et al. (2017) demonstrated that task-relevant (video demonstrations of the skill) and task-irrelevant choices (color of mat under target) equally benefited the learning of a lasso-throwing task. In line with these findings, autonomy-supportive instructional language, delivered in a respectful manner (Englert & Bertrams, 2015) or suggesting that learners have some freedom in terms of how they approach task practice, has been found to be more effective than controlling language (Hooyman, Wulf, & Lewthwaite, 2014).

Because of its impact on learning, performer autonomy is one of three key factors in the OPTIMAL theory of motor learning (Wulf & Lewthwaite, 2016). (The other two factors are enhanced expectancies for future performance and an external focus of attention.) According to the theory, a sense of autonomy allows 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). Opportunities for choice enhance expectations for positive experience and outcomes, including self-efficacy (Hooyman et al., 2014; Lemos, Wulf, Lewthwaite, & Chiviacowsky, 2017; Murayama, Izuma, Aoki, & Matsuyama, 2016). Reward expectations elicit dopaminergic responses that are important for the development of neural connections necessary for successful performance, including the production of force (Foreman, Singer, Addison, Marcus, LaStayo, & Dibble, 2014). Autonomy is therefore seen as an important contributor to goal-action coupling (Wulf &

Lewthwaite, 2016). By linking movement goals with necessary actions autonomy leads to effective and efficient motor performance and learning.

While motor learning has consistently been shown to be more effective when practice conditions are autonomy supportive (see above), the notion that movement efficiency should be enhanced when performers have some degree of autonomy still lacks direct empirical support. Indirect evidence comes from two recent studies in which autonomy support led to greater maximum force production (Halperin et al., 2016; Iwatsuki, et al., 2017). In the study by Halperin and colleagues, experienced boxers performed a series of different punches under two conditions, a standard condition in which the order of punches was pre-specified and a choice condition in which they selected the order of punches. The choice condition led to higher punching velocities and greater impact forces. In a subsequent study, Iwatsuki et al. found benefits of choice for a task requiring the production of repeated maximum forces using a handgrip dynamometer. Participants who were allowed to choose the order of hands on successive trials maintained force levels, whereas a yoked control group showed a significant decline in force across trials.

Maximum force production requires optimal coordination within (e.g., motor unit recruitment) and among muscles (e.g., reduction of unnecessary co-contractions). The studies by Halperin et al. (2016) and Iwatsuki et al. (2017) provide initial indirect evidence that autonomy support may indeed facilitate neurophysiological efficiency – similar to what is seen when performers' expectancies are directly enhanced (Hutchinson, Sherman, Martinovic, & Tenenbaum, 2008; Montes, Wulf, & Navalta, 2017; Stoate, Wulf, & Lewthwaite, 2012) or their attentional focus is directed to the movement goal (e.g., Lohse, Sherwood, & Healy, 2011; Vance, Wulf, Töllner, McNevin, & Mercer, 2004). The purpose of the present study was to examine the effect of autonomy support on motor performance by including direct measures of movement efficiency. Participants were asked to run on a treadmill at a submaximal intensity. The choice given to one group was related to pictures they viewed while running. We used metabolic measures (e.g., oxygen consumption) to test the hypothesis that providing participants with such a relatively small choice would improve running efficiency relative to having no choice (yoked control group).

Method

Participants

Power analysis software, G*Power 3.1, was used to estimate a required sample size. Based on an estimated large effect size (f = .57) with the α-level set at .05 and the power value set at .90, the sample size of 22 participants was needed to detect an effect (Faul, Erdfelder, Lang, & Buchner, 2007). Thirty-two university students volunteered to participate in this study. Their mean age was 22.59 ± 2.46 years (choice: 22.94 ± 2.69 years; control: 22.25 ± 2.24 years). Mean height was 171.10 ± 11.01 cm (choice group: 170.27 ± 10.29 cm; control group: 171.92 ± 11.97 cm), and the average weight was 68.18 ± 15.48 kg (choice group: 71.43 ± 17.33 kg; control group: 66.94 ± 13.57 kg). All participants (16 male, 16 female) were had low risk for exercise-related complications (e.g., cardiovascular, pulmonary, metabolic), as determined by the American College of Sports Medicine Risk Stratification Screening Questionnaire. Participants were naïve as to the purpose of the study. They were informed that their fitness level would be assessed. Written informed consent was obtained from all participants before beginning the experiment. The university's institutional review board approved the study.

Apparatus and Task

A motor-driven treadmill (T914, Nautilus, Vancouver, WA) was used for walking (warm up) and running. An open-circuit respiratory metabolic system (Moxus, AEI Technologies, Pittsburgh, PA) was calibrated prior to each test and was used to determine oxygen consumption (VO_2) and respiratory exchange ratio (*RER*) throughout the two-day experiment. *RER* indicates how fatty acids and carbohydrate are used. A high *RER* suggests the predominant use of carbohydrates, whereas a low *RER* indicates that more fatty acids are being used (Muoio, Leddy, Horvath, Awad, & Pendergast, 1994; Pendergast, Leddy, & Venkatraman, 2000). A heart rate monitor (Polar Electro Inc., Lake Success, NY) was utilized to determine heart rate (*HR*). The heart rate monitor was positioned on the diaphragm throughout the experiment.

Procedure

Participants were asked to come to the exercise physiology laboratory on two separate occasions. Prior to participating in the experiment on Day 1, participants' height and weight were obtained. All participants then completed a graded exhaustive exercise test to determine their VO_2 *max*. The initial treadmill speed was set to 3 mph (4.83 km/h) for 2 minutes, followed by 5 mph (8.05 km/h) for 1 minute, and 6 mph (9.66 km/h) for 1 minute. Subsequently, running speed was increased by .5 mph (.08 km/h) every minute until participants reached their self-selected comfortable running speed. That speed was kept throughout the rest of the graded exhaustive test. The grade of the treadmill was then increased by 3% every 2 minutes until the participant could no longer maintain adequate running speed and reached maximum exhaustion. Upon completion of the graded exhaustive exercise test, participants were allowed a cool-down period based on a self-selected pace.

One week later, participants returned to the laboratory and performed a 20-minute submaximal run at a speed that corresponded to 65% of their VO_2 *max*. Quasi randomization (gender, VO_2 *max*) was used to assign them to one of the two groups, the choice and control groups. Prior to the run, participants in the choice group were asked to choose 5 of 10 photos shown to them on a computer screen. They were informed that they would be able to see those photos during their run on a monitor placed in front of the treadmill. The photos included 5 city (e.g., New York, Tokyo) and 5 nature motifs (e.g., Yosemite National Park, Rocky Mountains). Participants could also choose the order in which the photo would be displayed. Control group participants were shown the same 10 photos, but were then informed which 5 of those photos they would be seeing during their run, as well as the order in which they would see them. Each participant in the control group was yoked to a participant in the choice group (in terms of the photos and their order), unbeknownst to them. The 5 photos were rotated every minute during the 20-minute run. Thus, each photo was shown 4 times.

Prior to the 20-minute run, participants warmed up for 5 minutes. The warm-up protocol involved an initial walk at 2 mph (3.21 km/h) for 2 minutes, followed by a 3-minute run at 3 mph (4.83 km/h) for 3 minutes. Next, the treadmill was set to a speed that corresponded to 65% of the participant's VO_2 *max*, as determined by the metabolic equation in the absence of grade {speed = [VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$) - 3.5] / 0.2}, provided by the American College of Sports Medicine and Pescatello (2014).

Participants ran at that speed for 20 minutes. *RER* (i.e., ratio between produced carbon dioxide and consumed oxygen), *HR*, and VO_2 were recorded every 30 seconds. Participants were also asked to rate their perceived exertion every 2 minutes, using Borg's (1982) 20-point rating of perceived exertion (*RPE)* scale. After the completion of the 20-minute run, participants were given a cool-down period at a self-selected speed. Finally, participants were debriefed about the purpose of the study, provided with feedback (e.g., VO_2 *max*), and thanked for their time.

Data Analysis

RER, *HR*, and VO_2 data were averaged across 5-minute intervals. *RER*, *HR*, and VO_2 data were each analyzed in 2 (group: choice, control) x 4 (time: 1-5 minutes, 6-10 minutes, 11-15 minutes, 16-20 minutes) repeated-measure analysis of variance (ANOVA). *RPE* was analyzed in a 2 (group: choice, control) x 10 (time: every 2 minutes) ANOVA with repeated measures on the last factor. Mauchly's test was used to assess the sphericity assumption. If the assumption was violated, Greenhouse-Geisser epsilon values were used to adjust the degrees of freedom. Bonferroni corrections were used for pairwise post-hoc tests. The level of significance was set to .05.

Results

Maximal Exertion Measures

On Day 1, all participants performed a VO_2 *max* test. The results showed no significant differences between the choice and control groups on any measure: VO_2 *max* (choice: 45.50 ± 7.32 ml·kg-1·min-1; control: 46.148 ± 6.68 ml·kg-1·min-1; $p = .661$); *RER max* (choice: 1.14 ± 0.08, control: 1.14 ± 0.9; $p = .740$); and *HR max* (choice: 192.80 ± 8.46, control: 196.07 ± 7.94; $p = .536$), $p > .05$.

Respiratory Exchange Ratio

RER can be seen in Figure 2. Even though the control group tended to have higher values than the choice group, especially early in the run, the main effect of group, F (1, 30) = 3.007, $p = .093$, $\eta_\rho^2 = .091$, and the interaction of group and time were not significant, F (1.36, 40.71) = 2.466, $p = .115$, $\eta_\rho^2 = .076$. The main effect of time was significant, F (1.36, 40.71) = 27.639, $p > .001$, $\eta_\rho^2 = .480$.

