Int. J. Sport Psychol., 2021; 52: 159-171
doi: 10.7352/IJSP.2021.52.159

Autonomy support facilitates team motor learning

SUZETE CHIVIACOWSKY, LUIZA BORGES MARTINS, PRISCILA CARDOZO

Federal University of Pelotas, Brazil

The present study was designed to examine the effects of practice with autonomy support over a team strategy on pairs of participants collaboratively sharing the learning of a sequential motor task. Twenty-eight 10-year-old children practiced a speed-cup-stacking task. In the autonomy-support (Choice group) condition, each pair of participants could choose which participant would perform the first (up-stacking) or the second (down-stacking) phase of the task before each block of practice. In the control (Control group) condition, the order of participants within each pair was yoked to the order of a counterpart pair from the Choice group. The movement times to jointly perform each trial were measured using a stopwatch. One day after practice, participants performed retention and transfer tests. The results showed better learning for the Choice group, with less time needed to complete the task during the retention and transfer tests relative to the Control group. These findings are in line with previous studies showing that the benefits of autonomy support on learning at an individual level extend to team motor learning.

KEY WORDS: Children, Choice, Motivation, Team learning.

Introduction

Autonomy has been linked with enhanced performance and learning in several domains (Cordova & Lepper, 1996; Hackman & Oldham, 1976; Markant, DuBrow, Davachi, & Gureckis, 2014; Murty, DuBrow, & Davachi, 2015; Tafarodi, Milne, & Smith, 1999). Self-Determination Theory (SDT) refers to autonomy as the need to be the agent or to be in control of one's actions instead of feeling controlled or pressured (Deci & Ryan, 2000; 2008). Together with competence and relatedness, autonomy is a fundamental psychological need; it is a psychological nutrient essential for individuals' adjust-

Correspondence to: Suzete Chiviacowsky, Escola Superior de Educação Física, Universidade Federal de Pelotas Rua Luís de Camões, 625 - CEP 96055-630. *Pelotas - RS, Brazil (e-mail: suzete@ufpel.edu.br)*

ment, integrity, and growth (Ryan & Deci, 2017). The present study investigates the effect of providing choice in a motor learning setting to contribute to understanding the role of autonomy support in learning.

The effects on motor learning of providing some kind of autonomy support during practice have received increased attention from researchers in different contexts and populations. Such experiments have included choices over delivery of feedback (e.g., Chiviacowsky, 2014; Chiviacowsky & Wulf, 2002; 2005; Grand, Bruzi, Dyke, Godwin, Leiker, Thompson, Buchanan, & Miller, 2015; Janelle, Barba, Frehlich, Tennant, & Cauraugh, 1997; Ste-Marie, Vertes, Law, & Rymal, 2013; for a recent review see Chiviacowsky, 2020), movement demonstrations (Bund & Wiemeyer, 2004; Lemos, Wulf, Lewthwaite, & Chiviacowsky, 2017; Wulf, Raupach, & Pfeiffer, 2005), use of assistive devices (Chiviacowsky, Wulf, Lewthwaite, & Campos, 2012; Hartman, 2007; Wulf & Toole, 1999), number of practice trials (Lessa & Chiviacowsky, 2017; Post, Fairbrother, & Barros, 2011; Post, Fairbrother, Barros, & Kulpa, 2014), and even choices over aspects not directly relevant to the task (Lewthwaite, Chiviacowsky, Drews, & Wulf, 2015; Wulf, Lewthwaite, Cardozo, Chiviacowsky, 2017; Wulf, Iwatsuki, Machin, Kellogg, Copeland, & Lewthwaite, 2018).

Other recent studies have shown that autonomy support enhances not only movement effectiveness, but also movement efficiency (e.g., Iwatsuki, Abdollahipour, Psotta, Lewthwaite, & Wulf, 2017; Iwatsuki, Navalta, & Wulf, 2019; Iwatsuki, Shih, Abdollahipour, & Wulf, 2019). Such practice conditions satisfying learners' individual need for autonomy have consistently been found to result in more effective learning relative to control conditions in which participants were not allowed to choose. In view of its robust impact in motor learning, autonomy is considered a key motivational factor in the OPTIMAL theory of motor learning (Wulf & Lewthwaite, 2016).

