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Choices Over Feedback Enhance Motor Learning in Older Adults

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Granting learners autonomy over certain aspects of the practice context—for example, by providing them with the opportunity to choose when to receive augmented feedback or observe a model—has been consistently shown to facilitate the acquisition of motor skills in several populations. However, studies investigating the provision of autonomy support to older adults remain scarce. The purpose of the present experiment was to investigate the effects of providing choice over feedback on motor learning in older adults. Participants were divided into two groups, choice and no-choice, and practiced 36 trials of a linear positioning task. Before each block of six trials, participants from the choice group were given the choice to control, or not, when to receive feedback in the block. No-choice group participants received feedback according to the same schedule as their choice group counterparts, but they could not choose when to receive it. Two days later, participants of both groups performed retention and transfer tests. The choice group demonstrated lower absolute error scores during transfer compared with the no-choice group. The findings reinforce outcomes of previous autonomy support studies and provide the first evidence that choice over feedback can enhance the learning of motor skills in older adults.

Keywords: autonomy, self-controlled practice, knowledge of results, aging

Autonomy is thought to influence intrinsic motivation by satisfying basic psychological (Deci & Ryan, 2000, 2008) as well as biological (Leotti & Delgado, 2011; Leotti, Iyengar, & Ochsner, 2010) needs. It has been linked with enhanced memory, 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). In the motor learning area, the effects of providing autonomy support to learners, in different contexts and populations, have received increased attention from researchers (e.g., Ali, Fawver, Kim, Fairbrother, & Janelle, 2012; Chiviacowsky & Wulf, 2002, 2005; Janelle, Barba, Frehlich, Tennant, & Cauraugh, 1997; Patterson, Carter, & Sanli, 2011; Post, Fairbrother, Barros, & Kulpa, 2014; Wu & Magill, 2011; Wulf & Adams, 2014). In these studies, participants who are allowed to make choices about a specific aspect

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of the instructional setting usually demonstrate superior learning compared with control participants practicing without the chance to choose. Given the positive effects of the provision of choices during practice, learner autonomy was recently acknowledged as a key motivational variable in the OPTIMAL theory of motor learning (Wulf & Lewthwaite, 2016).

The benefits of providing learners with choices over different practice factors in motor learning have been predominantly evaluated in young adults, with few experiments reporting outcomes in an older adult population. One such experiment, observing parkinsonian individuals learning a balance task, assessed the effects of the self-controlled use of a physical-assistance device (Chiviacowsky, Wulf, Lewthwaite, & Campos, 2012). Participants in the self-control group, who had the choice of whether to use a balance pole in each of 10 practice trials, demonstrated not only higher learning of the task, measured through a delayed retention test, but greater motivation, less nervousness, and less concern about their body movements than did yoked participants. In other research, the advantages of choice over the amount of practice on motor learning were observed in older adults learning a speed cup-stacking task, when compared with participants who were not allowed to choose (Lessa & Chiviacowsky, 2015).

While some autonomy supportive practice conditions have been shown to benefit motor skill learning in older adults, the effect of providing choices over feedback in this population remains unclear. Feedback, or information related to aspects of one's performance or understanding—usually provided by an external agent such as a teacher, peer, or coach—is well established as a potent influence on learning (Hattie & Timperley, 2007). The motivational (for a review, see Lewthwaite & Wulf, 2012) and informational (for reviews, see Salmoni, Schmidt, & Walter, 1984; Schmidt, 1991; Swinnen, 1996; Wulf & Shea, 2004) functions of feedback for motor learning have been extensively studied to date. Practice with autonomy over feedback has indeed been shown to benefit motor learning in children (Chiviacowsky, Wulf, Medeiros, Kaefer, & Tani, 2008; Ste-Marie, Vertes, Law, & Rymal, 2013), young adults (e.g., Ali et al., 2012; Carter, Carlsen, & Ste-Marie, 2014; Chiviacowsky & Wulf, 2002; Janelle et al., 1997; Patterson & Carter, 2010), individuals with different personality traits (Kaefer, Chiviacowsky, Meira, & Tani, 2014) or physical activity levels (Fairbrother, Laughlin, & Nguyen, 2012), and individuals with intellectual or motor disabilities (Chiviacowsky, Wulf, Machado, & Rydberg, 2012; Hemayattalab, 2014).

In a motor learning experiment by Carter and Patterson (2012), however, results failed to demonstrate positive effects in older adults. In this research, young participants provided with choices regarding feedback outperformed a yoked group in the learning of a discrete motor task, while learning differences among older adults following the same self-controlled and yoked feedback schedules were not found. Indeed, age-related differences between older and young adults have already been identified, both in terms of cognitive performance (Gopie, Craik, & Hasher, 2011; Henninger, Madden, & Huettel, 2010; Ren, Wu, Chan, & Yan, 2013; Smyth & Shanks, 2011) and motor learning processes (Coats, Wilson, Snapp-Childs, Fath, & Bingham, 2014; Van Dijk & Hermens, 2006; Wishart, Lee, Cunningham, & Murdoch, 2002). Studies have shown, for example, that older adults prefer less autonomy and fewer options, and seek less information when making decisions than do young adults (Mather, 2006; Reed, Mikels, & Simon, 2008). These age-related differences may explain why older adults did not benefit from standard self-controlled feedback manipulation as used in previous research (e.g., Carter & Patterson, 2012; Chiviacowsky & Wulf, 2002; Fairbrother et al., 2012) in the same way as young adults did. In these experiments, self-controlled participants were responsible for their own feedback schedule during the entire practice period, deciding whether to request such information after each trial. It remains unknown, however, whether older adults would prefer to control their feedback schedule throughout all practice or not, if provided with this choice before each block of practice, and what the consequences of these choices on learning are.