Oxygen Consumption

As can be seen from Figure 3, the choice group had a lower VO_2 than the control group. The main effect of group was significant, F (1, 30) = 4.408, $p < .05$, $\eta_\rho^2 = .128$. The main effect of time was also significant, F (1.30, 39.08) = 191.072, $p < .001$, $\eta_\rho^2 = .864$, reflecting the fact that VO_2 increased for both groups. The interaction of group and time was not significant, F (1.30, 39.08) = 1.903, $p = .174$, $\eta_\rho^2 = .060$.

Heart Rate

Throughout the run, the choice group had lower *HR* than the control group (see Figure 4). The main effect of group was significant, F (1, 30) = 6.821, $p < .05$, $\eta_\rho^2 = .185$. As *HR* generally increased, the main effect of time was also significant, F (1.37, 41.16) = 198.226, $p < .001$, η_ρ^2

= .869. The interaction of group and time was not significant, F (1.37, 41.16) = 1.492, p = .235, η_ρ^2 = .047.

Rate of Perceived Exertion

RPE generally increased over the 20-minute run (see Figure 5). The main effect of time was significant, F (1.79, 53.76) = 34.52, p < .001, η_ρ^2 = .535. *RPE* did not differ significantly between groups, however, F (1, 30) = .778, p = .385, η_ρ^2 = .025. The interaction of group and time was not significant either, F (1.79, 53.76) = 1.196, p = .307, η_ρ^2 = .038.

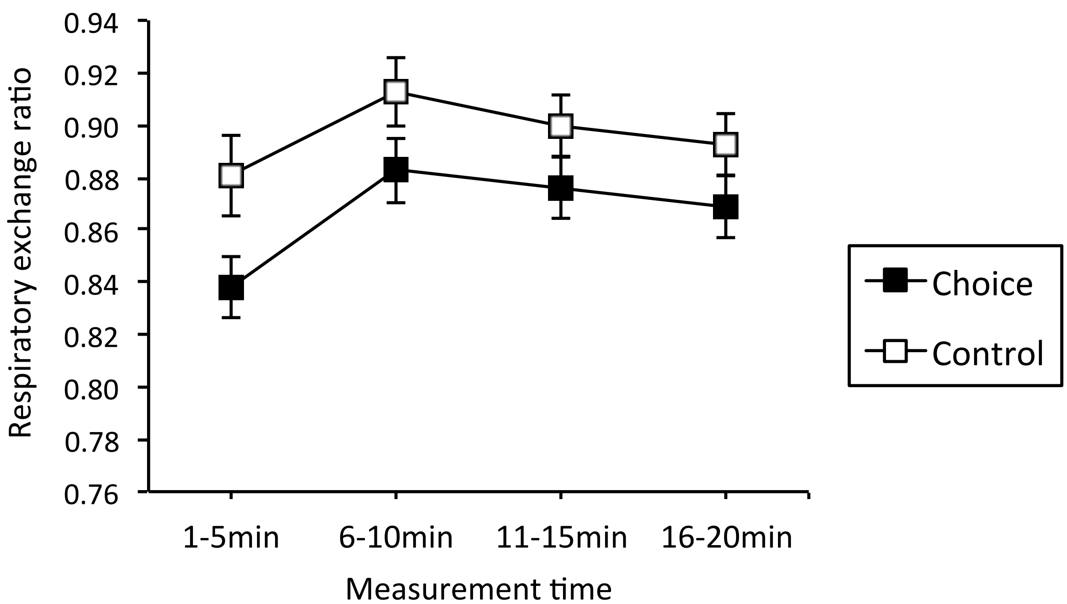

Figure 2. Respiratory exchange ratio (*RER*) in the choice and control group across measurement times.

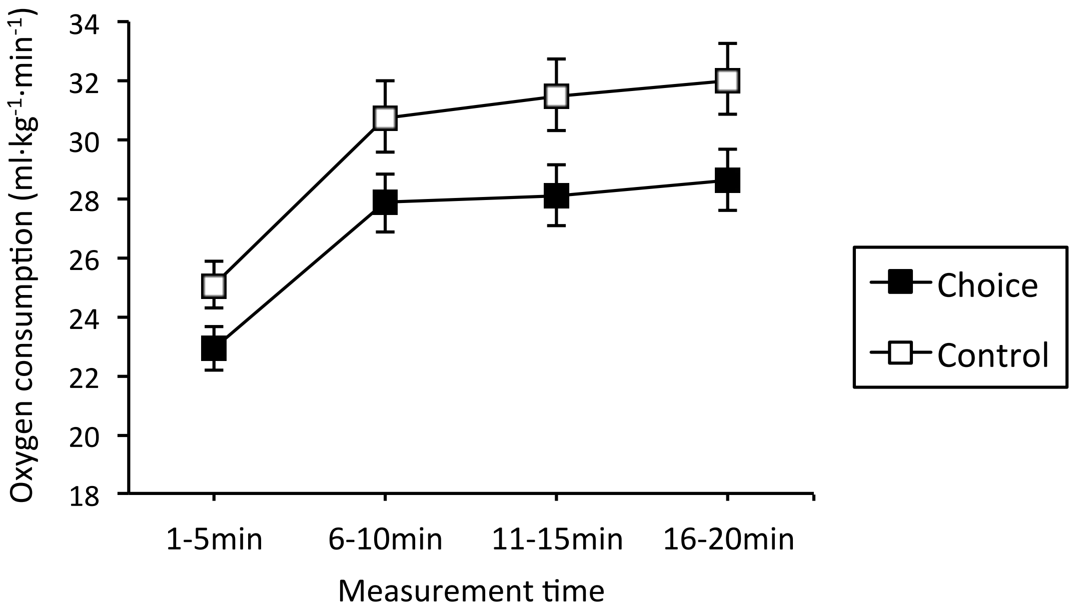

Figure 3. Oxygen consumption (*VO_2*) in the choice and control groups across measurement times.

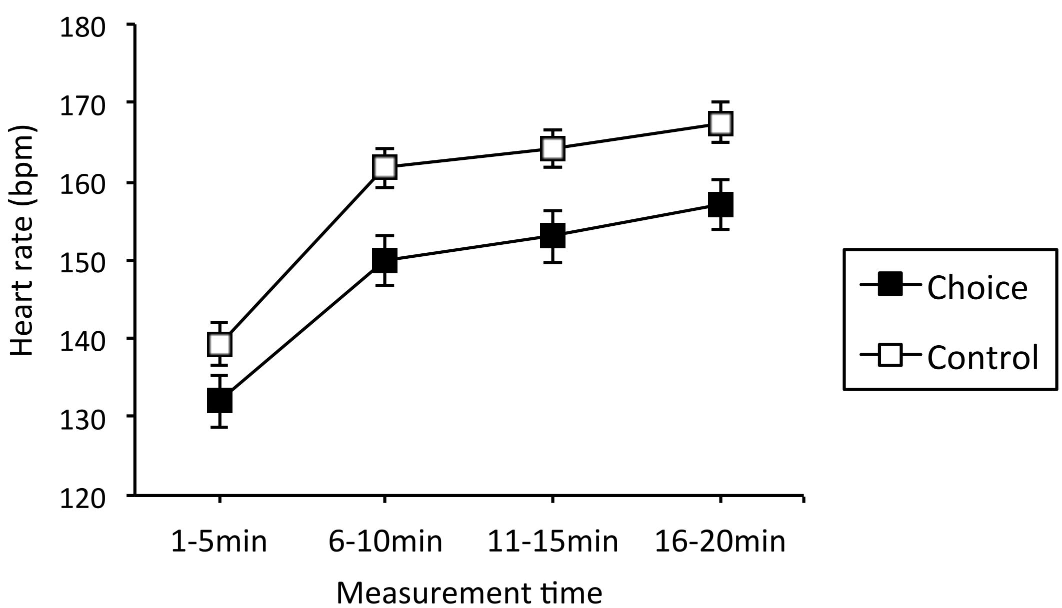

Figure 4. Heart rate (*HR*) in the choice and control group across measurement times.

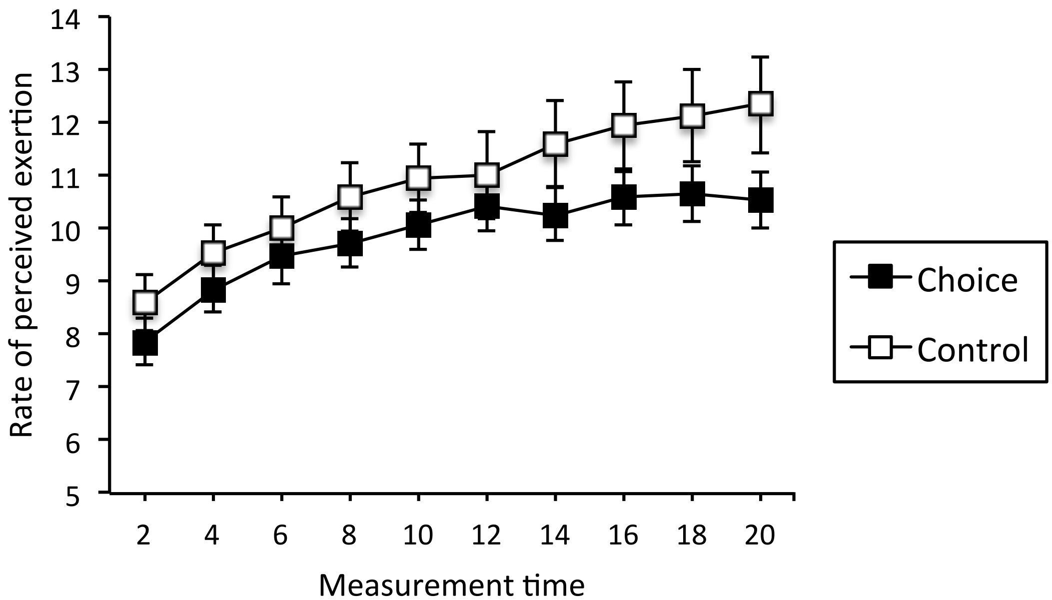

Figure 5. Rate of perceived exertion (*RPE*) reported by the choice and control groups every 2 minutes.