An important aspect of the cited research is that it involves learning mainly at an individual level, with participants usually practicing the task alone. In fact, very few studies to date have observed the effects of autonomy support in motor learning contexts other than the individual (e.g., Karlinsky, & Hodges, 2014; McRae, Patterson, & Hansen, 2015; van Maarseveen, Oudejans, & Savelsbergh, 2018; Wulf, Clauss, Shea, & Whitacre, 2001). One such experiment evaluated the effects of self-controlled practice in dyads (Wulf et al., 2001). Pairs of participants practiced a ski simulator task in a turn-taking form of paired practice, alternating practice and rest while observing each other's performances. While the first participant was able to choose whether to use the pole before each trial, the second participant of the pair had to use the pole yoked to the first, and was not able to choose.

The results confirmed enhanced learning of the task for the participants allowed to choose when to use the ski poles relative to participants not allowed to choose. In other research, the benefits of self-controlled video feedback were observed in highly talented youth teams training in soccer tactical skills, with three attackers playing against two defenders and a goalkeeper, compared with a yoked group (van Maarseveen et al., 2018). The findings showed that players in the self-control group spoke more and showed more initiative compared with the yoked group, suggesting a more active involvement of the players during the learning process.

To date, however, it remains unclear whether autonomy support could benefit motor learning in participants collaboratively sharing the learning of a motor task as a team, a common sight in physical education and sports settings. While scholars have acknowledged the importance of motivation in such practice contexts (e.g., Chow, Davids, Button, & Renshaw, 2015; Filho, 2020; Hastie, Rudisill, & Wadsworth, 2013; Van der Kamp, Duivenvoorden, Kok, & van Hilvoorde, 2015; Ntoumanis, 2001; Van den Berghe, Vansteenkiste, Cardon, Kirk, & Haerens, 2014; Weiss, 2020), there is still a dearth of motor learning research into the effects of motivational factors - including autonomy support - on joint or coordinated learning.

The objective of the present experiment was, therefore, to observe pairs of participants sharing the learning of a sequential motor task, and comparing a group having autonomy over a specific strategy (order of participants) with a group in which the order of each pair of participants was externally controlled. Specifically, 10-year-old children were asked to practice a two-phase sequential motor task as a team. In the choice condition, each pair of participants was given the opportunity to choose, before each block of trials, which participant would perform the first and the second phase of the task, while in the control group, the order of the participants in each block was controlled by the experimenter. In this case, the change in the order of participants after the first block was yoked to a counterpart pair of the choice group. Learning was measured by assessment of time to complete the task on delayed retention and transfer tests. Given the important functions of autonomy support for motor learning (Ryan & Deci, 2017; Wulf & Lewthwaite, 2016), that differences in the practice context make it difficult to generalize the findings of experiments at an individual learning level to team level, and the lack of studies investigating autonomy support in team motor learning, it was considered important to conduct the current research. The results might have important implications for the practical settings of teams, if the expected learning advantages of choices over a team strategy were confirmed. We hypothesized that the choice condition would result in enhanced team learning of the sequential motor task, observed through retention and transfer tests, compared with the control condition.

Methods

Participants

Twenty-eight children (20 boys, 8 girls), with an average age of 10.60 years (*SD* = 0.77) and without mental or physical disabilities, participated in the study. Participants were recruited from a southern Brazilian city. All participants were naive as to the purpose of the experiment and none had previous experience with the task. The study was approved by the university's institutional review board, the children gave their assent, and informed consent was obtained from the childrens' parents or guardians.

Apparatus And Task

The participants were invited to learn the speed-cup-stacking task (as in Granados & Wulf, 2007), in which 12 cups initially positioned as towers must be transformed into pyramids and then back to towers. The cups have three small holes in the top to allow air to escape quickly during movement. Initially stacked upside down inside each other, the cups were positioned on a rectangular (120 × 80 cm) table at the beginning of each trial, between each pair of participants, with one three-cup tower on the left, one six-cup tower in the middle, and one three-cup tower on the right. The task consisted of two phases: "up-stacking" and "down-stacking", with each participant in a pair being responsible for one phase, using both hands to perform the complete 3 × 6 × 3 cup-stacking task. The first participant was responsible for building a three-cup pyramid on the left, a six-cup pyramid in the middle, and a three-cup pyramid on the right. Following the "up-stacking" phase, the second participant began the "down-stacking" phase, which consisted of dismantling the three pyramids and placing the cups in the original arrangement, with three towers positioned as they were at the beginning of the task. Each pair of participants was instructed to always perform both stacking phases from left to right during practice and retention. If any error occurred while performing the task, the participant was required to correct the errors and continue until the cups were placed in the appropriate arrangements. For the transfer phase, the first participant of the pair was asked to build only one pyramid using 10 cups, with four, three, two, and one cup, respectively, at the four different levels. The 10 cups were also positioned in front of the participants, forming only one 10-cup tower. The second participant of the pair was asked to disassemble the pyramid, forming only one tower with the cups stacked one inside the other as in the initial arrangement. The time taken to perform each trial of the task ("up-stacking" and "down-stacking" phases) was measured using a stopwatch.