The increase in the elderly contingent is a growing worldwide phenomenon affecting both developed and developing countries (Ciolac, 2013). There is consensus that regular participation in physical activity programs can minimize alterations that occur during aging and may contribute to improving and maintaining health in older adults (Nelson et al., 2007). Being able to move with a certain level of motor skill is, however, a critical requirement for active participation in different types of motor activities, and motor learning research has the potential to inform those who work with older adults. The purpose of the present experiment was, therefore, to further examine the effects of choices over feedback on the learning of a motor task in older adults. Given the important functions of feedback for motor learning (Lewthwaite & Wulf, 2012; Schmidt, 1991; Swinnen, 1996), that age-related differences may make the generalization to older adults of findings of experiments using young adults difficult (Carter & Patterson, 2012; Coats et al., 2014; Wishart et al., 2002), and the dearth of studies investigating autonomy support over this learning variable in this population, it was deemed important to conduct such research. The results might have important implications for the practical settings of older adults, if the expected learning advantages of choice over feedback were confirmed.

Participants in the choice group were allowed to choose, before each block of six trials, whether to self-control their feedback schedule during the block, while participants in the no-choice group were not allowed to choose and received feedback schedules according to their choice group counterparts. We were also interested in determining older adults' preferences regarding choices over feedback, and asked all participants to complete a questionnaire immediately after practice. Considering the importance of autonomy support for intrinsic motivation and learning (Deci & Ryan, 2000, 2008; Wulf & Lewthwaite, 2016), and the previously observed benefits of providing choices in other practice contexts on motor learning in older adults (Chiviacowsky et al., 2012b; Lessa & Chiviacowsky, 2015), we hypothesized that participants given choice over feedback would display higher learning, measured through retention and transfer tests, relative to participants not allowed to choose.

Method

Participants

Twenty-two female older adults with a mean age of 62.33 ± 4.8 years (age range: 62–79) were recruited from a physical activity group belonging to an association of retired people. Voluntary participation was confirmed by informed consent, and the university's institutional review board approved the experiment. Participants were not aware of the specific purpose of the experiment, were right-handed, and had no prior experience with the experimental task.

Apparatus and Task

The task, identical to one used by Chiviacowsky, Campos, and Domingues (2010), involved a linear positioning apparatus used to measure spatial accuracy, consisting of a slider attached to a fixed surface in a straight line. A one-meter measuring device on one side of the apparatus was secured to the base and used to measure the horizontal displacement of the slide. The slide could be easily moved from side to side by hand, and the target was readily achievable within the normal reach of the participants. Participants sat in front of the apparatus, opposite the measuring device, with the left shoulder in line with the starting position of the slide, and were asked to move the slide and stop it on the target using their right hand (they were all right-handed). Swimming goggles with opaque lenses were worn by participants to avoid the effect of visual cues. In the acquisition and retention phases, the goal was to slide the bar and position it at a distance of 60 cm from the starting point, while in the transfer phase, the target distance was 45 cm. The difference in distance between the predetermined target and the actual location achieved by the participant in each trial was used as a measure of spatial accuracy, providing the absolute, constant, and variable errors.

Procedure

Participants were randomly assigned to either the choice or no-choice group (11 participants per group). They were informed that they would perform 36 trials of practice in a linear positioning task with the purpose of sliding the bar to position it 60 cm from the starting point. Then all participants performed a one-trial pretest. After the pretest, participants in the choice group were informed that they could choose whether to control when to receive feedback before starting each six-trial practice block. If they chose to control feedback, they were informed that they would receive feedback only when they requested it, making trial-by-trial decisions as they completed the trials in that block. Participants were also informed that, for the blocks in which they chose not to control feedback, it would be provided by the experimenter for two trials, selected from the six. In this case, feedback was provided for the second and sixth trials of the block. Participants in the no-choice group were each yoked to a participant in the choice group, and were informed that they would receive feedback occasionally. They received feedback according to the same temporal schedule as their choice group counterparts, without any chance to choose.

Feedback was provided to the participants on the direction (i.e., whether they overshot or undershot the target) and extent of the deviation in cm (e.g., – 4 cm). Two days later, participants of both groups performed retention and transfer tests, each consisting of 6 trials without feedback. The transfer test was performed 5 min after the retention test, in which the distance goal of the task was 45 cm. Upon completion of the practice phase, all participants completed a multiple-choice questionnaire on their choices over feedback (adapted from Chiviacowsky & Wulf, 2002). The questions are listed in Table 1.