Discussion

Running efficiency has been widely examined using various motivational interventions, including injected placebos (saline) (Ross, Gray, & Gill, 2015), altering facial expressions (e.g., smiling) (Brick, McElhinney, & Metcalfe, 2018), self-selected music (Hutchinson, Jones, Vitti, Moore, Dalton, & O'Neil, 2018), or associative versus dissociative cognitive strategies (for a review, see Masters & Ogles, 1998). The present study examined effect of autonomy support on running efficiency. The present findings are in line with our hypothesis that providing performers with a choice would enhance movement efficiency. Supporting participants' need for autonomy by providing them the opportunity to choose pictures they would view during their submaximal run resulted in reduced oxygen consumption relative to the control group. Oxygen consumption is the product of heart rate, stroke volume, and arteriovenous oxygen difference (Fick equation; Acierno, 2000; Fagard & Conway, 1990). The relationship between oxygen consumption and heart rate has been well documented (e.g., Anderson, 1996; Barnes & Kilding, 2015; Morgan & Craib, 1991; Sparrow & Newell, 1998). In our study, heart rate was also significantly lower in the choice condition. *RER* also tended to be reduced among choice group participants compared with participants who had no choice, although that effect was not statistically significant. Subjective ratings of perceived exertion did not differ significantly between groups. Yet, the two main physiological measures (HR, VO_2) indicated that the choice group ran more economically than the control group at the same relative speed.

The present findings add an important piece to the mosaic of effects that performer autonomy has on motor performance and learning. They demonstrate that movement efficiency can be enhanced by autonomy-supportive conditions, even if the choices provided to performers are relatively small and incidental (see Lewthwaite et al., 2015; Wulf et al., 2017). According to the OPTIMAL theory (Wulf & Lewthwaite, 2016), having a sense of autonomy enhances performance and learning in two ways. First, performer autonomy leads to higher expectations for future performance. Autonomy support has indeed been shown to increase perceived competence (Chiviacowsky, 2014) or self-efficacy (Chiviacowsky, 2014; Hooyman et al., 2014; Wulf, Chiviacowsky, & Cardozo, 2014). The positive relationship between self-efficacy (confidence) and motor performance is well documented (e.g., Feltz, Chow, & Hepler, 2008; Moritz, Feltz, Fahrbach, & Mack, 2000). In fact, enhancing performance expectancies *directly* has been found to reduce oxygen consumption in experienced runners during a submaximal run (Stoate et al., 2012) and increase maximal oxygen consumption (Montes et al., 2017). Second, autonomy protects the performer from down-regulatory effect of cortisol on the brain's reward network (Montoya, Bos, Terburg, Rosenberger, & van Honk, 2014). The stress hormone cortisol is increased under controlling conditions relative to autonomy-supportive conditions (Reeve & Tseng, 2011) and likely degrades performance and learning by reducing dopamine.

Autonomy is a variable that is essential for goal-action coupling, or the fluidity with which the intended movement goal is translated into action (Wulf & Lewthwaite, 2016). An important feature of goal-action coupling is effective and efficient neuromuscular coordination (e.g., recruitment of motor units). Two recent studies have provided preliminary evidence for enhanced neuromuscular coordination by demonstrating benefits of autonomy support for sustained maximum force production (Halperin et al., 2016; Iwatsuki et al., 2017) – an effect that appears to be due to enhanced excitability of the corticospinal system (i.e., inceased ampltiudes of motor evoked potentials; Fiorio, Emadi Andani, Marotta, Classen, & Tinazzi, 2014). The need for less oxygen (i.e., greater movement efficiency) seen in the choice condition of the present study also appears to be an indication of enhanced coordination among and/or within muscles.

Neural activation patterns typically seen in advanced performers, such as increased efficiency in muscle or motor unit recruitment (e.g., Conley, Stone, Nimmons, & Dudley, 1997; Green & Wilson, 2000; Ploutz, Tesch, Biro, & Dudley, 1994) – and presumably when performance conditions are optimized – are the result of effective connectivity at the central level. Functional connectivity, that is, temporal linkages among task-related neural networks that are seen in expert performers (Bernardi, Ricciardi, Sani, Gaglianese, Papasogli, Ceccarelli, …Pietrini, 2013; Kim, Chang, Kim, Seo, Ryu, Lee, Woo, & Janelle, 2014; Milton, Solodkin, Hluštík, & Small, 2007), is central to the notion of goal-action coupling (see Lewthwaite & Wulf, 2017; Wulf & Lewthwaite, 2016). Choice, or the anticipation of choice, is associated with activity in brain regions that are involved in motivational processes, including the striatum and the ventromedial prefrontal cortex (Murayama et al., 2016). Choice is also associated with dopamine release (Aarts, Bijleveld, Custers, Dogge, Deelder, Schutter, & Haren, 2012; Lee & Reeve, 2013; Leotti & Delgado, 2011). The assumed mechanisms for autonomy support include its role in generating a dopaminergic response. Dopamine is thought to contribute to efficient goal-action coupling via functional (and structural) neural connectivity. Reward expectations, such as the anticipation of choice, have been shown to reduce electroencephalographic (EEG) beta activity that inhibits motor activity (Meadows, Gable, Lohse, & Miller, 2016). Dopamine suppresses beta activity (Jenkinson & Brown, 2011) and prepares the motor system for action as seen, for instance, by faster reaction times (Meadows et al., 2016).

Future studies will likely provide more direct evidence for increased neurophysiological efficiency resulting from autonomy support by examining electromyographic activity or brain activity, including beta suppression, intracortical inhibition (e.g., Kuhn, Keller, Ruffieux, & Taube, 2016), or functional connectivity. It would also be interesting to further explore possible additive effects of autonomy support and other conditions thought to be key to optimal performance (Wulf & Lewthwaite, 2016), such as enhanced expectancies (e.g., Lewthwaite & Wulf, 2010) and an external focus of attention (e.g., Kal, van der Kamp, & Houdijk, 2013). Recent studies have shown that all three factors seem to make unique contributions to performance and learning and have additive effects (Abdollahipour, Palomo Nieto, Psotta, & Wulf, 2017; Pascua, Wulf, & Lewthwaite, 2015; Wulf et al., 2014; Wulf, Chiviacowsky & Drews, 2015; Wulf, Lewthwaite, Cardozo, & Chiviacowsky, 2017). Both enhanced expectancies (Stoate et al., 2012) and an external focus (Schücker, Hagemann, Strauss, & Völker, 2009) have also been shown to improve running economy. Furthermore, all three variables have been found to facilitate sustained force production relative to "neutral" control conditions (Hutchinson et al., 2008; Iwatsuki et al., 2017; Marchant, Greig, Bullough, & Hitchen, 2011). Together these findings show that all factors have the capacity to enhance movement efficiency, in addition to their frequently demonstrated benefits for various measures of movement effectiveness (e.g., accuracy). Whether movement efficiency can be further by combining autonomy-supportive conditions with those that enhance expectations for performance or promote an external focus remains to be determined.

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Chapter 4

Autonomy Support Reduces Muscular Activity

Significance of the Chapter

Experiment 1 and 2 provided indirect (sustained maximum force production) and more direct evidence (reduced oxygen consumption, heart rate), respectively, for increased movement efficiency resulting from autonomy support. Experiment 3 was designed to examine a possible mechanism underlying these findings. We used surface electromyography (sEMG) to examine muscular activity during the performance of ankle plantar flexion task. The same participants were asked to perform the task at each of the 3 target torques (corresponding to 80%, 50%, and 20% of their maximal voluntary contraction) under choice and conditions. In the choice condition, participants were asked to choose in the order of target torque levels, whereas they were assigned the order in the control condition. It was hypothesized that participants would generally show less EMG activity in the choice relative to the control condition despite comparable levels of torque production.

Abstract

The purpose of this study was to examine whether supporting performers' need for autonomy by providing choices would increase movement efficiency. We evaluated neuromuscular activation as a function of choice, using surface electromyography (sEMG), during isometric torque production. Participants (N = 16) were asked to perform plantar flexions at each of the 3 target torques (80%, 50%, 20% of maximum voluntary contractions) under both choice and control conditions. In the choice condition, they were able to choose the order of target torques whereas the order was pre-determined in the control condition. Results demonstrated that EMG activity was lower in the choice relative to the control condition, while the similar torques were produced under both conditions. Thus, providing choices led to reduced neuromuscular activity, or an increase in movement efficiency. This finding is in line with the notion that autonomy support facilitates goal-action coupling (Wulf & Lewthwaite, 2016).

Key words: Choice, self-control, EMG, force production

Introduction

Having some control over one's environment fulfills a fundamental psychological need (Deci & Ryan, 2000, 2008). In motor learning literature, numerous studies over the past two decades or so have demonstrated that learner-controlled (or self-controlled) practice, enhances the learning of motor skills (for reviews, see Sanli, Patterson, Bray, & Lee, 2013; Wulf, 2007; Wulf & Lewthwaite, 2016). Janelle and colleagues (1995) conducted the first study to examine whether feedback schedules based on learners' request would enhance learning. The authors demonstrated the effectiveness of self-controlled practice. Since then, the positive effects of self-controlled practice on the learning of motor skills have been shown for various factors, including the timing/frequency of feedback (Chiviacowsky & Wulf, 2002; Lim et al., 2015) and video demonstrations (Aiken, Fairbrother, & Post, 2012; Janelle, Barba, Frehlich, Tennant, & Cauraugh, 1997; Ste-Marie, Vertes, Law, & Rymal, 2013; Wulf, Raupach, & Pfeiffer, 2005), the use of assistive devices (Chiviacowsky, Wulf, Lewthwaite, & Campos, 2012; Hartman, 2007; Wulf & Toole, 1999), and the amount of practice (Lessa & Chiviacowsky, 2015; Post, Fairbrother, & Barros, 2011).