Procedure

Each participant was randomly assigned to the choice or control group, and also to a partner, with an equal number of participants in each group, matched according to sex. Each group was composed of seven pairs of participants. The experiment took place in a private room with the presence of one pair of participants and the experimenter. Data collection took around 20 min each day. Participants received general instructions regarding the task, observed one video demonstration of the cup up-stacking and down-stacking movements, and were asked to perform the task as quickly as possible as a team. One participant of the pair performed the "up-stacking" phase, while the other performed the "down-stacking" phase. Participants were also informed that they would be tested the next day as a team, and that the amount of time taken to perform the "up-stacking" and "down-stacking" phases would be considered for each trial. Participants from the choice group also received the instruction that they would be able to choose, before each block of 10 trials, which participant of the pair would begin by performing the "up-stacking" phase, while the other would perform the "down-stacking" phase. Participants from the control group were informed that the experimenter would choose which participant of the pair would specifically perform the "up-stacking" and "down-stacking" phases before each block of practice. In this case, alphabetical order was used as a way to randomly determine which participant of the pair, unbeknownst by him or her, would begin performing the "up-stacking" phase in the first block. In the next blocks, changes in the order of participants were yoked to the changes in the choice group, that is, each pair of control participants had to follow the choices of a pair of participants from the choice group. For example, if a pair of participants in the choice group changed the order in the second block and again in the third block of practice, the yoked pair in the control group also changed the order in the second and third blocks. All teams of participants received feedback after each trial of practice, consisting of the time taken to perform the "up-stacking" and "down-stacking" phases. The practice phase consisted of 30 trials (i.e., 3 blocks of 10). As a previous study with the same task showed that 10-second inter-trial intervals with dialogue versus no dialogue did not affect motor learning (Granados & Wulf, 2007), we used the same inter-trial interval and allowed dialogue for both groups. Retention and transfer tests, each consisting of 10 trials, were performed one day later, without feedback or choices over team strategy. For both groups, the order of participants in the retention and transfer tests was also determined randomly using alphabetical order.

Data analysis

Task times (the time taken to perform the "up-stacking" and "down-stacking" phases of each trial) were averaged across blocks of 10 trials and analyzed using a standard between-dyads design with undistinguishable dyad members, organized with participant as unit of analysis (Kenny, Kashy, & Cook, 2006). The practice data were analyzed in a 2 (groups) × 3 (blocks of trials) analysis of variance (ANOVA), with repeated measures on the last factor. Retention and transfer tests data were analyzed using one-way ANOVA to assess the differential effects of choice on team learning. Alpha was set at .05 for all analyses. SPSS software version 22 was used to analyze the data.

Results

Number Of Order Changes

All participants in the choice group had 3 chances to choose which participant of the team would begin performing the "up-stacking" phase and which would perform the "down-stacking" phase during practice, before each of the 3 blocks of trials. From the seven pairs of participants in the choice group, three pairs changed the initial order on the second and third blocks, two pairs changed on the second block only, and two pairs changed the initial chosen order only in the last block. Each pair of the control group was yoked regarding the choices of their counterpart pair from the choice group.

Task time

Descriptive statistics. While similar in the first block of practice (choice: M = 17.435, SD = 2.475; control: M = 17.359, SD = 1.627), task times in the second (choice: M = 14.861, SD = 2.228; control: M = 16.795, SD = 2.728), and third (choice: M = 13.230, SD = 1.948; control: M = 15.273, SD = 2.232) practice blocks were shorter for the choice group than for the control group. Shorter task time results were also observed in retention (choice: M = 12.491, SD = 1.985; control: M = 13.735, SD = 0.777) and transfer (choice: M = 13.978, SD = 1.988; control: M = 16.621, SD = 2.655) tests for the choice relative to the control group.

Differences in performance during practice. The groups reduced their task times across blocks of practice, with the choice group showing shorter task times than the control group. The main effects of block, F (2, 52) = 33.768, $p < .001$, $\eta_p^2 = .565$, and interaction of block and group, F (2, 52) = 4.857, $p = .012$, $\eta_p^2 = .157$, were significant, while the main effect of group, F (1, 26) = 2.951, $p = .098$, $\eta_p^2 = .102$, was not significant (Figure 1).