Table 1 Feedback Questionnaire With Responses of Choice and No-Choice Participants

Group	*N*	*P*
Choice		
1. When/why did you want to receive feedback?		
After good trials	5	46
After bad trials	0	0
After good and bad trials equally	6	54
None of the above	0	0
2. Why did you choose to control feedback in some blocks?		
I just wanted to choose	4	58
I wanted to choose, and the feedback provided was not sufficient	1	14
I wanted to choose, and feedback was not being provided at the right time	0	0
I did not want to choose, but the feedback provided was not sufficient	1	14
I did not want to choose but, feedback was not being provided at the right time	0	0
None of the above	1	14
3. Why did you choose to NOT control feedback in some blocks?		
I just did not want to choose	0	0
I did not want to choose, and feedback was being sufficiently provided	2	18
I did not want to choose, and feedback was being provided at the right time	5	46
I wanted to choose, but was unsure about when to do it	4	36
None of the above	0	0
No-Choice		
1. Do you think you received feedback after the right trials?		
Yes	10	91
No	1	9
2. Would you have preferred to be able to choose when to receive feedback?		
Yes, because feedback was not being sufficiently provided	3	27
Yes, because feedback was not being provided at the right time	1	9
No, because feedback was being sufficiently provided	5	46
No, because feedback was being provided at the right time	2	18

Note. N = number of participants; P = percentage of total responses for the group.

Data Analysis

The dependent variables—measured in cm and averaged across blocks of six trials for practice, retention, and transfer—were absolute error (AE), representing the absolute difference between the goal movement distance and actual distance irrespective of error direction; constant error (CE), representing the difference between the actual distance and goal movement distance; and variable error (VE), representing movement consistency (Schmidt & Lee, 2013). A one-way analysis of variance (ANOVA) was used to test for possible differences in the pretest. Spatial accuracy practice data were analyzed in a 2 (groups) × 6 (blocks of 6 trials) analysis of variance (ANOVA) with repeated measures on the last factor, while separate one-way ANOVA was used for the retention and transfer tests. Bonferroni post hoc test was used for follow-up analysis. Partial eta-squared values (η_p^2) were used to indicate effect sizes. Alpha was set at .05 for all analyses. Multiple-choice questionnaire responses were evaluated by tabulating participants' responses. To determine whether the participants of the choice group requested feedback after more or less efficient trials, average AE scores for feedback and no-feedback trials were calculated for the blocks where participants controlled their own feedback schedule during practice.

Results

Spatial Accuracy

Absolute Error. On the pretest, there was no significant difference between groups, $F(1, 20) = .000$, $p = .992$, $\eta_p^2 = .000$ (see Figure 1). Participants of both groups reduced their AE scores across the blocks of practice. The main effect of block was significant, $F(5, 100) = 17.050$, $p = .000$, $\eta_p^2 = .460$. Post hoc tests confirmed differences between block 1 and all the other blocks, $p < .01$. There were no other differences between blocks. The main effect of group, $F(1, 20) = .490$, $p = .492$,

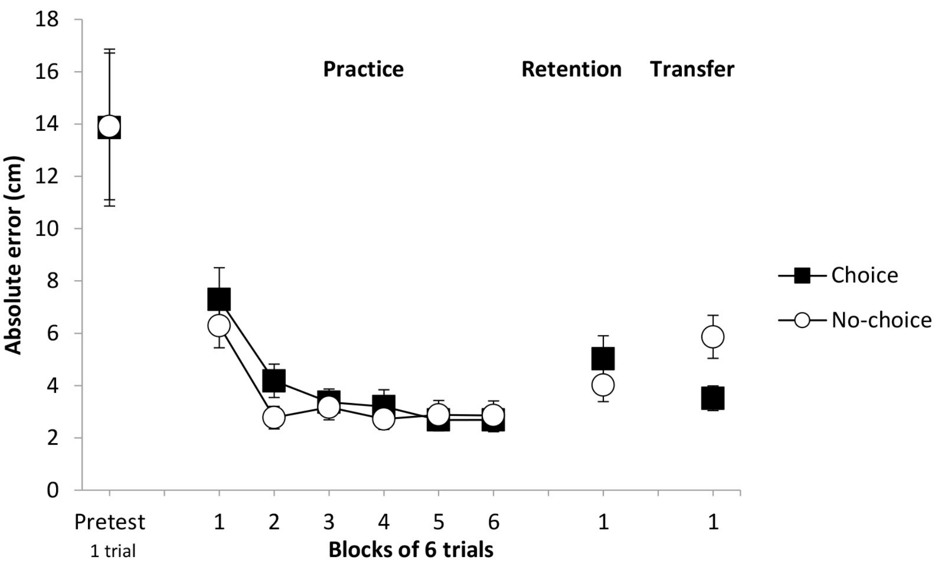

Figure 1 — Absolute error scores of the Choice and No-Choice groups in pretest, practice, retention, and transfer. Error bars represent *SE*.

η_p^2 = .024, and the group × block interaction, $F(5, 100) = .741$, $p = .595$, η_p^2 = .036, were not significant. During the retention test, significant differences were not observed between the groups, $F(1, 20) = .790$, $p = .385$, $\eta_p^2 = .038$. However, differences were identified between the choice and no-choice groups during the transfer test, $F(1, 20) = 5.604$, $p = .028$, $\eta_p^2 = .219$.