Recent studies have demonstrated that even if the variables over which learners are given control are not directly task-relevant, they may still enhance motor learning (Lewthwaite, Chiviacowsky, Drews, & Wulf, 2015; Wulf & Adams, 2014; Wulf, Iwatsuki, Machin, Kellogg, Copeland, & Lewthwaite, 2017). For instance, effective learning outcomes were demonstrated by allowing learners to decide the color of balls to be used (Lewthwaite et al., 2015, Experiment 1) or the color of a mat to be placed under a target (Wulf et al., 2017) relative to no-choice conditions. Moreover, providing learners with two completely task-unrelated choices facilitated the learning of a balance task compared with a control group (Lewthwaite et al., 2015, Experiment 2). Whether task-relevant or task-irrelevant choices differentially influenced motor skill learning was examined by Wulf et al. (2017). In this study, task-relevant (video demonstration) and task-irrelevant (color of mat placed under the target) choices equally benefited the learning of a novel throwing-lasso task. Either choice led to more effective learning than no choice. In fact, small choices have been found to be more motivating compared with task-relevant choices in a meta-analysis (Patall, Cooper, & Robinson, 2008).

Autonomy support is a key variable in the OPTIMAL theory of motor learning (Wulf & Lewthwaite, 2016). Autonomy-supportive conditions can include providing control over practice conditions, autonomy-supportive instructional language, and small or incidental choices. Supporting individuals' need for autonomy is one way to enhance expectations and facilitate motor performance through the coupling of goal and action (Wulf & Lewthwaite, 2016). A few recent studies have demonstrated that providing performers small choices enhanced motor performance and movement efficiency (Halperin, Chapman, Martin, Lewthwaite, & Wulf, 2016; Iwatsuki, Abdollahipour, Psotta, Lewthwaite, & Wulf, 2017; Iwatsuki, Navalta, & Wulf, 2018). For example, allowing kick boxers to choose the order of four different punches enhanced punching velocity and increased impact forces relative a prescribed order of punches (Halperin et al., 2016). Similar, letting a population of college students to choose the order of hands on a handgrip dynamometer task allowed them to maintain repeated maximum forces, compared with individuals who had no choice (Iwatsuki et al., 2017). Most recently, more direct evidence that providing choices increases movement efficiency was provided by using metabolic measures (e.g., oxygen consumption) (Iwatsuki et al., 2018). In the study by Iwatsuki et al., allowing performers to select pictures to be viewed during a 20-minute submaximal run (65% of VO_2 max), reduced oxygen consumption and heart rate.

How can providing choices, or autonomy support, have an immediate benefit for motor performance and enhanced movement efficiency? Lee and Reeve (2013) found that imagery of self-determined tasks, as opposed to tasks that were not self-determined, was linked to the activation of the anterior insular cortex, a region of the brain associated with a sense of agency. Similar to self-determined situations, having choices induces a sense of agency. This condition is also associated with dopamine release (Aarts, Bijleveld, Custers, Dogge, Deelder, Schutter, & Haren, 2012). Dopamine is critical for motor performance and movement coordination. When dopamine agonist medications were administered to individuals with Parkinson diseases, movement kinematics and kinetics (e.g., rapid force production) were improved (Foreman, Singer, Addison, Marcus, LaStayo, & Dibble, 2014). Conditions that support performer's autonomy, therefore, would be expected to increase movement efficiency (Wulf & Lewthwaite, 2016).

Efficient force production requires optimal coordination, including motor unit recruitment. Force production has been shown to be enhanced when performer's expectations were increased (Hutchinson, Sherman, Martinovic, & Tenenbaum, 2008; Kalasountas, Reed, & Fitzpatrick, 2007) or the performer's focus of attention was specifically directed to the movement effect (Lohse, Sherwood, & Healy, 2011; Vance, Wulf, Tollner, McNevin, & Mercer, 2004). Furthermore, compared with focusing on body movements (internal focus), a focus on the intended movement effect (external focus) led to reduced muscular activity as measured by electromyography (EMG) and enhanced movement outcomes (Lohse & Sherwood, 2012; Lohse, Sherwood, & Healy, 2010; Marchant, Greig, & Cott, 2009; Vance et al., 2004; Wulf, Dufek, Lozano, & Pettigrew, 2010; Zachry, Wulf, Mercer, & Bezodis, 2005). It remains to be determined whether providing choices can also produce neurophysiological advantages. Halperin et al. (2016) and Iwatsuki et al.'s (2017) findings provide indirect evidence that autonomy support can result in greater movement efficiency. Therefore, the purpose of the present study was to examine the effect of autonomy support on movement efficiency by measuring neuromuscular activity through the use of surface EMG. Participants were asked to perform a plantar flexion task under both choice and control conditions. We hypothesized that providing a choice would enhance movement efficiency, relative to having no choice condition.

Method

Participants

Participants were 16 college students (11 females, 5 males) with an average age of 22.75 ± 2.35 years. The average height was 168.86 ± 7.09 cm, and the average weight was 70.67 ± 12.62 kg. The study was approved by the university's institutional review board. Prior to the experiment, all participants gave written informed consent. Participants were not aware of the specific purpose of the study.

Apparatus and Task

A HUMAC NORM Isokinetic Extremity System Dynamometer (Computer Sports Medicine Inc., Stoughton, Massachusetts, USA) was used to record plantar flexion. The dominant leg was used throughout the experiment. To determine the dominant leg, participants were asked which leg they used to kick a soccer ball. Participants were seated on the dynamometer according to the manufacturer guideline for testing plantar flexion. Muscle activation during the plantar-flexor isometric contraction was obtained using surface EMG (sEMG) (Delsys Inc., Natick, Massachusetts, USA). The sEMG data were collected from the medial gastrocnemius. The sEMG signal was recorded with the Nexus Motion Capture Software (Oxford Metrics, Oxfordshire, UK) at 2000 Hz sampling frequency.

Procedure

Participants were asked to perform 3 isometric plantar flexion trials at 3 target torques, corresponding to 80%, 50%, and 20% of their maximum voluntary contraction (MVC), under both choice and control conditions after examining their MVC with plantar flexion. The choice given in one condition (choice condition) was to select the order of 3 target torques, while a pre-determined order of torques was provided in control condition. Condition order was counterbalanced among participants.

Before the experiment, the skin was prepared by shaving and cleaning it with alcohol to reduce skin impedance. One electrode was positioned to record the activity of agonist muscle (medial gastrocnemius). It was placed over the muscle belly parallel with the direction of the muscle fibers. An elastic bandage was wrapped around the electrode to secure it from extraneous movement without hindering movement about the knee joint. All plantar-flexor isometric contractions were performed within one testing session, and no electrode replacement was necessary during the experiment.

All the participants were asked to push the top of the platform away with the front part of their shoe. Participants were then asked to practice with sub-maximal effort until they felt comfortable with the dynamometer. For maximal trials, participants were instructed to reach maximum torque as quickly as possible and hold it for 4 seconds. They performed 3 maximal trials with 1-minute rest periods between the trials. The highest average value of the last 3 seconds (1-4 seconds) of the 3 maximum trials was used as the participant's maximum value. This value was then used to calculate each of the 3 target torques, 80%, 50%, and 20% of MVC. Each participant performed 3 trials (after 1 practice trial) under each of the 3 target torques (80%, 50%, and 20% of MVC), with 30-second rest periods between trials. A line representing the target torque as well as the remaining time was displayed on a computer monitor (Figure 6). Participants were asked to reach the target line as quickly as possible and to maintain that force level for 10 seconds. In the choice condition, participants were asked to choose which target torque they wanted to complete first. After 3 trials on one of the 3 target torques, they were asked to choose the second target torque, and then completed the third and last target torque. In the control condition, participants were instructed to perform the 3 target torques in a pre-determined order, which was chosen by the previous participant in the choice condition. The very first participant was provided with the 80%, 50%, and 20% of MVC, as there was no previous participant. The rest period between the two conditions (choice, control) was 10 minutes. Finally, participants were debriefed and thanked for their time.

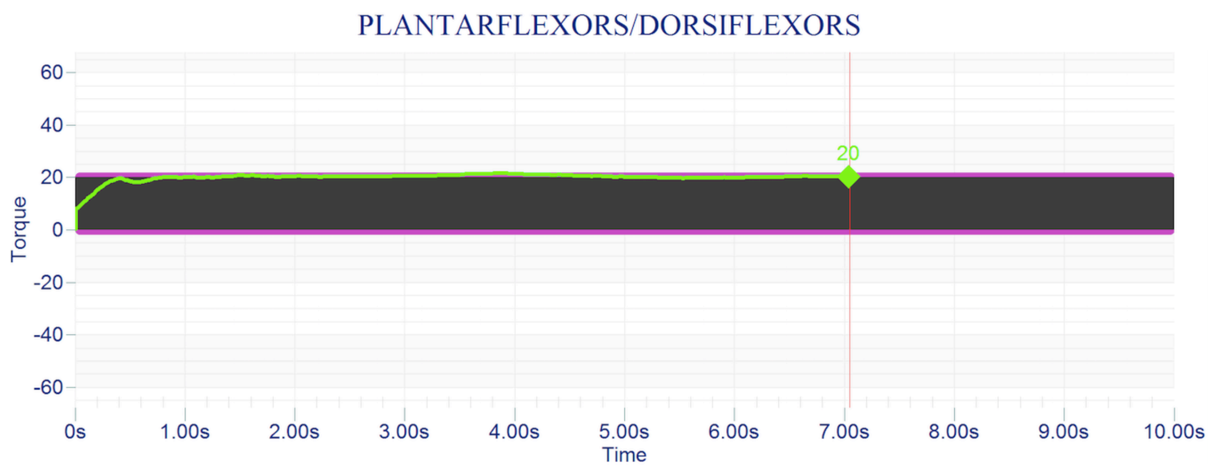

Figure 6. Target line and feedback, including actual torque and remaining time, provided on a computer monitor.