Differences in performance during retention. On the retention test, choice participants also showed shorter task times than the control group. The main effect of group was significant, F (1, 26) = 4.429, $p = .045$, $\eta_p^2 = .146$ (Figure 1).

Differences in performance during transfer. Choice participants outperformed the control group on the transfer test. The main effect of group was significant, F (1, 26) = 8.246, $p = .008$, $\eta_p^2 = .241$ (Figure 1).

Discussion

The goal of the present experiment was to examine whether the learning advantages of autonomy support at an individual level of practice would also be observed under team practice conditions. The findings demonstrate that providing learners with choice over a team strategy – order of participants –

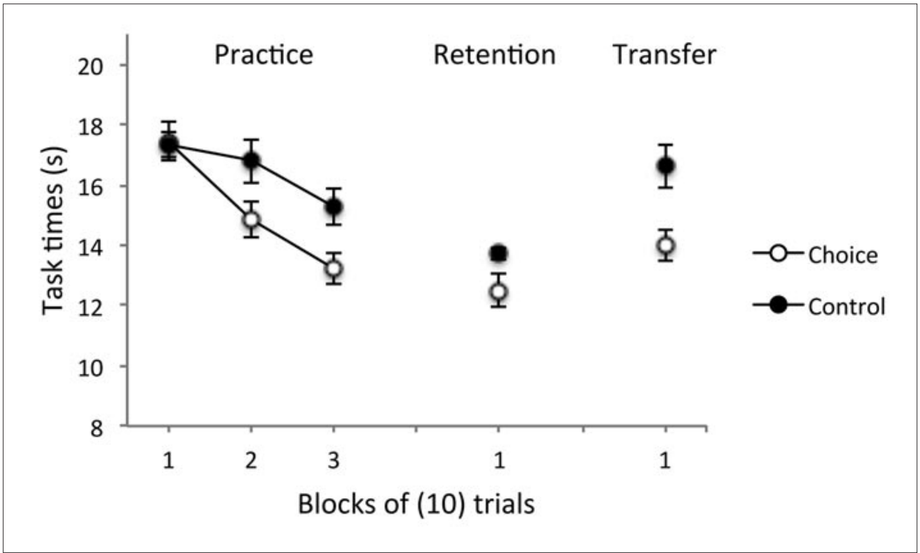

Fig. 1. - Team task times (s) of the choice and control groups in practice, retention, and transfer. Error bars indicate standard errors.

enhanced the learning of a sequential motor task relative to not allowing them to choose; the choice group needed less time to complete the task during the retention and transfer tests relative to the control group. The results are in line with previous studies showing that autonomy support benefits the acquisition of motor skills in individuals practicing alone (Chiviacowsky & Lessa, 2017; Chiviacowsky & Wulf, 2002; Grand et al., 2015; Janelle et al., 1997; Lemos et al., 2017; Lewthwaite et al., 2015; Post et al., 2014; Wulf et al., 2017) or turn-taking practice and rest in dyads (e.g., Wulf et al., 2001), and extend those findings by providing evidence of such benefits on team motor learning. They are also in line with the OPTIMAL theory (Wulf & Lewthwaite, 2016), which proposes that practice conditions promoting an external focus of attention, enhancing performance expectancies, and providing autonomy support during practice can facilitate motor learning by contributing to the fluidity with which movement plans are translated into action; that is, goal-action coupling.

Being able to choose during practice is considered to benefit motor learning through distinct routes. Autonomy, as well as competence and relatedness needs, is considered essential to developing and maintaining intrinsic motivation (Ryan & Deci, 2017). When autonomy is satisfied, one experiences a sense of integrity, a perception that one's actions, thoughts, and feelings are self-endorsed and authentic, thus increasing and maintaining motivation. Conversely, a sense of pressure and threatening experiences, such as feeling pushed in an unwanted direction, is experienced when autonomy is frustrated, thus decreasing motivation (Vansteenkiste, Ryan, & Soenens, 2020).

