Journal of Physical Education and Sport ® (JPES), Vol 19 (Supplement issue 3), Art 124, pp 859 - 866, 2019
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Relatedness affects eye blink rate and movement form learning

SUZETE CHIVIACOWSKY[1], NATÁLIA HARTER[2], FABRICIO DEL VECCHIO[3], REZA ABDOLLAHIPOUR[4]

[1,2,3,]Federal University of Pelotas, BRAZIL
[4]Palacky University of Olomouc, CZECH REPUBLIC

Published online:May 31, 2019
(Accepted for publication March 30, 2019)
DOI:10.7752/jpes.2019.s3124

Abstract

Relatedness represents the need to experience satisfaction regarding interpersonal acceptance and closeness and has been identified as a fundamental psychological human need. In several different domains, higher relatedness to others such as parents, teachers, peers, or coaches has been directly correlated with higher levels of positive affect and intrinsic motivation, with both factors being associated with increased dopamine activity. In the present experiment, we tested the effects of social relatedness on the learning of a gymnastic skill and observed eye blink rate (EBR), considered associated with dopamine activity. Two groups of young adults practiced a task in which they were required to learn a specific movement form of a gymnastic skill. Before practice, participants in the relatedness support condition (RS group) received instructions emphasizing acknowledgment, caring, and interest in the participants' experiences, while participants in the relatedness thwart condition (RTh group) received instructions emphasizing disinterest in the participant as a person. EBR was measured while the participants observed a 1-min demonstration video before and during practice. One day after practice, participants completed a retention test. The results demonstrate higher EBR during practice and enhanced movement form of the gymnastic skill in the retention test in the RS group relative to the RTh group. The findings show that relatedness affects gymnastic skill learning and reveal dopamine as a potential underlying mediator of relatedness effects.
Key words: Psychological needs; motivation; dopamine; gymnastic.

Introduction

The motivational perspective of innate human psychological needs for relatedness, competence, and autonomy, from Self Determination Theory (Deci & Ryan, 2000, 2008), has been acknowledged as providing a useful framework for recent motor learning research (for reviews, see Lewthwaite & Wulf, 2012; Sanli, Patterson, Bray, & Lee, 2013). Relatedness represents the need to experience satisfaction regarding interpersonal acceptance and closeness, competence refers to the need to feel oneself as capable of skillfully mastering challenges in one's environment, and autonomy implies the need to control or to be the agent of one's action (Ryan, 1995). These three needs are considered as necessary conditions for human psychological growth, integrity and well-being, and the suppression of any one is considered harmful to an individual (Deci & Ryan, 2000).

While the positive effects on motor learning of providing learners with autonomy (Aiken, Fairbrother, & Post, 2012; Andrieux, Danna, & Thon, 2012; Chiviacowsky, 2014; Chiviacowsky, & Lessa, 2017; Chiviacowsky & Wulf, 2002; Janelle, Barba, Frehlich, Tennant, & Cauraugh, 1997; Laughlin, Fairbrother, Wrisberg, Alami, Fisher, & Huck, 2015; Ste-Marie, Vertes, Law, & Rymal, 2013; Wulf, Raupach, & Pfeiffer, 2005) and competence support (Abbas & North, 2017; Chiviacowsky & Wulf, 2007; Chiviacowsky & Harter, 2015; Gonçalves, Cardozo, Valentini, & Chiviacowsky, 2018; Saemi, Porter, Varzaneh, Zarghami, & Maleki, 2012; Stoate, Wulf & Lewthwaite, 2012) have been extensively demonstrated, to date only one experiment (Gonzalez & Chiviacowsky, 2018) has observed the effects of social relatedness on the acquisition of motor skills. In that study, young adults provided with relatedness support during practice showed enhanced learning of a swimming task compared with participants in whom social relatedness was not acknowledged.

The verified impact of learner relatedness on motor learning is in line with previous experiments from several theoretical different perspectives, where the need for relatedness has been described. Such studies suggest that the extent and quality of social relationships have a critical impact on several psychological and physical health aspects. Higher relatedness to others such as parents, teachers, peers, or coaches has been directly correlated with higher levels of positive affect and intrinsic motivation (Ryan, Stiller, & Lynch, 1994; Sheldon & Filak, 2008), perceived competence and well-being (Wilson & Bengoechea, 2010), enjoyment (Mueller,

Corresponding Author: SUZETE CHIVIACOWSKY, E-mail: suzete@ufpel.edu.br

Georges, & Vaslow, 2007), and engagement (Furrer & Skinner, 2003; Slater & Tiggemann, 2010; Williams, Whipp, Jackson, & Dimmock, 2013). Considering the important role of relatedness for human psychological growth and well-being (Deci & Ryan, 2000) and the dearth of studies looking at relatedness in motor learning, the objective of the present experiment was to verify whether the effects found on the learning of a swimming task (Gonzalez & Chiviacowsky, 2018) would extend to other types of tasks and measures, as, for example, the learning of a movement form from gymnastic skills.