Dependent Variables and Data Analysis

Torque was averaged from Seconds 2-9 (for 7 seconds) of each 10-second trial, where the produced torques were relatively steady. The raw EMG signal was converted to root mean square (RMS). Similar to torque, we used Seconds 2-9 for further data analysis. EMG data were then normalized to the maximum value obtained during the participant's MVC. A customized MATLAB (MathWorks Inc., Natick, MA, USA) code was utilized to extract raw EMG data.

The dynamometer and EMG data were each analyzed in a 2 (condition: choice vs. control) x 3 (target torque: 80%, 50%, 20% of MVC) x 3 (trials) analysis of variance (ANOVA) with the repeated measures on the last two factors. Mauchly's test was utilized to assess the sphericity assumption. If the assumption was violated, the Greenhouse-Geisser epsilon values were used to adjust the degrees of freedom. Bonferroni corrections were performed for all adjustments and post-hoc tests. The level of significance was set at .05. All analyses were performed using the Statistical Package for the Social Sciences (IBM Statistics 24.0; SPSS Inc., Chicago, IL).

Results

Maximum Voluntary Contractions and Order of Target Torques

Maximum voluntary contractions (MVC) resulted in 75.4 Nm (*SD* = 36.9), on average. Average target torques were 60.3 Nm (*SD* = 29.5) at 80%, 37.7 Nm (*SD* = 18.4) at 50%, and 15.1 Nm (*SD* = 7.4) at 20% of MVC, respectively. Participants chose the target torque corresponding to 80% of MVC predominantly for the first 3-trial block (75%) and to a lesser degree (25%) for the last block. The torque corresponding to 50% MVC was mostly chosen for the second block (87.5%), and 12.5% of the time for the third block. Finally, the torque corresponding to 20% of MVC was performed first 25% and third 62.5% of the time.

Torque

The average amounts of torque produced in the choice and control conditions at each level are shown in Figure 7. As can be seen, the actual torques were very similar in the two conditions. The main effect of condition was not significant, F (1, 15) = 2.429, p = .140, η_ρ^2 = .139. The main effect of target torque was significant, F (1.01, 15.17) = 70.36, p < .000, η_ρ^2 = .824. Post-hoc tests indicated that torques produced at 80%, (M = 61.1 ± 28.6 Nm), 50% (M = 38.9 ± 18.2 Nm), and 20% of MVC (M = 16.5 ± 7.8 Nm) all differed from each other, *ps* < .001. There was no main effect of trial, F (2, 30) = .729, p = .491, η_ρ^2 = .046. The interactions of target torque and condition, F (1.43, 25.51) = .931, p = .380, η_ρ^2 = .058, target torque and trial, F (2.60, 38.99) = 1.478, p = .028, η_ρ^2 = .090, condition and trial, F (1, 30) = 1.203, p = .314, η_ρ^2 = .074, and target torque, condition, and trial were not significant, F (2.17, 32.48) = 1.928, p = .159, η_ρ^2 = .114.

EMG

EMG activity in the choice and control conditions can be seen in Figure 8. EMG activity was lower in the choice relative to the control condition. The main effect of condition was significant, F (1, 15) = 5.014, $p = .041$, $\eta_\rho^2 = .251$. The difference between conditions was numerically largest at the torque corresponding to 80% of MVC and smallest at the 50% level (see Figure 9). This was reflected in a significant interaction of target torque and condition, F (2, 30) = 3.61, $p = .039$, $\eta_\rho^2 = .194$. Post-hoc tests showed that EMG activity differed significantly between conditions at 80%, $p = .023$, but not at 50% or 20% of MVC, $ps > .05$. The main effect of target torque was significant, F (1.31, 19.59) = 128.926, $p < .000$, $\eta_\rho^2 = .896$. Post-hoc tests showed that EMG activity was different at all torque levels, $ps < .001$. The main effect of trial was not significant, F (2, 30) = .465, $p < .633$, $\eta_\rho^2 = .030$. The interactions of target torque and trial, F (2, 04, 30.60) = 1.630, $p = .212$, $\eta_\rho^2 = .098$, condition and trial, F (2, 30) = 2.025, $p = .150$, $\eta_\rho^2 = .119$, and target torque, condition, and trial, F (1, 72, 25.86) = 1.785, $p = .191$, $\eta_\rho^2 = .106$, were not significant.

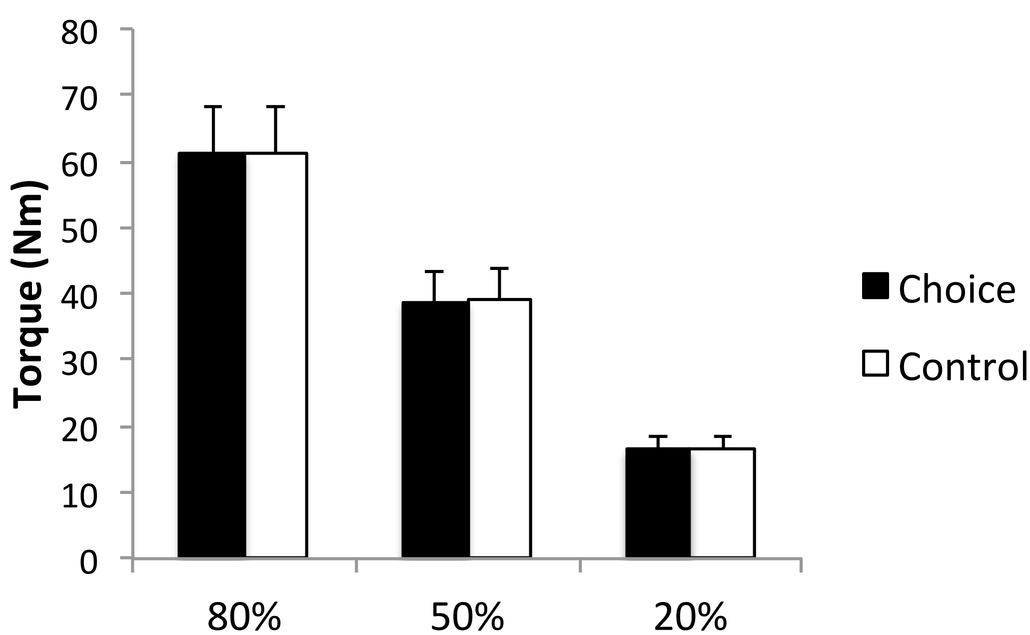

Figure 7. Actual torques produced at each target level in the choice and control conditions.

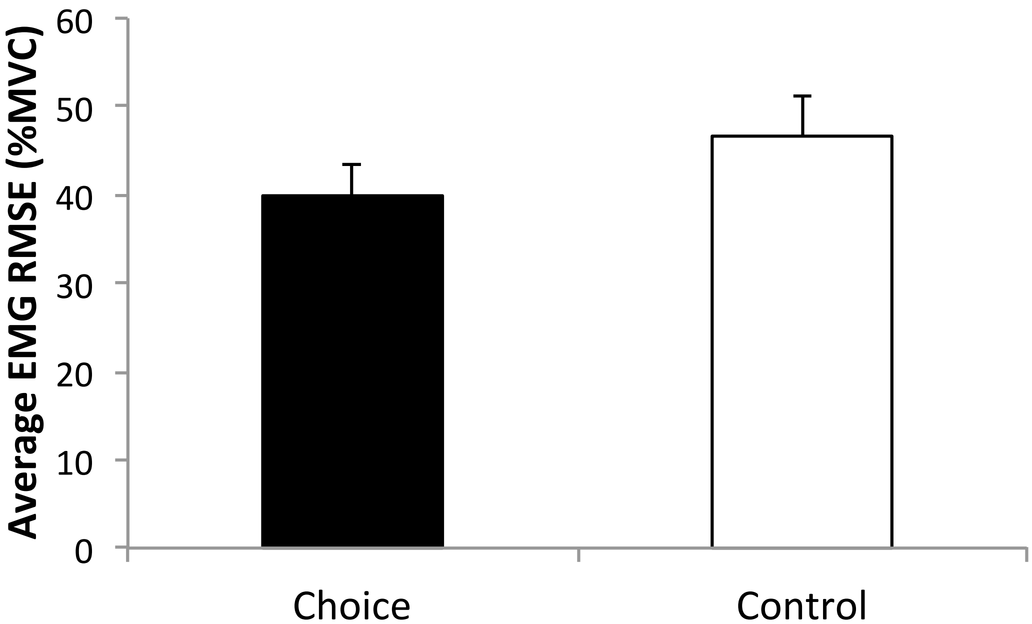

Figure 8. Average EMG activity in the choice and control conditions.