Multiple neural structures and processes mediate the complex cognitive, affective, and behavioral phenomenon of intrinsic motivation (Di Domenico & Ryan, 2017). Autonomy can increase neuroaffective reactions (Legault & Inzlicht, 2013) and promote a general sense of respect for participants' agency or capabilities, which has been shown to boost perceived competence/self-efficacy and learning in the academic (Tafarodi et al., 1999; Cordova & Lepper, 1996) and motor (Chiviacowsky, 2014) domain. It can also enhance attention to performance errors, positively impacting motivation and motor learning while providing the opportunity to confirm successful performance (Chiviacowsky, Wulf, & Lewthwaite, 2012; Grand et al., 2015; Kim, Kim, Kim, Kwon, Lee, & Park, 2019). Increased brain activity related to reward processing is observed when opportunities for choice are available, confirming the existence of an inherent reward with the exercise of control (Leotti & Delgado, 2011). Rewards can, in turn, activate dopaminergic responses (Hosp & Luft, 2013; Leotti, Iyvengar, & Ochsner, 2010; Schultz, 2013), observed to contribute to the encoding of new motor memories when present during practice (Floel, et al., 2008; Kawashima, Ueki, Kato, Matsukawa, Mima, Hallett, & Ojika, 2012). Dopamine can affect voluntary action through different pathways (Aarts, Bijleveld, Custers, Dogge, Deelder, Schutter, & van Haren, 2012; Ashby, & Isen, Turken, 1999; Di Domenico, & Ryan, 2017; Dreisbach, & Goschke, 2004; Ridderinkhof, van Wouwe, Band, Wylie, Van der Stigchel, van Hees, Buitenweg, et al., 2012), playing an important role in modulating not only motivational, but cognitive control, facilitating working memory (Ashby et al., 1999; Bolte, Goschke, & Kuhl, 2003; Green & Noice, 1988). It is implicated in the "stamping-in" of memories that brings motivational importance to otherwise neutral environmental stimuli (Wise, 2004).

In fact, choice itself, even when provided over task-irrelevant information, is sufficient to enhance motivation, positive affect, motor performance and learning (Chua, Wulf & Lewthwaite, 2018; Wulf, Chiviacowsky, & Cardozo, 2014; Wulf, Chiviacowsky, & Drews, 2015; Wulf et al., 2018). Individuals with Parkinson's disease given autonomy support over the use of a balance physical aid showed increased motivation, less nervousness, and enhanced motor learning (Chiviacowsky et al., 2012). Children choosing when to observe a ballet video demonstration and young adults choosing the order of golf practice devices showed enhanced positive affect and thoughts, confidence, self-efficacy, and motor learning (An, Lewthwaite, Lee, & Wulf; 2020; Lemos et al., 2017). Similar findings were found when more autonomous instead of more controlled type of language during instructions was used in adults (Hooyman, Wulf, & Lewthwaite, 2014).

In conclusion, our findings are the first evidence that providing autonomy support during practice can facilitate shared collaborative motor learning. Team of participants allowed choice over a strategy before each block of practice demonstrated enhanced learning of a speed-cup-stacking sequential task, relative to teams not allowed choice. Instructors may take advantage of these effects by providing choices over strategies during practice in teams, to support participants' need for autonomy, benefiting motor learning. Such contexts could include institutional settings such as physical education lessons or training at sports clubs, where motor skill learning is usually taught in groups.

The present study was limited to observing the impact of practice with autonomy support in the form of choice over a simple team strategy (order of participants) on pairs of children collaboratively sharing the learning of a sequential motor task, using participant as the unit of analysis. Future studies could include larger sample sizes and investigate not only dyad as the unit of analysis, but also the impact of each individual's performance on the performance of other team members as well as on team choice strategies. The use of questionnaires (e.g., collective efficacy) could also provide further insights on the effects of choices on team motor learning. It may also be important to evaluate the generalization of the present results to different populations, types of tasks, and different types of choices, as well as to other learning situations that represent the substantial variety of what constitutes team motor learning.

REFERENCES

Aarts, H., Bijleveld, E., Custers, R., Dogge, M., Deelder, M., Schutter, D., & van Haren, N. E. (2012). Positive priming and intentional binding: Eye-blink rate predicts reward information effects on the sense of agency. *Social Neuroscience*, *7*, 105-112.

An, J., Lewthwaite, R., Lee, S., & Wulf, G. (2020). Choice of practice-task order enhances golf skill learning. *Psychology of Sport and Exercise*, 101737.

Ashby, F. G., & Isen, A. M., Turken, U. (1999). A neuropsychological theory of positive affect and its influence on cognition. *Psychological Review*, *106*, 529-550.

Bolte, A., Goschke, T., & Kuhl, J. (2003). Emotion and intuition: Effects of positive and negative mood on implicit judgments of semantic coherence. *Psychological Science*, *14*, 416-421.