Constant Error. No significant difference between groups, $F(1, 20) = .022$, $p = .884$, $\eta_p^2 = .001$, was found on the pretest (see Figure 2). Participants of both groups showed similar CE scores across blocks of practice. The main effect of block, $F(5, 100) = .366$, $p = .870$, $\eta_p^2 = .018$, group, $F(1, 20) = .164$, $p = .690$, $\eta_p^2 = .008$, and the group × block interaction, $F(5, 100) = .589$, $p = .708$, $\eta_p^2 = .029$, were not significant. Differences between groups were also not found during the retention, $F(1, 20) = .127$, $p = .725$, $\eta_p^2 = .006$, and transfer tests, $F(1, 20) = .055$, $p = .817$, $\eta_p^2 = .003$.

Variable Error. On the pretest, there was no significant difference between groups in variable error, $F(1, 20) = .000$, $p = .992$, $\eta_p^2 = .000$ (see Figure 3). Participants of both groups reduced their VE scores across blocks of practice. The main effect of block was significant, $F(5, 100) = 13.411$, $p = .01$, $\eta_p^2 = .401$. Post hoc tests confirmed differences between block 1 and all the other blocks $p < .05$. There were no other differences between blocks. The main effect of group, $F(1, 20) = .065$, $p = .802$, $\eta_p^2 = .003$, and the group × block interaction, $F(5, 100) = 1.375$, $p = .240$, $\eta_p^2 = .064$, were not significant. During the retention test, significant differences were not observed between the groups, $F(1, 20) = .021$, $p = .886$, $\eta_p^2 = .001$. Significant differences were also not found between the choice and no-choice groups during the transfer test, $F(1, 20) = 3.122$, $p = .093$, $\eta_p^2 = .135$.

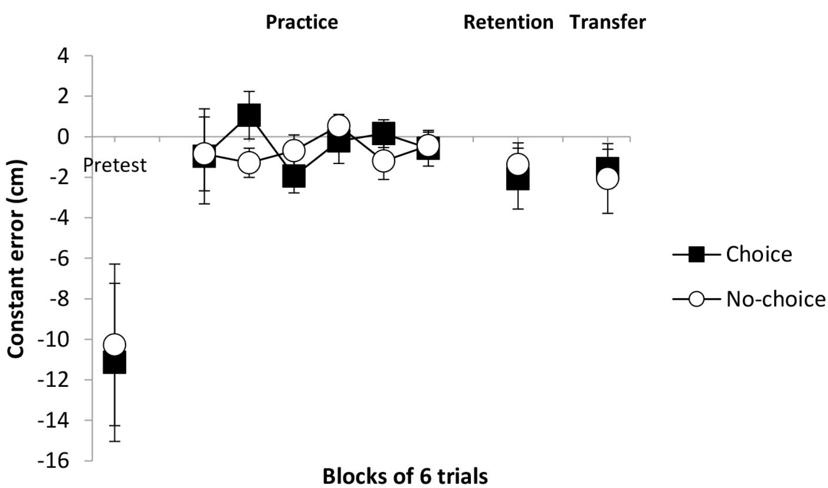

Figure 2 — Constant error scores of the Choice and No-Choice groups in pretest, practice, retention, and transfer. Error bars represent *SE*.

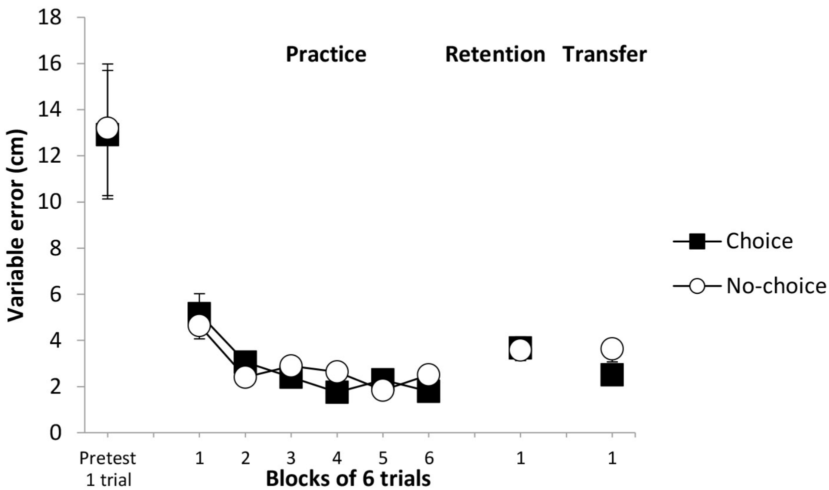

Figure 3 — Variable error scores of the Choice and No-Choice groups in pretest, practice, retention, and transfer. Error bars represent *SE*.

Feedback Requests and Questionnaire

Of the 11 participants in the choice group, seven chose to control their own feedback schedule in some of the practice blocks. More specifically, from these seven participants, four decided to control their feedback only in one block of trials (one participant in block 1, one participant in block 2, and two participants in block 3); one participant chose to control her feedback in two blocks of practice (blocks 1 and 2); and two participants decided to control their feedback in three blocks of practice (blocks 2, 3, and 5; and blocks 4, 5, and 6). Thus, they decided to control when to receive feedback mainly during the first half of the practice, and in a small number of blocks (16.66% of the practice blocks). Participants asked for feedback in these specific blocks in 45.83% of the trials.