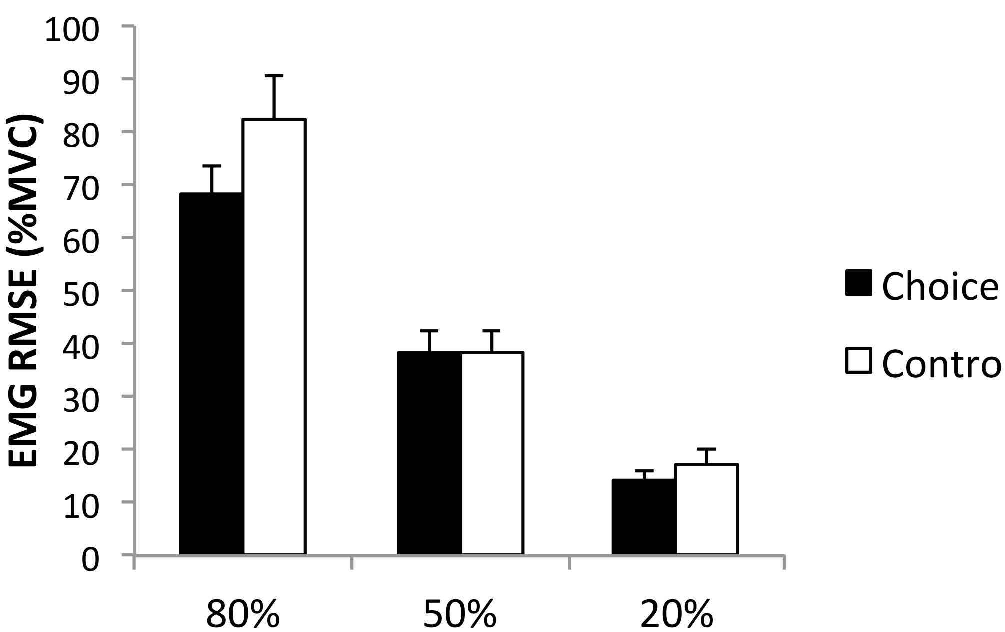

Figure 9. EMG activity at each target torque in the choice and control conditions.

Discussion

The present findings support our hypothesis that providing the opportunity to make small choices (i.e., select the order of target torques) would increase movement efficiency. The order of torques was identical for both groups (with the exception of the first participants' control condition), and participants produced the similar average torques under choice and control conditions. Yet, the choice condition resulted in reduced muscular activity relative to the control condition. Interestingly, this was the case even though for half of the participants (n = 8) the assigned and chosen order happened to be the same. While there are two recent studies showing that offering choices enhances movement efficiency in force production tasks (Halperin et al., 2016; Iwatsuki et al., 2017) and a submaximal run (Iwatsuki et al., 2018), to our knowledge, this is the first study demonstrating the effect of autonomy support on movement efficiency at the neuromuscular level.

Exercising control is considered to be inherently rewarding (Fujiwara et al., 2013; Leotti & Delgado, 2011, 2014). Rewards experiences trigger dopaminergic responses (Hosp & Luft, 2013; Leotti, Iyengar, & Ochsner, 2010), which has directly or indirectly been shown to enhance movement efficiency and effectiveness (Foreman et al., 2014; Jenkinson & Brown, 2011; Meadows, Gable, Lohse, & Miller, 2016). For instance, Meadows et al. (2016) examined whether increased motivation mediated by monetary incentives influenced motor performance. They found that higher motivation led to faster pre-motor movement reaction time as seen in electroencephalographic (EEG) beta suppression. As beta activity is suppressed by dopamine release (Jenkinson & Brown, 2011), this condition is assumed to enhance movement efficiency (Wulf & Lewthwaite, 2016). Direct evidence comes from individuals with Parkinson's disease.

When dopamine agonists were administered, clinical motor disease severity was diminished and rapid force production in the lower extremity (i.e., ankle) was facilitated (Foreman et al., 2014).

Furthermore, conditions that support performer autonomy have been found to enhance expectations or task-specific self-efficacy (Hooyman, Wulf, & Lewthwaite, 2014; Lemos, Wulf, Lewthwaite, & Chiviacowsky, 2017; Murayama, Izuma, Aoki, & Matsumoto, 2016; Wulf, Chiviacowsky, & Drews, 2015). For instance, Hooyman et al. (2014) demonstrated that individuals who were instructed with autonomy-supportive language had higher self-efficacy, compared with those who received controlling language instructions. When performance expectations were directly enhanced, effective motor performance and increased movement efficiency have been experimentally demonstrated (McKay, Lewthwaite, & Wulf, 2012; Montes, Wulf, & Navalta, 2017; Stoate, Wulf, & Lewthwaite, 2012). For example, oxygen consumption – an indicator of movement efficiency – was reduced during a submaximal run (Stoate et al., 2012) and increased during a maximum graded exhaustive test (Montes et al., 2017). Furthermore, placebos have been found to enhance motor performance, including force production tasks (Fiorio, Emadi Andani, Marotta, Classen, & Tinazzi, 2014; Kalasountas et al., 2007). Importantly, these conditions that enhance performer expectations are associated with the release of dopamine (de la Fuente-Fernández, 2009; Lidstone et al., 2010) – leading to greater movement efficiency (e.g., Foreman et al., 2014; Jenkinson & Brown, 2011; Wulf & Lewthwaite, 2016). These findings, including those of the present study, support that the notion that providing choices, or autonomy support, is one way to enhance expectations for future performance and in turn motor performance (Wulf & Lewthwaite, 2016).

More efficient motor unit recruitment patterns are beneficial for motor performance. The present findings suggest that autonomy support led to greater effectiveness in motor unit recruitment, and that increased muscular activity in the control condition hampered movement control. Reduced neuromuscular activity is also seen with an external relative to an internal focus of attention (Lohse & Sherwood, 2012; Lohse et al., 2010; Marchant et al., 2009; Vance et al., 2004; Wulf et al., 2010; Zachry et al., 2005). In fact, a study by Chiviacowsky et al. (2012) demonstrated that a no-choice control condition resulted in a greater focus on body movements than did a choice condition. Thus, it is possible that the control condition in the present study promoted an internal focus (e.g., feet), whereas the choice condition facilitated an external focus (e.g., platform). However, this issue will need be examined in further investigations. In the future, researchers should attempt to measure types of attentional focus as a function of providing choices, and examine the relation to muscular activity. Autonomy support may also enhance movement coordination between muscles (inter-muscular coordination). However, future studies are needed to examine whether autonomy support reduces co-contractions between agonist and antagonist muscles.

The findings of the present study add to the literature on autonomy support and motor performance. To our knowledge, this is the first study to investigate the effects of autonomy support on movement efficiency at the neurophysiological level. The results are in line with previous research that demonstrate the positive effect of performer autonomy on movement efficiency in force production tasks (Halperin et al., 2016; Iwatsuki et al., 2017) and submaximal running (Iwatsuki et al., 2018). From an applied perspective, coaches, trainers, and practitioners could provide choices – even relatively small or incidental choices in regard to the task – that may result in improved motor performance in their athletes and patients.

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Chapter 5

Overall Conclusions

The purpose of this dissertation was to examine whether providing autonomy support by giving performers choices would increase movement efficiency. The three experiments reported here support the notion that autonomy support has an immediate impact on motor performance and increases movement efficiency.

The first study examined the generalizability of the findings of Halperin, Chapman, Martin, Lewthwaite, and Wulf (2016), where providing choices (order of punches) enhanced punching velocity and increased impact forces among kick boxers in a within-participant design. Experiment 1 compliments their findings and extends them in two ways. First, it replicated the findings with a non-athlete population and with the use of a between-participant design and a yoking procedure. Second, a manipulation check, the perception of choice sub-scale of Intrinsic Motivation Inventory, was used. It confirmed that the choice manipulation was associated with greater perceived choice. Experiments 2 and 3 used more direct measures of movement efficiency. The second study demonstrated that providing choices, namely, pictures to be viewed during a sub-maximal run, reduced oxygen consumption and heart rate, compared with having no choice. Neurophysiological advantages associated with having choices were seen in the third study. Compared with having no choice, offering small choices (order of 3 target torques) reduced muscular activity, even though participants produced the similar torques in the choice and control conditions. Thus, the three studies demonstrated, indirectly or directly, an increase in movement efficiency when choices were provided.

How does this dissertation contribute to the motor control and learning literature? Experimental evidence that demonstrates the effects of autonomy support on movement efficiency has been lacking. This dissertation provides evidence to support the notion that autonomy has an immediate impact on motor performance and, specifically, movement efficiency. The three studies of this dissertation are in line with the notion that autonomy support facilitates movement efficiency through goal-action coupling (Wulf & Lewthwaite, 2016). In future studies, researchers may want to consider examining neuromuscular activity (e.g., co-contraction) or brain activity (e.g., beta suppression, intracortical inhibition, functional connectivity) under autonomy-supportive conditions. From an applied perspective, the present findings are important for coaches and other practitioners who wish to enhance the motor performance or movement efficiency of their athletes and patients.

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Appendix 1

Chapter 2 Article Copyright

The article comprising Chapter 2 entitled "Autonomy Facilities Repeated Maximal Force Production" has been published in *Human Movement Science*. The publisher for *Human Movement Science,* Elsevier, allows published articles to be included in dissertations. Therefore, no copyright approval was required for this manuscript.
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Iwatsuki, T., Abdollahipour, Z., Rudolf, P., Lewthwaite, L., & Wulf, G. (2017). Autonomy facilitates repeated maximum force productions. *Human Movement Science, 55*, 264-268.
https://www.sciencedirect.com/science/article/pii/S0167945717300842

Appendix 2

Chapter 3 Article Copyright

The article comprising Chapter 3 entitled “Autonomy Enhances Running Efficiency” is an author’s original manuscript of an article submitted for consideration in *Journal of Sports Sciences* [copyright Taylor & Francis/society]; *Journal of Sports Sciences* is available at: http://www.tandfonline.com/toc/rjsp20/current

Appendix 3

Chapter 4 Article Copyright

The article comprising Chapter 4 entitled "Autonomy Support Reduces Muscular Activity" has been submitted for publication consideration in *Human Movement Science*. The publisher for *Human Movement Science,* Elsevier, allows, allows manuscripts to be included in dissertations.