Bund, A., & Wiemeyer, J. (2004). Self-controlled learning of a complex motor skill: Effects of the learners' preferences on performance and self-efficacy. *Journal of Human Movement Studies*, *47*, 215-236.

Chiviacowsky, S. (2020). The motivational role of feedback in motor learning: Evidence, interpretations, and implications. In: M. Bertollo, E. Filho, & P. C. Terry (Eds.). *Advancements in Mental Skills Training*. (London: Routledge), 44-56.

Chiviacowsky, S. (2014). Self-controlled practice: Autonomy protects perceptions of competence and enhances motor learning. *Psychology of Sport and Exercise*, *15*, 505-510. doi: 10.1016/j.psychsport.2014.05.003

Chiviacowsky, S., & Lessa, H. T. (2017). Choices over feedback enhance motor learning in older adults. *Journal of Motor Learning and Development*, *5*, 304-318.

Chiviacowsky, S., & Wulf, G. (2002). Self-controlled feedback: Does it enhance learning because performers get feedback when they need it? *Research Quarterly for Exercise and Sport, 73,* 408-415.

Chiviacowsky, S., & Wulf, G. (2005). Self-controlled feedback is effective if it is based on the learner's performance. *Research Quarterly for Exercise and Sport*, *76*, 42-48.

Chiviacowsky, S., Wulf, G., Lewthwaite, R., & Campos, T. (2012). Motor learning benefits of self-controlled practice in persons with Parkinson's disease. *Gait & Posture, 35,* 601-605.

Chiviacowsky, S., Wulf, G., & Lewthwaite, R. (2012). Self-controlled learning: the importance of protecting perceptions of competence. *Frontiers in Psychology*, *3*, 458.

Chow, J. Y., Davids, K., Button, C., & Renshaw, I. (2015). *Nonlinear pedagogy in skill acquisition: An introduction*. Routledge.

Chua, L. K., Wulf, G., & Lewthwaite, R. (2018). Onward and upward: Optimizing motor performance. *Human Movement Science*, *60*, 107-114.

Cordova, D. I., & Lepper, M. R. (1996). Intrinsic motivation and the process of learning: Beneficial effects of contextualization, personalization, and choice. *Journal of Educational Psychology, 88*, 715-730.

Deci, E. L., & Ryan, R. M. (2000). The "what" and "why" of goal pursuits: Human needs and the self-determination of behavior. *Psychological Inquiry, 11*, 227-268

Deci, E. L., & Ryan, R. M. (2008). Self-Determination Theory: A macrotheory of human motivation, development, and health. *Canadian Psychology, 49,* 182-185.

Di Domenico, S. I., & Ryan, R. M. (2017). The emerging neuroscience of intrinsic motivation: A new frontier in self-determination research. *Frontiers in Human Neuroscience*, *11*, 145. doi: 10.3389/fnhum.2017.00145

Dreisbach, G., & Goschke, T. (2004). How positive affect modulates cognitive control: Reduced perseveration at the cost of increased distractibility. *Journal of Experimental Psychology-Learning Memory and Cognition*, *30*, 343-352.

Filho, E. (2020). Team dynamics theory: Implications for the development of high-performing teams. In: M. Bertollo, E. Filho, & P. C. Terry (Eds.). *Advancements in Mental Skills Training*. (London: Routledge), 83-93. https://doi.org/10.4324/9780429025112

Floel, A., Garraux, G., Xua, B., Breitenstein, C., Knecht, S., Herscovitch, P., et al. (2008). Levodopa increases memory encoding and dopamine release in the striatum in the elderly. *Neurobiology of Aging, 29,* 267-279.

Granados, C., & Wulf, G. (2007). Enhancing motor learning through dyad practice: contributions of observation and dialogue. *Research Quarterly for Exercise and Sport*, *78*, 197-203.

Grand, K. F., Bruzi, A. T., Dyke, F. B., Godwin, M. M., Leiker, A. M., Thompson, A. G., Buchanan, T. L., & Miller, M. W. (2015). Why self-controlled feedback enhances motor learning: Answers from electroencephalography and indices of motivation. *Human Movement Sciences, 43,* 23-32.

Greene, T. R., & Noice, H. (1988). Influence of positive affect upon creative thinking and problem solving in children. *Psychological Reports*, *63*, 895-898.

Hackman, J. R., & Oldham, G. R. (1976). Motivation through the design of work: Test of a theory. *Organizational Behavior and Human Performance, 16,* 250-279.