We also considered it important to further examine the underlying mechanisms of the effects of social relatedness on motor learning. Gonzalez and Chiviacowsky (2018) showed that participants provided with relatedness support during practice reported higher positive affect and motivational experiences relative to conditions not supporting the need. Positive affect has been strongly associated with dopamine release, possibly affecting voluntary action through different dopamine pathways (Aarts, Bijleveld, Custers, Dogge, Deelder, Schutter, & van Haren, 2012; Ashby, & Isen, Turken, 1999; Dreisbach, & Goschke, 2004; Ridderinkhof, van Wouwe, Band, Wylie, Van der Stigchel, van Hees, Buitenweg, et al., 2012). Dopamine is central to the way we value our world; its' action define rewards (our goals or desires) that should be sought, playing a central role in guiding our behavior, choices, and thoughts (Montague, Hyman, & Cohen, 2004). Dopamine is considered important for social relevant associations (Aragona, Liu, Curtis, Stephan, & Wang, 2003; Gingrich, Liu, Cascio, Wang, & Insel, 2000), and also implicated in the "stamping-in" of memories that brings motivational importance to otherwise neutral environmental stimuli (Wise, 2004). It plays a crucial role in motivational control, supporting brain networks for seeking, evaluation, and value learning, and in choosing actions to gain the "good" things and avoid the "bad" things (Bromberg-Martin, Matsumoto, & Hikosaka, 2010). Considered to contribute to the optimization of reward-seeking behaviors, dopamine acts by mediating learning signals that allow the system to expect, or better predict, when rewards are likely to occur (Montague, Dayan, & Sejnowski, 1996; Montague et al., 2004). It also plays an important role in modulating cognitive control, facilitating working memory, and improving tasks requiring cognitive flexibility (Ashby et al., 1999; Bolte, Goschke, & Kuhl, 2003; Green & Noice, 1988). Furthermore, dopamine has been observed to contribute to the encoding of new motor memories when present during practice (Floel, et al., 2008; Kawashima et al., 2012). As such, there is a strong possibility that dopamine is involved in the mechanisms responsible for the observed effects of relatedness on motor learning.

Different methods and conditions have been used to measure dopamine activity, some based on expensive neuroimaging techniques such as positron emission tomography (PET). Eye blink rate (EBR), however, is a simpler, neurobehavioral non-invasive measure that is considered an effective marker of central dopaminergic function (Bodfish, Powell, Golden, & Lewis, 1995; Karson, 1983; Dreisbach, Müller, Goschke, Strobel, Schulze, Lesch, & Brocke, 2005; Jongkees & Colzato, 2016; Zhang, Mou, Wang, Tan, Jiang, Lijun, & Li, 2015). Dopamine acts by modulating input to and excitability of the spinal trigeminal complex, which plays a direct role in the spontaneous blink generator circuit, resulting in increased spontaneous blinking (Kaminer Thakur, & Evinger, 2015; Kaminer, Powers, Horn, Hui, & Evinger, 2011). EBR is considered to predict hypo- and hyper-dopaminergic activity, and the normalization of this activity following treatment; it can also predict individual differences in performance in many cognitive tasks, particularly those related to reward-driven behavior and cognitive flexibility (Jongkees & Colzato, 2016). Reduced and increased dopamine activity is directly associated with low and high EBR, respectively (Groman, James, Seu, Tran, Clark, Harpster, et al., 2014; Karson, 1983; 1992). The decrease in blink rate in Parkinson' Disease, a condition characterized by progressive severe loss of dopaminergic neurons in the striatum (Dauer and Przedborski, 2003), is considered a classical example of EBR and dopamine association (Fitzpatrick, Hohl, Silburn, O'Gorman, & Broadley, 2012). While there is variability in the way EBR is measured, one of the most frequently used methods is direct observation and counting by a researcher (Jongkees & Colzato, 2016).

In the present experiment, two groups of participants practiced a gymnastics sport skill. In addition to movement form demonstrations, the groups received instructions emphasizing interest, acknowledgement, and caring in the participants' experiences (relatedness support group), or instructions emphasizing disinterest in the participant as a person (relatedness thwart group). The relatedness support condition was hypothesized to result in higher EBR during practice, and enhanced learning of the skill movement form, relative to the relatedness thwart condition.

Methods

Participants

Twenty-five university students (11 females, 14 males) with an average age of 22.7 years (*SD* = 2.8) participated in this study. The participants had no previous experience with the task and were not aware of the aim of the study. The university's institutional review board approved the experiment and informed consent was obtained from the participants.