Table 1 displays the results of the feedback questionnaire for the choice and no-choice groups. When asked when they preferred to receive feedback, the participants of the choice group were divided between two feedback preferences, with five participants (45.45%) preferring to receive feedback mainly after good trials, and six participants (54.55%) preferring feedback after perceived good and bad trials equally. In contrast, no participant reported a preference for receiving feedback mainly after bad trials. With respect to why (seven) participants chose to control feedback in some blocks, the most frequent response was that they "just wanted to choose" (71.42%), while one participant (14.29%) responded that she wanted to choose because the feedback provided by the researcher was insufficient; another participant (14.29%) responded that she did not want to choose but that the feedback provided was insufficient. Finally, the 11 participants of the choice group stated why they chose to not control feedback in some or any of the practice blocks. Of the 11, seven responded that they simply did not want to choose (63.63%). The other four (36.36%) participants of the choice group responded that they wished to choose but were unsure about when to do it.

The majority of participants in the no-choice group (10 out of 11, or 90.91%) thought that they had received feedback after the right trials; only one (9.09%) did not agree. When asked whether they would have preferred to be able to choose when to receive feedback after each trial, seven participants of the no-choice group answered no, five of them because feedback was adequate and the other two because it was provided at the right time. The other four participants of the no-choice group answered yes, three of them identified that it was because feedback was not being sufficiently provided, and the other one because it was not provided at the right time.

Average AE scores for feedback and no-feedback trials, calculated to determine whether the seven participants of the choice group requested feedback after more or less efficient trials, showed no significant differences with respect to trial type, $F(1, 11) = .44, p > .05$.

Discussion

Satisfying the need for autonomy has been considered a key element of optimal human psychological well-being, predicting better functioning and learning in several domains (Deci & Ryan, 2000, 2008; Hackman & Oldham, 1976; Markant et al., 2014; Tafarodi et al., 1999). While self-controlled feedback has indeed demonstrated to enhance motor learning in several populations (e.g., Ali et al., 2012; Chiviacowsky et al., 2008b; Ste-Marie et al., 2013), the benefits of this kind of practice in older adults' motor learning have not been determined. Previous research (Carter & Patterson, 2012) using a typical self-controlled feedback design did not find enhanced learning in older adults when compared to a yoked control group. In the present research, we investigated whether supporting older adults' need for autonomy, by allowing them choices over feedback, would enhance their learning. Since autonomy support is considered an important variable for learning (Deci & Ryan, 2000, 2008; Wulf & Lewthwaite, 2016) and health in older adults (Boyle, 2005; Bruin, Parker, & Fischhoff, 2012; Finucane, Slovic, Hibbard, Peters, Mertz, Macgregor, 2002), we considered it fruitful to further investigate the effect of choices over this significant learning factor in this population.

Our results showed that choice and no-choice groups had similar performance during practice and retention, but the provision of choice resulted in better spatial accuracy in transfer. Thus, the findings demonstrate more effective learning of the task for the choice group when compared to no-choice participants. It was also interesting to note that, while most of the choice participants chose to control their feedback schedule (even if in a small number of blocks), one-third chose to never control it, instead preferring to passively receive feedback from the experimenter. These findings are in line with the questionnaire responses, whereby some participants reported that they simply did not want to exercise control over feedback in some blocks, felt unsure about when to do it, or reported feeling satisfied with the feedback schedule provided by the experimenter.

Together, the choices observed during practice and reported through the questionnaire seem to support existing literature showing that older adults prefer less responsibility, less autonomy, and fewer options when making decisions than do young adults (Besedeš, Deck, Sarangi, & Shor, 2012; Finucane et al., 2002; Mather, 2006; Reed et al., 2008). Nonetheless, learning was enhanced for spatial accuracy in transfer in participants given the chance to choose when to exercise control over feedback, when compared to participants not allowed to make choices. The results reinforce the outcomes of previous experiments with older adults (Chiviacowsky et al., 2012b; Lessa & Chiviacowsky, 2015), demonstrating the importance of providing practice with autonomy support to this population.

The provision of choices during practice is thought to benefit motor learning by allowing learners to adapt the practice setting to meet individual needs and preferences (Chiviacowsky & Wulf, 2002; Laughlin, Fairbrother, Wrisberg, Alami, Fisher, & Huck, 2015), promoting deeper processing of relevant information (Chen & Singer, 1992; Grand et al., 2015), encouraging error estimation (Carter et al., 2014; Chiviacowsky & Wulf, 2005), and enhancing motivation, mainly by satisfying the learners' need to autonomy (for reviews, see Sanli, Patterson, Bray, & Lee, 2013; Lewthwaite and Wulf, 2012). In fact, participants exercising choices over the use of a physical aid have reported increased motivation, less nervousness, and less concern about their body movements than did control participants (Chiviacowsky et al., 2012b). Higher motivation was likewise found in participants who self-controlled their feedback schedule (Chiviacowsky, 2014; Grand et al., 2015). Interestingly, research has also demonstrated the benefits of providing choices for motivation and motor learning, even when choices are not directly related to information specific to the task (e.g., Hooyman, Wulf, & Lewthwaite, 2014; Lewthwaite, Chiviacowsky, Drews & Wulf, 2015; Wulf, Chiviacowsky, & Cardozo, 2014). It has also been considered that autonomy supportive conditions may convey a general sense of respect for participants' agency or capabilities, thus enhancing learners' confidence and subsequent task-specific self-efficacy (Lewthwaite et al., 2015; Wulf & Lewthwaite, 2016). In fact, autonomy over feedback was observed to increase learners' self-efficacy, benefiting motor learning by providing learners with both the opportunity to confirm successful performance (Chiviacowsky, Wulf, & Lewthwaite, 2012) and an intrinsically rewarding opportunity through the exercise of control (Chiviacowsky, 2014).