Hartman, J. M. (2007). Self-controlled use of a perceived physical assistance device during a balancing task. *Perceptual and Motor Skills, 104*, 1005-1016.

Hastie, P. A., Rudisill, M. E., & Wadsworth, D. D. (2013). Providing students with voice and choice: lessons from intervention research on autonomy-supportive climates in physical education. *Sport, Education and Society*, *18*, 38-56.

Hooyman, A., Wulf, G., & Lewthwaite, R. (2014). Impacts of autonomy-supportive versus controlling instructional language on motor learning. *Human Movement Science*, *36*, 190-198.

Hosp, J. A., & Luft, A. R. (2013). Dopaminergic meso-cortical projections to M1: role in motor learning and motor cortex plasticity. *Frontiers in Neurology*, *4*, 145.

Iwatsuki, T., Abdollahipour, R., Psotta, R., Lewthwaite, R., & Wulf, G. (2017). Autonomy facilitates repeated maximum force productions. *Human Movement Science*, *55*, 264-268.

Iwatsuki, T., Navalta, J. W., & Wulf, G. (2019). Autonomy enhances running efficiency. *Journal of Sports Sciences*, *37*, 685-691.

Iwatsuki, T., Shih, H.-T., Abdollahipour, R., & Wulf, G. (2019). More bang for the buck: Autonomy support increases muscular efficiency. *Psychological Research, 37*, 685-691.

Janelle, C.M., Barba, D. A., Frehlich, S. G., Tennant, L. K., & Cauraugh, J. H. (1997). Maximizing performance effectiveness through videotape replay and a self-controlled learning environment. *Research Quarterly for Exercise and Sport, 68*, 269-279.

Karlinsky, A., & Hodges, N. J. (2014). Evaluating the effectiveness of peer-scheduled practice on motor learning. *Journal of Motor Learning and Development*, *2*, 63-68.

Kawashima, S., Ueki, Y., Kato, T., Matsukawa, N., Mima, T., Hallett, M., ... & Ojika, K. (2012). Changes in striatal dopamine release associated with human motor-skill acquisition. *PloS one*, *7,* 2, e31728.

Kenny, D. A., Kashy, D. A., & Cook, W. L. (2006). *Dyadic data analysis*. Guilford press.

Kim, Y., Kim, J., Kim, H., Kwon, M., Lee, M., & Park, S. (2019). Neural mechanism underlying self-controlled feedback on motor skill learning. *Human Movement Science*, *66*, 198-208.

Legault, L., & Inzlicht, M. (2013). Self-determination, self-regulation, and the brain: Autonomy improves performance by enhancing neuroaffective responsiveness to self-regulation failure. *Journal of Personality and Social Psychology*, *105*, 123.

Lemos, A., Wulf, G., Lewthwaite, R., & Chiviacowsky, S. (2017). Autonomy support enhances performance expectancies, positive affect, and motor learning. *Psychology of Sport and Exercise*, *31*, 28-34.

Leotti, L. A., & Delgado, M. R. (2011). The inherent reward of choice. *Psychological Science, 22*, 1310-1308.

Leotti, L. A., Iyvengar, S. S., & Ochsner, K. N. (2010). Born to choose: The origins and value of the need for control. *Trends in Cognitive Science, 14*, 457-463.

Lessa, H. T., & Chiviacowsky, S. (2015). Self-controlled practice benefits motor learning in older adults. *Human Movement Science*, *40*, 372-380.

Lewthwaite, R., Chiviacowsky, S., Drews, R., & Wulf,G. (2015). Choose to move: The motivational impact of autonomy support on motor learning. *Psychonomic Bulletin & Review, 22*, 1383-1388.

Markant, D., DuBrow, S., Davachi, L., & Gureckis, T. M. (2014). Deconstructing the effect of self-directed study on episodic memory. *Memory & Cognition*, *42*, 1211-1224.

McRae, M., Patterson, J. T., & Hansen, S. (2015). Examining the preferred self-controlled KR schedules of learners and peers during motor skill learning. *Journal of Motor Behavior*, *47*, 527-534.

Murty, V. P., DuBrow, S., & Davachi, L. (2015). The simple act of choosing influences declarative memory. *The Journal of Neuroscience*, *35*, 6255-6264.

Ntoumanis, N. (2001). A self determination approach to the understanding of motivation in physical education. *British Journal of Educational Psychology*, *71*, 225-242.

Post, P. G., Fairbrother, J. T., & Barros, J. A. (2011). Self-controlled amount of practice benefits learning of a motor skill. *Research Quarterly for Exercise and Sport*, *82*, 474-481.