Apparatus and task

Participants were required to perform a vertical jump with a half turn, involving crossing the hands in front of the chest during the turn while airborne (Figure 1). The task was introduced as a basic gymnastics skill that should be performed with a perfect technique, as any fault (e.g., body alignment, feet and knee position, landing) could result in a deduction. The initial position of the task was standing, feet together, arms extended downward, with straight body and head alignment. The experiment was carried out in the lab on a flat surface, and a video camera was used to record all the jumps. The camera was mounted onto a tripod that was placed at a distance of 3 m to the left side of the participant. The video recordings were later used for assessing the movement technique (form) by raters. In addition, a laptop placed on a table was used to show a 1-min video of an expert gymnast performing the task.

Procedure

The participants were randomly assigned to two groups, a relatedness support (RS) group and a relatedness thwart (RTh) group, and the experiment was conducted over 2 days. At the beginning of the experiment, a verbal description of the task was presented to the participants by the experimenter. Four important features of the skill were highlighted: 1) standing on the floor in the position of both feet together, arms extended and pointing downward, and body straight and head upright; 2) take-off with both feet, extending the whole body vertically, and jumping as high as possible; 3) turning 180° with arms crossing in front of the chest while airborne; and 4) landing with both feet together, in perfect alignment and without any extra steps. Then, an expert gymnast demonstrated the task two times in both sagittal and frontal plans.

After the experimenter demonstration, participants were asked to sit on a chair located 0.5 m in front of a table and watch a 1-min video of an expert gymnast performing the task. The 1-min video involved a demonstration of the task in the sagittal and frontal planes, twice at a normal speed, twice in slow motion, and twice again at a normal speed. An audio beep sound was set at the beginning and end of the video. Participants were asked to carefully watch the video and to not move their head. When the first video demonstration finished, participants were asked to perform two pre-test trials.

Relatedness instructions were given to participants after the pre-test trials. In the RS group, participants were given the following instructions: “Please perform the movement as much as possible similar to the video. One thing you need to know is that to me, everybody is unique. I care about each person as an individual, and I am trying to understand each person’s learning process. So, I hope you’ll share your experiences with me after we’re done’’. In the RTh group, participants received the following instructions: “Please perform the movement as much as possible similar to the video. One thing you need to know is that to us, everybody is the same. I am not really concerned about you as an individual; I only care about the data. So, please keep your observations to yourself during the process’’. All participants watched the video again and performed 25 trials, with a 10-s rest interval between each trial. A video demonstration was provided to participants before each block of 5 trials. A relatedness instruction reminder was provided to each group prior to the video demonstration of block four, during the practice phase. In the RS condition, the participants were informed: ‘‘Just to remind you: we care about you and your individual learning style. So, please be sure to remember what you were thinking and feeling, so we can discuss your reactions later’’. For participants in the RTh condition, the experimenter said: ‘‘Just to remind you: we’re not really interested in your reactions and individual learning style. So, please keep your questions and observations to yourself, as we go through the procedure’’. This manipulation was based on the procedures of relatedness support (versus relatedness thwart) of previous studies (Gonzalez & Chiviacowsky, 2018; Sheldon & Filak, 2008), following Deci and Ryan’s (2000) definition of conceptual psychological relatedness need.

Video demonstration was provided to participants before each block of 5 trials. EBR was evaluated by two separate observers for 1 min (as in Chen, Chiang, Hsu, & Liu, 2003) at baseline (prior to the relatedness manipulation) and during practice (after the relatedness instructions reminders), while the participants observed the demonstration video. Each observer was sitting on a chair located at a distance of 2 m from the participant and at an angle of 45 °. Given that EBR is considered to be stable during daytime, while increasing in the evening (Barbato, Ficca, Muscettola, Fichele, Beatrice, & Rinaldi, 2000), all data were collected between 8 am and 5 pm. Participants were not provided feedback on their performance at any phase of the experiment and were not aware that EBR was being assessed. A retention test composed of 5 trials was performed one day later, without any relatedness instructions or video observation, where participants of both groups were told: “We want to choose the best participant who can perform the task with perfect technique. Therefore, two experts will later rate your movement form during these specific trials”.