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KIN 312: Motor Control and Learning (TA) F-17, S-18
KIN 414/614: Enhancing Mental and Motor Abilities (IR) S-16, F-16, S-17, SU-17

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ASIAN 122: First Year Japanese II (LI) S-14, S-15

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PEAC 141: Table Tennis (IR) F-12, S-13, F-13, S-14

Nihon University - Dept. of Health Sciences and Physical Education
Sport Psychology (TA) S-10, F-10
Sport Training Theory (TA) S-9, F-9, S-10, F-10

Invited Guest Lectures

UNLV
KIN 735: Sports Medicine Rehabilitation Principles and Practices (Graduate course) F-17
KIN 414/614: Enhancing Mental and Motor Abilities F-15

High School/Middle School/Kindergarten

Nichidai Mishima High School
Student Teacher, Physical Education and Health Sciences Jun-Jul 2008

Amherst Japanese Language School (Middle School Level)
Teacher, Japanese and Mathematics 2013 - 2014

Nihon Kindergarten
Physical Education Teacher, Physical Education 2010 - 2011

License

Master's Level Teacher's License in Health Sciences and Physical Education 2011
Master's level licensed teacher in high and middle school in Japan.

Scholarly Activities

Motor Learning and Performance Laboratory Research Assistant, UNLV 2015 - 2018

Researcher, Palacký University, Olomouc, Czech Republic May-Aug 2016

Research Assistant, Springfield College 2012 - 2014

Research Assistant, Nihon University 2009 - 2011

Academic Publications

Peer-Reviewed Publications

##. **Iwatsuki, T.**, Navalta, J., & Wulf, G. (2018). Autonomy enhances running efficiency. *Journal of Sports Sciences*. (Manuscript revised and re-submitted for publication)

12. **Iwatsuki, T.**, Van Raalte, J., Brewer, B., Petipas, A., & Takahashi, M. (2018). Relations among reinvestment, self-regulation, and perception of choking under pressure. *Journal of Human Kinetics.*

11. Van Raalte, J. L., Cornelius, A., Mullin, E., Brewer, W. B., Van Dyke, E., Johnson, A. J., & **Iwatsuki, T.** (2018). I will use declarative self-talk… or will I? Replication, extension, and meta-analyses. *The Sport Psychologist, 32*, 16-25.

10. **Iwatsuki, T.**, Abdollahipour, Z., Rudolf, P., Lewthwaite, L., & Wulf, G. (2017). Autonomy facilitates repeated maximum force productions. *Human Movement Science, 55*, 264-268.

09. Wulf, G., **Iwatsuki, T.**, Machin, B., Kellogg, J., Copeland, C., & Lewthwaite, R. (2017). Lassoing skill through learner choice. *Journal of Motor Behavior, 49*, 1-8.

08. Hagiwara, G., **Iwatsuki, T.**, Isogai, H., Van Raalte, J., & Brewer, B. (2017) Relationship among sport helplessness, depression, and social supports with teammates among American student-athletes. *Journal of Physical Education and Sports, 17*(2), 753-757.

07. **Iwatsuki, T.**, Takahashi, M., & Van Raalte, J. (2016). Effects of the intention to hit a disguised backhand drop shot on skilled tennis performance. *International Journal of Sport Science & Coaching, 11*(3), 365-373.

06. **Iwatsuki, T.** & Wright, P. (2016). Relationship among movement reinvestment, decision-making reinvestment, and perceived choking under pressure. *International Journal of Coaching Sciences, 10*(1), 25-35.

05. **Iwatsuki, T.**, Van Raalte, J., Brewer, B., Petipas, A., & Takahashi, M. (2016). Psychological factors related to choking under pressure. *International Tennis Federation Coaching and Sport Science Review, 68*, 11-12.

04. **Iwatsuki, T.** & Takahashi, M. (2014). Movement analysis of tennis backhand drop shot: Compare with backhand slice. *Japanese Journal of Tennis Science, 22,* 11-22.

Peer-Reviewed Publications (Continued)

03. **Iwatsuki, T.** & Takahashi, M. (2012). Game analysis between world-class tennis players on first services on different court surfaces: The case of Roger Federer versus Rafael Nadal. *Japanese Journal of Tennis Science, 20,* 1-12.

02. **Iwatsuki, T.**, Takahashi, M., & Watanabe, S. (2011). The game analysis focused on first services of world-class men's players. *Journal of Physical Education, Health and Sport Science, 45,* 19-26.

01. Takahashi, M., Mizukami, H., Suzuki, O., Sato, S., Kondo, K., & **Iwatsuki, T.** (2009). Relationships between bone mineral densities measured by an ultrasound bone densitometer and physical fitness and lifestyle in collegiate freshmen. *Journal of Physical Education, Health and Sport Science, 44,* 1-14.

Articles in Preparation

02. Chua, L., **Iwatsuki, T.**, Abdollahipour, Z., & Wulf, G. (In preparation). Random practices promote external focus and enhance motor learning.

01. **Iwatsuki, T.**, Bodell, N., & Navalta, J. (In preparation). The effects of changing power pose and powerless pose on motor performance.

Presentations and Invited Talks

Conference Presentations

23. **Iwatsuki, T.**, Wulf. G., & Navalta, W. J. (2017). *Autonomy enhances movement efficiency*. Poster will be presented at the North American Society for the Psychology of Sport and Physical Activity, Denver, CO.

22. **Iwatsuki, T.**, Chua, L., Abdollahipour, R., & Wulf. G. (2017). *Random relative to blocked practice promotes an external focus and leads to more effective motor learning*. Poster presented at the Association for Applied Sport Psychology, Orlando, FL.

21. **Iwatsuki, T.**, Abdollahipour, Z., Rudolf, P., Lewthwaite, L., & Wulf. G. (2017). *Autonomy facilitates repeated maximum force productions*. Lecture presented at the North American Society for the Psychology of Sport and Physical Activity, San Diego, CA.

20. **Iwatsuki, T.** (2017). *Does autonomy support enhance movement efficiency?* Lecture presented at the Northwest Regional Association for Applied Sport Psychology, Springfield, MA.

19. **Iwatsuki, T.**, & Wulf. G. (2016). *Giving learners task-relevant or task-irrelevant choices enhances motor skill learning*. Lecture presented at the Association for Applied Sport Psychology, Phoenix, AZ.

18. **Iwatsuki, T.**, & Wulf. G. (2016). *Does random practice promote a more effective focus of attention than blocked practice?* Poster presented at the North American Society for the Psychology of Sport and Physical Activity, Montreal, Canada.

Conference Presentations (Continued)

17. Wulf. G., Machin, B., Kellogg, J., Copeland, C., Lethwaite., & **Iwatsuki, T.** (2016). *Lassoing positive affect and motor learning through choice*. Poster presented at the North American Society for the Psychology of Sport and Physical Activity, Montreal, Canada.

16. Van Dyke, E., Van Raalte, J., Vincent, A., Johnson, A., Caldwell, C., **Iwatsuki, T.**, Shu, J., Maaranen-Hincks, A., & Brewer, B. (2015). *The Effects of Interrogative and Declarative Self-Talk on Performance: Replication and Extension*. Poster presented at the 14th European Federation of Sport Psychology, Bern, Switzerland.

15. **Iwatsuki, T.**, Van Raalte, J., Brewer, B., & Petipas, A. (2014). *Choking under pressure in tennis: Relationship among reinvestment, self-regulation, and perceived choking.* Lecture presented at the Association for Applied Sport Psychology, Las Vegas, NV.

14. **Iwatsuki, T.**, Van Raalte, J., Brewer, B., & Petipas, A. (2014). *Psychological factors related to choking under pressure in tennis.* Lecture presented at the Asian-South Pacific Association of Sport Psychology, Tokyo, Japan.

13. **Iwatsuki, T.**, Wright P., & Van Raalte, J. (2014). *Relationships among perceived choking, movement reinvestment, and decision reinvestment in collegiate athletes.* Poster presented at the North American Society for the Psychology of Sport and Physical Activity, Minneapolis, MN.

12. **Iwatsuki, T.**, Takahashi, M., Kato, F., & Tanaka, Y. (2011). *Disguised drop shot in tennis.* Poster presented at the Japan Society on Tennis Science, Tokyo, Japan.

11. Tanaka, T., Takahashi, T., Sato, M., Shibukura, Y., Mizuno, T., & **Iwatsuki, T.** (2011). *The time between points in tennis matches: The case of Roger Federer versus Nikola Davydenko.* Poster presented at the Japan Society on Tennis Science, Tokyo, Japan.

10. **Iwatsuki, T.**, Suzuki, T., Mizuochi, F., & Kondo, K. (2010). *Control of exercise intensity using lactate curve as an indicator in summer training of cross-country skiers*. Poster presented at the International Congress on Science and Skiing, Innsbruck, Austria.

09. Suzuki, T., Mizuochi, F., Iwasaki, K., Takeda, M., Fujita, Z., Kondo, K. **Iwatsuki, T.**, & Sato, S. (2010). *Sport science support for cross-country skiing to the 21th Olympic Winter Game Vancouver 2010.* Poster presented at the International Congress on Science and Skiing, Innsbruck, Austria.

08. **Iwatsuki, T.**, & Takahashi, M. (2010). *The effect on tennis performance of intention to complete an unanticipatable drop shot.* Lecture presented at Nihon University, Department of Physical Education, Tokyo, Japan.

07. **Iwatsuki, T.**, Takahashi, M., & Yoshimoto, T. (2010). *Three dimensional analysis of drop shot in terms of backhand stroke in tennis.* Poster presented at the Japan Society of Physical Education, Health and Sport Science, Aichi, Japan.

06. **Iwatsuki, T.**, Takahashi, M., Mizuochi, F., Suzuki, T., Sato, H., & Kondo, K. (2009). *Game analysis between World-Class tennis players on first services on different court surfaces.* Poster presented at the Japan Society on Tennis Science, Okinawa, Japan.

Conference Presentations (Continued)

05. Takahashi, M., Mizuochi, F., Suzuki, T., Tanaka, T., & **Iwatsuki, T.** (2009). The effect of self-talk on tennis performance. Poster presented at the Japan Society on Tennis Science, Okinawa, Japan.