In conclusion, the present findings advance the results of previous experiments on self-controlled motor learning, providing the first evidence that choice over feedback can enhance the learning of motor skills in older adults. Specifically, the results show that allowing older adults the choice of whether to control when to receive feedback during practice positively impacted their learning. The findings also support growing evidence for the important role of autonomy in fostering well-being throughout the lifespan, even considering that the manner in which autonomy is expressed and satisfied varies with age, and challenges that change with age (Ryan & Deci, 2001; Ryan & La Guardia, 2000). The results are also in line with the OPTIMAL theory of motor learning (Wulf & Lewthwaite, 2016) and corroborate evidence showing the beneficial effects of practice with autonomy support in older adults' motor learning. The findings also have implications in practical settings, suggesting that professionals involved in teaching–learning contexts give older adults the opportunity for choice over feedback during practice to enhance motor learning.

Some limitations of the present experiment include the small number of participants, preventing secondary follow-up analysis; the exclusion of young adult groups, which would have permitted potential age differences regarding autonomy over feedback to be observed; the fact that participants were all women; and the use of a simple laboratory task. Future research using a greater number of participants (e.g., Chiviacowsky, Wulf, Medeiros, Kaefer & Wally, 2008) could further explore the effects of different choices over feedback by, for example, comparing those who choose to exercise control over feedback when given choice with those who do not, and the impact of this on learning. The specific mechanisms mediating the relationship between autonomy support and the learning of motor skills in older adults, and why differences were found only in absolute but not in constant and variable error, are also not clear and are therefore deserving of further investigation. Including young-adult participants for comparison could also directly determine whether older adults, in fact, prefer less responsibility, autonomy, and fewer options when making decisions (Besedeš et al., 2012; Finucane et al., 2002; Mather, 2006; Reed et al., 2008) in the motor learning domain. The use of open-ended questions about the participants' experiences during practice (e.g., Carter, Rathwell, & Ste-Marie, 2016; Laughlin et al., 2015) could bring interesting insights. In addition, future studies could provide further evidence of the effects found in more complex tasks and other practice contexts.

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References

Ali, A., Fawver, B., Kim, J., Fairbrother, J., & Janelle, C. (2012). Too much of a good thing: Random practice scheduling and self-control of feedback lead to unique but not additive learning benefits. *Frontiers in Psychology, 3,* 1–9 [Article 503]. doi:10.3389/fpsyg.2012.00503

Besedeš, T., Deck, C., Sarangi, S., & Shor, M. (2012). Age effects and heuristics in decision making. *The Review of Economics and Statistics, 94,* 580–595. doi:10.1162/REST_a_00174

Boyle, G. (2005). The role of autonomy in explaining mental ill-health and depression among older people in long-term care settings. *Ageing and Society, 25,* 731–748. doi:10.1017/S0144686X05003703

Bruin, W.B., Parker, A.M., & Fischhoff, B. (2012). Explaining adult age differences in decision-making competence. *Journal of Behavioral Decision Making, 25,* 352–360. doi:10.1002/bdm.712

Carter, M.J., Carlsen, A.N., & Ste-Marie, D.M. (2014). Self-controlled feedback is effective if it is based on the learner's performance: A replication and extension of Chiviacowsky and Wulf (2005). *Frontiers in Psychology, 5,* Article 1325, 1–10. doi:10.3389/fpsyg.2014.01325

Carter, M.J., Rathwell, S., & Ste-Marie, D.M. (2016). Motor skill retention is modulated by strategy choice during self-controlled knowledge of results schedules. *Journal of Motor Learning and Development, 4,* 100–115. doi:10.1123/jmld.2015-0023

Carter, M.J., & Patterson, J.T. (2012). Self-controlled knowledge of results: Age-related differences in motor learning, strategies, and error detection. *Human Movement Science, 31,* 1459–1472. doi:10.1016/j.humov.2012.07.008

Chen, D., & Singer, R.N. (1992). Self-regulation and cognitive strategies in sport participation. *International Journal of Sport Psychology, 23,* 277–300.