Data analysis

Movement form deductions were allocated for incorrect body alignment, uncontrolled foot position, legs/feet bent or apart, incomplete rotation, uncontrolled arm movements, incorrect landing, and extra steps. Deductions were categorized separately for each error as follows: small error, 0.1; medium error, 0.2; large error, 0.3; and/or fall/unacceptable error, 0.5 (for more details, see Abdollahipour, Wulf, Psotta, & Palomo Nieto, 2015). Two international gymnastics judges, with 17 and 15 years of experience judging in gymnastics, respectively, assessed the movement form of the pretest, practice, and transfer performance recorded in the videos, based on the general and specific rules of the International Federation of Gymnastics code of points (2009–2012) for aerobic gymnastics. The raters were not aware of the purpose of the study and did not have information on the differences between the experimental groups. The intra-class correlation (ICC) between raters was high (0.972, $p < 0.001$), and the average of the raters’ deductions for each trial was therefore used. The practice data were averaged across the blocks of five trials and analyzed in a 2 (groups) × 5 (blocks) analysis of variance (ANOVA) with repeated measures on the last factor. One-way ANOVA was used for the pre-test and transfer test. Two observers separately evaluated EBR, calculated as the number of blinks per minute. The average ICC measurement was high (0.980, $p < .001$), and the observers' averaged EBR scores were analyzed using one-way ANOVA. Partial eta-squared values were used for estimating the effect sizes (η_p^2), indicating 0.01, 0.06, and 0.14 for a small, moderate, or large effect, respectively (Cohen, 2013; Lakens, 2013). For all analysis, the alpha value was set at 0.05.

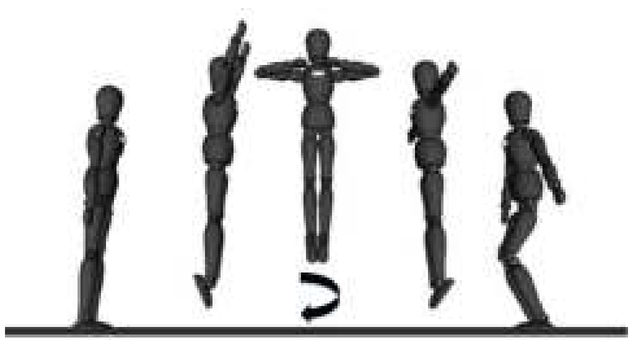

Figure 1. Schematic of the vertical jump with a half turn, involving crossing the hands in front of the chest during the turn while airborne.

Results

Movement form

In the pretest, execution deductions were not significantly different between the RS group and the RT group, F (1, 23) = .887, p = .356, η_p^2 = .037 (Figure 2).

In the practice phase, execution errors were not different between the groups (Figure 2). The main effect of group, F (1, 23) = .003, p = .956, η_p^2 = .000, and the interaction of group and block, F (4, 92) = .469, p = .758, η_p^2 = .020, were not significant. The groups improved performance during practice, and the main effect of block was significant, F (4, 92) = 9.531, p < .001, η_p^2 = .293. Post-hoc testing showed significant differences between block 1 and all the other blocks, block 2 relative to blocks 3 and 5, and block 4 relative to block 5. Other significant differences between practice blocks were not found.

In the retention test, participants in the RS group had smaller execution deductions than participants of the RTh group, F (1, 23) = 7.830, p = .010, η_p^2 = .254 (Figure 2).

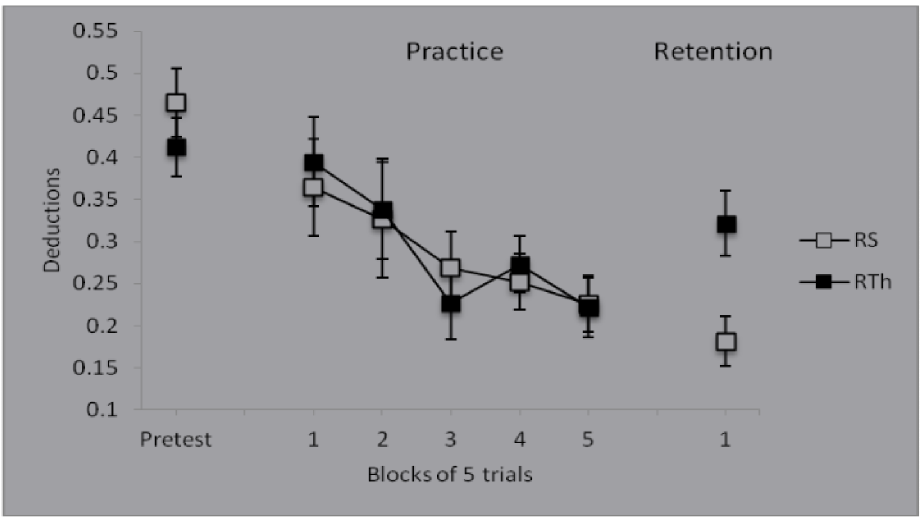

Figure 2. Execution deductions during pre-test, practice, and retention for the Relatedness Support (RS) and Relatedness Thwart (RTh) groups. Error bars indicate standard errors.