Post, P. G., Fairbrother, J. T., Barros, J. A., & Kulpa, J. D. (2014). Self-controlled practice within a fixed time period facilitates the learning of a basketball set shot. *Journal of Motor Learning and Development, 2,* 9-15.

Ridderinkhof, K. R., vanWouwe N. C., Band, G. P., Wylie, S.A., Van der Stigchel, S., van Hees, P., & van den Wildenberg, W. P. (2012). A tribute to Charlie Chaplin: Induced positive affect improves reward-based decision-learning in Parkinson's disease. *Frontiers in Psychology, 3* (Article 185). doi: 10.3389/fpsyg.2012.00185

Ryan, R. M., & Deci, E. L. (2017). *Self-determination theory: Basic psychological needs in motivation, development, and wellness*. New York: Guilford Publishing.

Schultz, W. (2013). Updating dopamine reward signals. *Current Opinion in Neurobiology*, *23*, 229-238.

Ste-Marie, D. M., Vertes, K. A., Law, B., & Rymal, A. M. (2013). Learner-controlled self-observation is advantageous for motor skill acquisition. *Frontiers in Psychology*, *3*, 556.

Tafarodi, R. W., Milne, A. B., & Smith, A. J. (1999). The confidence of choice: Evidence for an augmentation effect on self-perceived performance. *Personality and Social Psychology Bulletin, 25,* 1405-1416.

Van den Berghe, L., Vansteenkiste, M., Cardon, G., Kirk, D., & Haerens, L. (2014). Research on self-determination in physical education: Key findings and proposals for future research. *Physical Education and Sport Pedagogy*, *19*, 97-121.

Van der Kamp, J., Duivenvoorden, J., Kok, M., & van Hilvoorde, I. (2015). Motor skill learning in groups: Some proposals for applying implicit learning and self-controlled feedback. *Revista Internacional de Ciencias del Deporte*, *11*, 33-47.

Van Maarseveen, M. J., Oudejans, R. R., & Savelsbergh, G. J. (2018). Self-controlled video feedback on tactical skills for soccer teams results in more active involvement of players. *Human Movement Science*, *57*, 194-204.

Vansteenkiste, M., Ryan, R. M., & Soenens, B. (2020). Basic psychological need theory: Advancements, critical themes, and future directions. *Motivation and Emotion, 44*, 1-31.

Weiss, M. R. (2020). Motor Skill Development and Youth Physical Activity: A Social Psychological Perspective. *Journal of Motor Learning and Development*, 1-30. https://doi.org/10.1123/jmld.2020-0009

Wise, R. A. (2004). Dopamine, learning and motivation. *Nature Reviews Neuroscience, 5*, 1-12.

Wulf, G., Chiviacowsky, S., & Cardozo, P. (2014). Additive benefits of autonomy support and enhanced expectancies for motor learning. *Human Movement Science, 37,* 12–20.

Wulf, G., Chiviacowsky, S., & Drews, R. (2015). External focus and autonomy support: Two important factors in motor learning have additive benefits. *Human Movement Science, 40*, 176-184.

Wulf, G., Clauss, A., Shea, C. H., & Whitacre, C. A. (2001). Benefits of self-control in dyad practice. *Research Quarterly for Exercise and Sport*, *72*, 299-303.

Wulf, G., Iwatsuki, T., Machin, B., Kellogg, J., Copeland, C., & Lewthwaite, R. (2018). Lassoing skill through learner choice. *Journal of Motor Behavior*, *50*, 285-292.

Wulf, G., & Lewthwaite, R. (2016). Optimizing performance through intrinsic motivation and attention for learning: The OPTIMAL theory of motor learning. *Psychonomic Bulletin & Review, 23,* 1382-1414.

Wulf, G., Lewthwaite, R., Cardozo, P., & Chiviacowsky, S. (2017). Triple play: Additive contributions of enhanced expectancies, autonomy support, and external attentional focus to motor learning. *The Quarterly Journal of Experimental Psychology*, 1-9.

Wulf, G., Raupach, M., & Pfeiffer, F. (2005). Self-controlled observational practice enhances learning. *Research Quarterly for Exercise and Sport, 76*, 107-111.

Wulf, G., & Toole, T. (1999). Physical assistance devices in complex motor skill learning: Benefits of a self-controlled practice schedule. *Research Quarterly for Exercise and Sport, 70*, 265-272.

Manuscript submitted March 2019. Accepted for publication July 2020.