04. Suzuki. K., **Iwatsuki, T.**, & Mizuochi, F. (2009). *How college tennis athletes have committed to tennis*: Comparison between Japanese athletes and International athletes. Poster presented at the Japan Society on Tennis Science, Okinawa, Japan.

03. **Iwatsuki, T.**, Awano, H., Oginezawa, C., Shiroma, S., Nishimura, H., Mizuochi, F., & Takahashi, M. (2009). *The factors of stress for athletes living in dormitories.* Poster presented at the Japanese Psychological Association, Tokyo, Japan.

02. Mizuochi, F., Hashiguchi, Y., Ito, H., Suzuki, K., Igarashi, T., **Iwatsuki, T.**, Hirano, T., Fukami, M., & Kikuchi, F. (2009). *The effectiveness of image training and image recall ability of junior alpine skiers.* Poster presented at the Japanese Psychological Association, Tokyo, Japan.

01. **Iwatsuki, T.**, Takahashi, M., & Yoshimoto, T. (2009). *The game analysis focused on first services of World-Class men's tennis players.* Poster presented at the Japan Society of Physical Education Health and Sport Science, Hiroshima, Japan.

University Presentations

04. **Iwatsuki, T.** (2017). Random relative to blocked practice promotes an external focus and leads to more effective motor learning. Poster/Lecture presented at 20th Annual Graduate and Professional Student Research Forum, UNLV
    - 1st Prize in the Science and Health Section, and received *$200* scholarship.

03. **Iwatsuki, T.** (2016). Learning through choices? Giving a choice as a form of autonomy support. Lectures presented at Graduate College Rebel Grad Slam: 3-Minutes Thesis Competition.
    - **Advanced to the final round (9 presenters)** from the semi-final (27 presenters) and preliminary round (around 100 presenters), and received *$200* scholarship.
    - https://www.youtube.com/watch?v=PqK9Y7nYGdI&index=30&list=PLVXuVREd6LLimqDJ8xHqN3qdsGFR2qhoq (Video available)

02. **Iwatsuki, T.**, & Wulf. G. (2016). Giving learners choices enhances motor skill learning. Paper presented at the 9th annual Interdisciplinary Research Day.

01. **Iwatsuki, T.** (2015). Why do we succeed or fail under pressure situations? Lectures presented at Graduate College Rebel Grad Slam: 3-Minutes Thesis Competition.
    - Advanced to the semi-final round (27 presenters out of a total of 80+ presenters) from the first round, and received *$100* research scholarship.
    - https://www.youtube.com/watch?v=Q_jckdGOQXc (Video available)

Invited Talks at College/University

Nihon University: Invited to Sport Psychology class. Two lectures on motor learning, sport psychology and study abroad to 100+ undergraduate students. Dec 2017

UNLV, Kinesiology Club: Lectured on the field of Kinesiology and types of research assistant work to 40+ undergraduate students. Oct 2017

Invited Talks at College/University (Continued)

UNLV, Graduate & Professional Student Association: 3-Minute Thesis Competition: Student Panel. How to give a successful presentation and experiences from last year as the finalist presenter. Sep 2017

Osaka University of Physical Education, Osaka, Japan: Lectured on *"The Present and Future of Sport and Exercise Psychology in the United States"* to 70+ including faculty, graduate and mostly undergraduate students. Jan 2017

Osaka University of Physical Education: Lectured on *"Autonomy Facilitates Motor Learning and Performance"* to 20+ including faculty members and graduate students. Jan 2017

Palacký University, Olomouc, the Czech Republic: Lectured on "*Motor Performance and Learning Through Autonomy Support"* to 20+ including faculty and graduate students. May 2016

UNLV, Kinesiology Club: Lectured on presentation skills and job interview preparation to 20+ undergraduate students. Apr 2016

Nihon University: Invited to a Sport Psychology class. Lectured on sport psychology, motor learning and studying abroad to 200+ undergraduate students. Dec 2012

Grants and Funding

External Grants and Proposals (Funded $7,385)

Southwest Travel Award

Travel Grant for the Association for Applied Sport Psychology, Springfield, MA, 2017
https://www.unlv.edu/news-story/spring-17-southwest-student-travel-awards-takehiro-iwatsuki

Erasmus+ Mobility Research Grant

Research Grant for conducting series of studies and helping research projects at Palacký University, Olomouc, Czech Republic, 2016 ($4,185, equivalent to US dollars)

International Tennis Federation (ITF) Coaching

Research Grant, called, "*Psychological actors related to choking under pressure: A cross-cultural comparison of American and Japanese Division I College Tennis Players*", 2014 ($2,000)

Japan Society on Tennis Science

Young Researcher Grant "*Disguised backhand drop shot movement on skilled tennis performance*", 2010 ($600, equivalent to US dollars)

Internal Grants and Proposals (Funded $74,313)

Dept. of Kinesiology, Penn State Altoona

New Faculty Start-up Funds ($60,000)

Summer Doctoral Research Fellowship, UNLV

Research Grant for conducting studies during summer 2017 ($7,000)

Graduate & Professional Student Association, UNLV

Travel Grant for the Association for Applied Sport Psychology, Orlando, FL, 2017 ($1,225)

Internal Grants and Proposals (continued)

Graduate & Professional Student Association, UNLV
Travel Grant for the North American Society for the Psychology of Sport and Physical Activity, San Diego, CA, 2017 ($590)

Dept. of Kinesiology and Nutrition Sciences, UNLV
Travel Grant for the Association for Applied Sport Psychology, Springfield, MA, 2017 ($575)

Graduate & Professional Student Association, UNLV
Travel Grant for the Association for Applied Sport Psychology, Phoenix, AZ, 2016 ($600)

International Program, UNLV
Research Grant for conducting studies at Palacky University, Olomouc, the Czech Republic, 2016 ($1,100)

Graduate & Professional Student Association, UNLV
Travel Grant for the North American Society for the Psychology of Sport and Physical Activity, Montreal, Canada, 2016 ($1,000)

Dept. of Kinesiology and Nutrition Sciences, UNLV
Travel Grant for the North American Society for the Psychology of Sport and Physical Activity, Montreal, Canada, 2016 ($800)

Leadership & Coaching Experience

Head Men's and Women's Tennis Coach, Springfield College (NCAA Division III) 2014 - 2015

- Bio: http://www.springfieldcollegepride.com/sports/mten/coaches/Iwatsuki_Hiro?view=bio
- Women's team made it to the New England Division Championship Tournament.
- Prepared and implemented practice/competition related activities.
- Recruited students including two individuals from Japan and multiple students from the States.
- Managed *$10,000* budget and fundraised *$5,000* for a spring training trip in Orlando, Florida.
- Organized the spring training trip including logging location of the tournament sites, team activities, transportation, and visiting a sport facility.
- Initiated monthly team blog and regular Facebook activities to promote to the public.
- Supervised students academically, including a meeting every semester and earned men's and women's team average GPA of 3.56, aside from coaching throughout the season.

Assistant Men's Tennis Coach, Springfield College 2012 - 2014

- Prepared and implemented practice/competition related activities.
- Used a front-rush and other websites to recruit students.
- Provided campus tour to prospective students and their family.

Tennis Instructor, United States Air Force Academy, Colorado Springs, CO June 2014, 2015

Tennis/Camp Counselor, KentMont & KenWood Camps, Kent, CT June-August 2013, 2012

Counseling Experience & Consulting Services

Certified Consultant of the *Association for Applied Sport Psychology* In Progress
Completed 300 hours and remained 100 hours to be a *Certified Mental Performance Consultant.*

Athletic Counselor, Springfield College 2012 - 2014
6 teams: Baseball, Football, Soccer (W), Tennis (W), and Track & Field (M, W)

Athletic Counselor, Harvard University, Cambridge, MA 2012 - 2013
1 team: Tennis (W)

Workshop Facilitator, Mount Holyoke College 2012 - 2013
1 team: Soccer (W)

Media Recognition (Selected)

The Springfield College men's and women's tennis programs and myself featured in Tennis Magazine, the top-rated tennis publication in Japan Dec 2014
http://springfieldcollegepride.com/sports/mten/2014-15/releases/201412171f6yz7 (Article available)

Interviewed as head coach regarding Springfield College women's tennis success Oct 2014
https://www.youtube.com/watch?v=D0aXawDXKbc (Video available)

Interviewed as new head men's and women's tennis coach at Springfield College Sep 2014
http://scstudentmedia.com/2014/09/18/takehiro-iwatsuki-takes-over-as-springfield-colleges-tennis-coach/
(Article available)

Chosen as the student of the month for bi-weekly Springfield College Newspaper Nov 2013
https://scstudentmedia.com/2013/11/21/springfield-colleges-own-hiro/ (Article available)

Professional Memberships and Services

Current Professional Memberships

North American Society for the Psychology of Sport and Physical Activity (NASPSPA) 2014 - Present

Association for Applied Sport Psychology (AASP) 2013 - Present

Services in Professional Organizations

Conference Assistant Staff, NASPSPA Conference, Montreal, Canada 2016

Student Representative Nominations Committee, NASPSPA 2015

Reviewerships

Journal of Sports Sciences 2017 - Present

The Sport Psychologist 2016 - Present

Asian South-Pacific Association of Sport Psychology Conference 2013

Honors, Awards, & Scholarships

Academics (Selected)

1st Place, Graduate and Professional Student Research Forum, UNLV Feb 2018

Teaching Fellowship, Dept. of Kinesiology and Nutrition Sciences, UNLV 2017 - 2008

Finalist Presenter, 3-Minutes Thesis Competition, UNLV Oct 2016

Top Tier Graduate Research Assistant, GPSA, UNLV 2015 - 2017

Distinguished Graduate Student Award, Springfield College May 2014
Contributions in the areas of academic performance, research, leadership, and service to humanity, annually to only one graduate student from the School of Arts, Sciences and Professional Studies.

Graduate Assistant, Dept. of Physical Education, Springfield College 2012 - 2014