Eye blink rate

In the baseline measure, EBR was not significantly different between the RS and RTh groups, F (1, 23) = .000, p = .984, η_p^2 = .000 (Figure 3). During practice, however, the main effect of EBR was significant, F (1, 23) = 5.674, p = .026, η_p^2 = .198, with participants in the RS group showing a higher blink frequency relative to RTh participants.

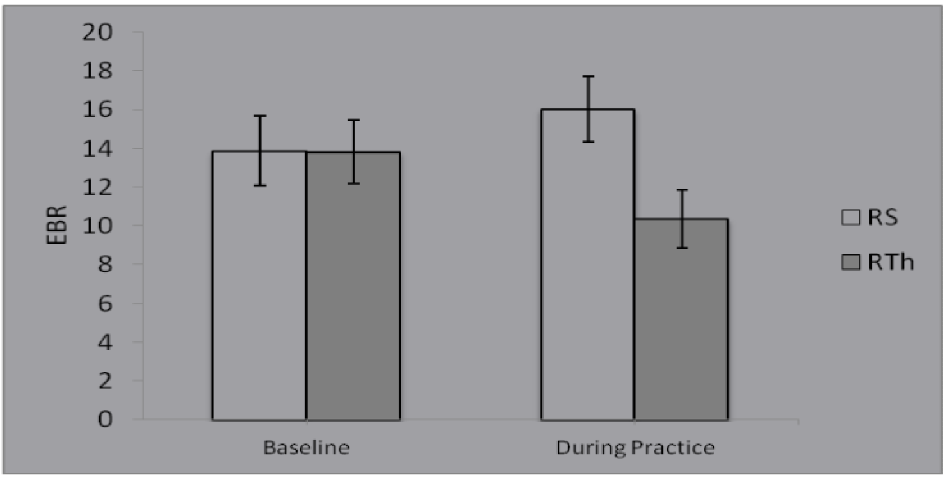

Figure 3. Eye blink rates (EBR) of the Relatedness Support (RS) and Relatedness Thwart (RTh) groups at baseline and during practice. Error bars indicate standard errors.

Discussion

The present experiment was designed to examine the effects of relatedness on the movement form learning of a gymnastic skill and to gain further insight into the underlying mechanisms of relatedness effects on motor learning. The results show that providing participants with instructions emphasizing acknowledgement and interest in their learning experiences led to higher EBR during practice and more effective movement form of the vertical jump with a half turn in the transfer test, relative to a condition where relatedness was not fully supported. The findings are in line with those of Gonzalez and Chiviacowsky (2018), extending the observed benefits of social relatedness to movement form learning of a specific sport skill. The results also support previous motor learning outcomes observed during practice supporting the learners' competence and autonomy needs (Chiviacowsky & Wulf, 2002, 2007; Chiviacowsky, Wulf, & Lewthwaite, 2012; Lewthwaite, Chiviacowsky, Drews, & Wulf, 2015; Patterson & Carter, 2010; Stevens, Anderson, O'Dwyer, & Williams, 2012; Stoate et al., 2012; Maarseveen, Oudejans, & Savelsbergh, 2018; Wulf, Chiviacowsky, & Cardozo, 2014).

EBR reflects dopaminergic activity (Aarts et al., 2012). The difference in EBR observed between groups during practice suggests that dopamine may play an important role in the effects of relatedness support on motor learning. Dopamine is well established as important for the motivation of actions and reinforcement learning (Wise, 2004). Playing different roles in motivational control, dopamine encodes motivational value, supporting brain networks for seeking, evaluation, and value learning; and motivational salience, supporting brain networks for orienting, cognition, and general motivation (Berridge & Robinson, 1998; Bromberg-Martin et al., 2010; Dalley, Lääne, Theobald, Armstrong, Corlett, Chudasama, & Robbins, 2005). Increased dopamine activity can also affect motivation by increasing the sense of agency over effects produced by determined behavior (Aarts et al., 2012). Dopamine is considered to influence synaptic plasticity as well, supporting reinforcement learning by adjusting the strength of synaptic connections between neurons (Goto, Yang, & Otani, 2010; Surmeier, Shen, Day, Gertler, Chan, Tian, & Plotkin, 2010). The background (tonic) dopamine level in the striatum is thought to be associated with motivational aspects that determine the vigor and effort expended in responding, while the phase (burst) dopamine release is considered to be related to the prediction errors driving reinforcement learning (Beeler, Daw, Frazier, & Zhuang, 2010; Niv, Daw, Joel, & Dayan, 2007; Salamone, Correa, Farrar, & Mingote, 2007; Treadway, Buckholtz, Cowan, Woodward, Li, Ansari et al., 2012).