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., Campos, T., & Domingues, M.R. (2010). Reduced frequency of knowledge of results enhances learning in persons with Parkinson's disease. *Frontiers in Psychology, 1,* Article 226, 1–6. doi:10.3389/fpsyg.2010.00226

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. doi:10.1080/02701367.2002.10609040

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. doi:10.1080/02701367.2005.10599260

Chiviacowsky, S., Wulf, G., & Lewthwaite, R. (2012a). Self-controlled learning: The importance of protecting perceptions of competence. *Frontiers in Psychology, 3,* 1–8. doi:10.3389/fpsyg.2012.00458

Chiviacowsky, S., Wulf, G., Lewthwaite, R., & Campos, T. (2012b). Motor learning benefits of self-controlled practice in persons with Parkinson's disease. *Gait & Posture, 35,* 601–605. doi:10.1016/j.gaitpost.2011.12.003

Chiviacowsky, S., Wulf, G., Machado, C., & Rydberg, N. (2012c). Self-controlled feedback enhances learning in adults with Down syndrome. *Brazilian Journal of Physical Therapy, 16,* 191–196. doi:10.1590/S1413-35552012005000019

Chiviacowsky, S., Wulf, G., Medeiros, F., Kaefer, A., & Wally, R. (2008a). Self-controlled feedback in 10-year-old children: Higher feedback frequencies enhance learning. *Research Quarterly for Exercise and Sport, 79,* 122–127.

Chiviacowsky, S., Wulf, G., Medeiros, F.L., Kaefer, A., & Tani, G. (2008b). Learning benefits of self-controlled knowledge of results in 10-year-old children. *Research Quarterly for Exercise and Sport, 79,* 405–410. doi:10.1080/02701367.2008.10599505

Ciolac, E.G. (2013). Exercise training as a preventive tool for age-related disorders: A brief review. *Clinics, 68,* 710–717. doi:10.6061/clinics/2013(05)20

Coats, R.O., Wilson, A.D., Snapp-Childs, W., Fath, A.J., & Bingham, G.P. (2014). The 50s cliff: perceptuo-motor learning rates across the lifespan. *PLoS One, 9,* 1–7. doi:10.1371/journal.pone.0085758

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. doi:10.1037/0022-0663.88.4.715

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. doi:10.1207/S15327965PLI1104_01

Deci, E.L., & Ryan, R.M. (2008). Self-determination theory: A macro theory of human motivation, development, and health. *Canadian Psychology, 49,* 182–185. doi:10.1037/a0012801

Fairbrother, J.T., Laughlin, D.D., & Nguyen, T.V. (2012). Self-controlled feedback facilitates motor learning in both high- and low-activity individuals. *Frontiers in Psychology, 3,* Article 323, 1–8. doi:10.3389/fpsyg.2012.00323

Finucane, M.L., Slovic, P., Hibbard, J.H., Peters, E., Mertz, C.K., & Macgregor, D.G. (2002). Aging and decision-making competence: An analysis of comprehension and consistency skills in older versus younger adults considering health-plan options. *Journal of Behavioral Decision Making, 15,* 141–164. doi:10.1002/bdm.407

Gopie, N., Craik, F., & Hasher, L. (2011). A double dissociation of implicit and explicit memory in younger and older adults. *Psychological Science, 22,* 634–640. doi:10.1177/0956797611403321

Grand, K.F., Bruzi, A.T., Dyke, F.B., Godwin, M.M., Leiker, A.M., Thompson, A.G., . . . Miller, M.W. (2015). Why self-controlled feedback enhances motor learning: Answers from electroencephalography and indices of motivation. *Human Movement Science, 43,* 23–32. doi:10.1016/j.humov.2015.06.013

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. doi:10.1016/0030-5073(76)90016-7

Hattie, J., & Timperley, H. (2007). The power of feedback. *Review of Educational Research, 77,* 81–112. doi:10.3102/003465430298487

Hemayattalab, R. (2014). Effects of self-control and instructor-control feedback on motor learning in individuals with cerebral palsy. *Research in Developmental Disabilities, 35,* 2766–2772. doi:10.1016/j.ridd.2014.07.006

Henninger, D., Madden, D., & Huettel, S. (2010). Processing speed and memory mediate age-related differences in decision making. *Psychology and Aging, 25,* 262–270. doi:10.1037/a0019096

Hooyman, A., Wulf, G., & Lewthwaite, R. (2014). Impacts of autonomy-supportive versus controlling instructional language on motor learning. *Human Movement Science, 36,* 190–198. doi:10.1016/j.humov.2014.04.005

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. doi:10.1080/02701367.1997.10608008

Kaefer, A., Chiviacowsky, S., Meira, C.M.J., & Tani, G. (2014). Self-controlled practice enhances motor learning in introverts and extroverts. *Research Quarterly for Exercise and Sport, 85,* 226–233. doi:10.1080/02701367.2014.893051

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. doi:10.1016/j.humov.2015.02.002

Lessa, H.T., & Chiviacowsky, S. (2015). Self-controlled practice benefits motor learning in older adults. *Human Movement Science, 40,* 372–380. doi:10.1016/j.humov.2015.01.013

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. doi:10.3758/s13423-015-0814-7

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 and practice* (pp. 173–191). London: Routlegde.

Leotti, L.A., & Delgado, M.R. (2011). The inherent reward of choice. *Psychological Science, 22,* 1310–1318. doi:10.1177/0956797611417005

Leotti, L.A., Iyengar, S.S., & Ochsner, K.N. (2010). Born to choose: The origins and value of the need for control. *Trends in Cognitive Sciences, 14,* 457–463. doi:10.1016/j.tics.2010.08.001

Mather, M. (2006). A review of decision-making processes: Weighing the risks and benefits of aging. *When I'm, 64,* 145, 145–173.