In this study, providing learners with relatedness support during practice may therefore have optimized motivation control and promoted more effective neural connections, both mediated by dopamine activity, resulting in superior learning of the task relative to a condition thwarting the participants' relatedness need. Conditions associated with practice that enhance the learners' expectancies for positive outcomes, and perceived autonomy, have been suggested to trigger dopaminergic responses, benefiting motor performance and making dopamine available for memory consolidation and neural pathway development, thus optimizing motor learning (Wulf & Lewthwaite, 2016). Taken together, the findings of Gonzalez and Chiviacowsky (2018) and the present study show that improving learners' perceived relatedness during practice might act via such a system, supporting the view of an underlying mechanism based on dopamine activity affecting motor learning.

In conclusion, the present findings provide evidence that dopamine may play a role in the motor learning process. Specifically, our results demonstrate that social relatedness influences eye blink rate, associated with dopamine activity, with consequences on learning. Instructions emphasizing acknowledgement and interest with regards to the participants' experiences resulted in higher EBR and movement form learning of a gymnastic skill, relative to instructions emphasizing disinterest in the participant as a person.

Relatedness effects, to date, have been observed only in young adults learning a swimming speed task or the movement form of a specific gymnastic skill (Gonzalez & Chiviacowsky, 2018, present study). Considering the importance of the psychological needs for human integrity and well-being (Deci & Ryan, 2000, 2008), future studies could test whether the present relatedness findings can be generalized to the learning of motor skills in different populations, contexts, and types of tasks. Also, the present study was limited to the comparison of a unique eye observation of EBR during practice with EBR at baseline. Follow up studies could measure EBR more frequently or throughout the complete practice period. While direct observation and counting by a researcher is one of the most frequently used method for EBR measurement (Jongkees & Colzato, 2016), EBR could also be filmed or captured through the use of eye tracking instruments in future studies. Furthermore, while the present study was the first demonstrating that relatedness can affect movement form learning, it would be interesting to test whether a relatedness support condition emphasizing acknowledgment, caring, and interest in the participants' experiences would benefit movement form learning relative to a control condition without any form of relatedness instructions. Lastly, the use of neuroimaging techniques such as positron emission tomography (PET) could more directly determine whether dopamine activity is affected by practice conditions that manipulate relatedness or the other two psychological needs (autonomy and competence).

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.

Abbas, Z. A., & North, J. S. (2018). Good-vs. poor-trial feedback in motor learning: The role of self-efficacy and intrinsic motivation across levels of task difficulty. *Learning and Instruction, 55,* 105-112.

Abdollahipour, R., Wulf, G., Psotta, R., & Palomo Nieto, M. (2015). Performance of gymnastics skill benefits from an external focus of attention. *Journal of Sports Sciences*, *33*, 1807-1813.

Aiken, C. A., Fairbrother, J. T., & Post, P. G. (2012). The effects of self-controlled video feedback on the learning of the basketball set shot. *Frontiers in Psychology*, *3*.

Andriex, M., Danna J., & Thon, B. (2012). Self-control of task difficulty during training enhances motor learning of a complex coincident-anticipation task. *Research Quarterly for Exercise and Sport, 83*, 27-35.

Aragona, B. J., Liu, Y., Curtis, J. T., Stephan, F. K., & Wang, Z. (2003). A critical role for nucleus accumbens dopamine in partner-preference formation in male prairie voles. *Journal of Neuroscience*, *23*, 3483-3490.

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.

Barbato, G., Ficca, G., Muscettola, G., Fichele, M., Beatrice, M., Rinaldi, F., (2000). Diurnal variation in spontaneous eye-blink rate. *Psychiatry Research, 93,* 145–151.

Beeler, J. A., Daw, N., Frazier, C. R., & Zhuang, X. (2010). Tonic dopamine modulates exploitation of reward learning. *Frontiers in Behavioral Neuroscience*, *4*.

Berridge, K. C., & Robinson, T. E. (1998). What is the role of dopamine in reward: hedonic impact, reward learning, or incentive salience? *Brain Research Reviews*, *28*, 309-369.

Bodfish, J. W., Powell, S. B., Golden, R. N., & Lewis, M. H. (1995). Blink rate as an index of dopamine function in adults with mental retardation and repetitive behavior disorders. *American Journal on Mental Retardation, 99,* 335-344.

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.

Bromberg-Martin, E. S., Matsumoto, M., & Hikosaka, O. (2010). Dopamine in motivational control: rewarding, aversive, and alerting. *Neuron*, *68*, 815-834.

Chen, W. H., Chiang, T. J., Hsu, M. C., & Liu, J. S. (2003). The validity of eye blink rate in Chinese adults for the diagnosis of Parkinson's disease. *Clinical Neurology and Neurosurgery*, *105,* 2, 90-92.

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

Chiviacowsky, S., Harter, N. M. (2015). Perceptions of competence and motor learning: performance criterion resulting in low success experience degrades learning. *Brazilian Journal of Motor Behavior, 9,* 1, 1-10.

Chiviacowsky, S., & Lessa, H. T. (2017). Choices Over Feedback Enhance Motor Learning in Older Adults. *Journal of Motor Learning and Development*, 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. (2007). Feedback after good trials enhances learning. *Research Quarterly for Exercise and Sport, 78*, 40-47.

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

Cohen, J. (2013). *Statistical power analysis for the behavioral sciences*. London: Routledge Academic.

Dauer, W., & Przedborski, S. (2003). Parkinson's disease: mechanisms and models. *Neuron*, *39*, 889-909.

Dalley, J. W., Lääne, K., Theobald, D. E., Armstrong, H. C., Corlett, P. R., Chudasama, Y., & Robbins, T. W. (2005). Time-limited modulation of appetitive Pavlovian memory by D1 and NMDA receptors in the nucleus accumbens. *Proceedings of the National Academy of Sciences*, *102*, 6189-6194.

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.

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.

Dreisbach, G., Müller, J., Goschke, T., Strobel, A., Schulze, K., Lesch, K. P., & Brocke, B. (2005). Dopamine and cognitive control: the influence of spontaneous eyeblink rate and dopamine gene polymorphisms on perseveration and distractibility. *Behavioral Neuroscience*, *119*, 483-490.

Fitzpatrick, E., Hohl, N., Silburn, P., O'Gorman, C., & Broadley, S. A. (2012). Case–control study of blink rate in Parkinson's disease under different conditions. *Journal of Neurology*, *259*, 739-744.

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.

Furrer, C., Skinner, E. (2003). Sense of relatedness as a factor in children's academic engagement and performance. *Journal of Educational Psychology, 95*, 148-162.

Gingrich, B., Liu, Y., Cascio, C., Wang, Z., & Insel, T. R. (2000). Dopamine D2 receptors in the nucleus accumbens are important for social attachment in female prairie voles (Microtus ochrogaster). *Behavioral Neuroscience*, *114,* 173-183.

Gonçalves, G. S., Cardozo, P. L., Valentini, N. C., & Chiviacowsky, S. (2018). Enhancing performance expectancies through positive comparative feedback facilitates the learning of basketball free throw in children. *Psychology of Sport and Exercise*, *36*, 174-177.

Gonzalez, D. H., & Chiviacowsky, S. (2018). Relatedness support enhances motor learning. *Psychological Research*, *82*, 439-447.

Goto, Y., Yang, C.R., and Otani, S. (2010). Functional and dysfunctional synaptic plasticity in prefrontal cortex: Roles in psychiatric disorders. *Biological Psychiatry, 67*, 199–207.

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

Groman, S. M., James, A. S., Seu, E., Tran, S., Clark, T. A., Harpster, S. N., ... & Elsworth, J. D. (2014). In the blink of an eye: relating positive-feedback sensitivity to striatal dopamine D2-like receptors through blink rate. *Journal of Neuroscience*, *34*, 14443-14454.

Jongkees, B. J., & Colzato, L. S. (2016). Spontaneous eye blink rate as predictor of dopamine-related cognitive function—A review. *Neuroscience & Biobehavioral Reviews*, *71*, 58-82.

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.

Kaminer, J., Powers, A. S., Horn, K. G., Hui, C., & Evinger, C. (2011). Characterizing the spontaneous blink generator: an animal model. *Journal of Neuroscience*, *31*, 11256-11267.

Kaminer, J., Thakur, P., & Evinger, C. (2015). Effects of subthalamic deep brain stimulation on blink abnormalities of 6-OHDA lesioned rats. *Journal of neurophysiology*, *113*, 3038-3046.

Karson, C. N. (1983). Spontaneous eye-blink rates and dopaminergic systems. *Brain*, *106*(3), 643-653.

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.

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for *t*-tests and ANOVAs. *Frontiers in Psychology, 4,* 863, 1-12.

Larson-Hall J. (2009). A guide to doing statistics in second language research using SPSS: Routledge.

Laughlin, D. D., Fairbrother, J. T., Wrisberg, C. A., Alami, A., Fisher, L. A., & Huck, S. W. (2015). Self-control behaviors during the learning of a cascade juggling task. *Human Movement Science*, *41*, 9-19.

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.

Lewthwaite, R., & Wulf, G. (2012). Motor learning through a motivational lens. In N.J. Hodges & A.M. Williams (Eds.), *Skill acquisition in sport: Research, theory & practice* (2nd ed.) (p. 173-191). London: Routledge.

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.