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. doi:10.3758/s13421-014-0435-9

Murty, V.P., DuBrow, S., & Davachi, L. (2015). The simple act of choosing influences declarative memory. *The Journal of Neuroscience, 35,* 6255–6264. doi:10.1523/JNEUROSCI.4181-14.2015

Nelson, M.E., Rejeski, W.J., Blair, S.N., Duncan, P.W., Judge, J.O., King, A.C., . . . & Castaneda-Sceppa, C. (2007). Physical activity and public health in older adults: Recommendation from the American College of Sports Medicine and the American Heart Association. *Circulation, 116,* 9, 1094–1105.

Patterson, J.T., & Carter, M. (2010). Learner regulated knowledge of results during the acquisition of multiple timing goals. *Human Movement Science, 29,* 214–227. doi:10.1016/j.humov.2009.12.003

Patterson, J.T., Carter, M., & Sanli, E. (2011). Decreasing the proportion of self-control trials during the acquisition period does not compromise the learning advantages in a self-controlled context. *Research Quarterly for Exercise and Sport, 82,* 624–633. doi:10.1080/02701367.2011.10599799

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. doi:10.1123/jmld.2013-0008

Reed, A.E., Mikels, J.A., & Simon, K.I. (2008). Older adults prefer less choice than young adults. *Psychology and Aging, 23,* 671–675. doi:10.1037/a0012772

Ren, J., Wu, Y.D., Chan, J.S., & Yan, J.H. (2013). Cognitive aging affects motor performance and learning. *Geriatrics & Gerontology International, 13,* 19–27. doi:10.1111/j.1447-0594.2012.00914.x

Ryan, R.M., & Deci, E.L. (2001). On happiness and human potentials: A review of research on hedonic and eudaimonic well-being. *Annual Review of Psychology, 52,* 141–166. doi:10.1146/annurev.psych.52.1.141

Ryan, R.M., & La Guardia, J.G. (2000). What is being optimized? Self-determination theory and basic psychological needs. In S.H. Qualls & N. Abeles (Eds.), *Psychology and the aging revolution: How we adapt to longer life* (pp. 145–72). Washington, DC: APA Books. doi:10.1037/10363-008

Salmoni, A.W., Schmidt, R.A., & Walter, C.B. (1984). Knowledge of results and motor learning: A review and critical reappraisal. *Psychological Bulletin, 95,* 355–386. doi:10.1037/0033-2909.95.3.355

Sanli, E., Patterson, J., Bray, S., & Lee, T.D. (2013). Understanding self-controlled motor learning protocols through the self-determination theory. *Frontiers in Movement Science and Sport Psychology, 3,* 1–17.

Schmidt, R.A. (1991). Frequent augmented feedback can degrade learning: Evidence and interpretations. In J. Requin & G.E. Stelmach (Eds.), *Tutorials in motor neuroscience* (pp. 59–75). Dordrecht, The Netherlands: Kluwer Academic Publishers. doi:10.1007/978-94-011-3626-6_6

Schmidt, R., & Lee, T. (2013). *Motor learning and performance, 5E with web study guide: From principles to application*. Champaign, IL: Human Kinetics.

Smyth, A., & Shanks, D. (2011). Aging and implicit learning: explorations on contextual cuing. *Psychology and Aging, 26,* 127–132. doi:10.1037/a0022014

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,* Article 556, 1–10. doi:10.3389/fpsyg.2012.00556

Swinnen, S.P. (1996). Information feedback for motor skill learning: A review. In H.N. Zelaznik (Ed.), *Advances in Motor learning and control* (pp. 37–66). Champaign, IL: Human Kinetics.

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. doi:10.1177/0146167299259006

Van Dijk, H., & Hermens, H.J. (2006). Effects of age and timing of augmented feedback on learning muscle relaxation while performing a gross motor task. *American Journal of Physical Medicine & Rehabilitation, 85,* 148–155. doi:10.1097/01.phm.0000197959.17247.5b

Wishart, L.R., Lee, T.D., Cunningham, S.J., & Murdoch, J.E. (2002). Age-related differences and the role of augmented visual feedback in learning a bimanual coordination pattern. *Acta Psychologica, 110,* 247–263. doi:10.1016/S0001-6918(02)00036-7

Wu, W.F., & Magill, R.A. (2011). Allowing learners to choose: Self-controlled practice schedules for learning multiple movement patterns. *Research Quarterly for Exercise and Sport, 82,* 449–457. doi:10.1080/02701367.2011.10599777

Wulf, G., & Adams, N. (2014). Small choices can enhance balance learning. *Human Movement Science, 38,* 235–240. doi:10.1016/j.humov.2014.10.007

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. doi:10.3758/s13423-015-0999-9

Wulf, G., & Shea, C.H. (2004). Understanding the role of augmented feedback: The good, the bad, and the ugly. In A.M. Williams & N.J. Hodges (Eds.), *Skill acquisition in sport: Research, theory and practice* (pp. 121–144). London: Routledge.

Wulf, G., Chiviacowsky, S., & Cardozo, P. (2014). Additive benefits of autonomy support and enhanced expectancies for motor learning. *Human Movement Science, 37,* 12–20. doi:10.1016/j.humov.2014.06.004