McKay, B., Wulf, G., Lewthwaite, R., & Nordin, A. (2015). The self: Your own worst enemy? A test of the self-invoking trigger hypothesis. *The Quarterly Journal of Experimental Psychology*, *68*, 1910-1919.
Montague, P. R., Dayan, P., & Sejnowski, T. J. (1996). A framework for mesencephalic dopamine systems based on predictive Hebbian learning. *Journal of Neuroscience*, *16*, 1936-1947.
Montague, P. R., Hyman, S. E., & Cohen, J. D. (2004). Computational roles for dopamine in behavioural control. *Nature*, *431*, 760-767.
Mueller, D., Georges, A., & Vaslow, D. (2007). Cooperative learning as applied to resident instruction in radiology reporting. *Academic Radiology, 14*, 1577- 1583.
Niv, Y., Daw, N. D., Joel, D., & Dayan, P. (2007). Tonic dopamine: opportunity costs and the control of response vigor. *Psychopharmacology*, *191*, 507-520.
Patterson, J. T., & Carter, M. (2010). Learner regulated knowledge of results during the acquisition of multiple timing goals. *Human Movement Science,* 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,* 185.
Ryan, R. M. (1995). Psychological needs and the facilitation of integrative processes. *Journal of Personality, 63*, 397–427.
Ryan, R. M., Stiller, J. D., & Lynch, J. H. (1994). Representations of relationships to teachers, parents, and friends as predictors of academic motivation and self-esteem. *The Journal of Early Adolescence*, *14*, 226-249.
Saemi, E., Porter, J. M., Varzaneh, A. G., Zarghami, M., & Maleki, F. (2012). Knowledge of results after relatively good trials enhances self-efficacy and motor learning. *Psychology of Sport and Exercise, 13,* 378 - 382.
Salamone, J. D., Correa, M., Farrar, A., & Mingote, S. M. (2007). Effort-related functions of nucleus accumbens dopamine and associated forebrain circuits. *Psychopharmacology*, *191*, 461-482.
Sanli, E. A., Patterson, J. T., Bray, S. R., & Lee, T. D. (2013). Understanding self-controlled motor learning protocols through the self-determination theory. *Frontiers in Psychology*, *3*, 611.
Sheldon, K. M., and Filak, V. (2008). Manipulating autonomy, competence, and relatedness support in a game-learning context: new evidence that all three needs matter. *British Journal of Social Psychology*, 47, 267-228.
Slater, A., & Tiggemann, M. (2010). "Uncool to do sport": A focus group study of adolescent girls' reasons for withdrawing from physical activity. *Psychology of Sport and Exercise*, *11*, 619-626.
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.
Stevens, D., Anderson, D. I., O'Dwyer, N. J., & Williams, A. M. (2012). Does self-efficacy mediate transfer effects in the learning of easy and difficult motor skills? *Consciousness and Cognition, 21,* 1122–1128.
Stoate, I., Wulf, G., & Lewthwaite, R. (2012). Enhanced expectancies improve movement efficiency in runners. *Journal of Sports Sciences*, *30*, 815-823.
Surmeier, D. J., Shen, W., Day, M., Gertler, T., Chan, S., Tian, X., & Plotkin, J. L. (2010). The role of dopamine in modulating the structure and function of striatal circuits. *Progress in brain research*, *183*, 148-167.
Treadway, M. T., Buckholtz, J. W., Cowan, R. L., Woodward, N. D., Li, R., Ansari, M. S., ... & Zald, D. H. (2012). Dopaminergic mechanisms of individual differences in human effort-based decision-making. *Journal of Neuroscience*, *32*, 6170-6176.
Williams, N., Whipp, P. R., Jackson, B., & Dimmock, J. A. (2013). Relatedness support and the retention of young female golfers. *Journal of Applied Sport Psychology*, *25*, 412-430.
Wilson, P. M., & Bengoechea, E. G. (2010). The relatedness to others in physical activity scale: evidence for structural and criterion validity. *Journal of Applied Biobehavioral Research*, *15*, 61-87.
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., & Lewthwaite, R. (2016). Optimizing Performance through Intrinsic Motivation and Attention for Learning: The OPTIMAL theory of motor learning. *Psychonomic Bulletin & Review,* doi: 10.3758/s13423-015-0999-9
Wulf, G., Raupach, M., & Pfeiffer, F. (2005). Self-controlled observational practice enhances learning. *Research Quarterly for Exercise and Sport, 76*, 107-111.
Zhang, T., Mou, D., Wang, C., Tan, F., Jiang, Y., Lijun, Z., & Li, H. (2015). Dopamine and executive function: Increased spontaneous eye blink rates correlate with better set-shifting and inhibition, but poorer updating. *International Journal of Psychophysiology*, *96*, 155-161.