Spring 2017

Learning Motor Skills with Rewarding Feedback and Variability

Weijie Xiao

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by

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A thesis submitted in partial fulfillment of the requirements
for graduation with Honors in the Psychology

R. Eliot Hazeltine
Thesis Mentor

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All requirements for graduation with Honors in the
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J. Toby Mordkoff
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Abstract

Objective: Rewarding feedback and variability of training schedule are known to have a positive effect on motor skill learning and retention, yet no previous research had examined the interaction between reward and variability. We designed a two-part study to investigate how could such interaction affect motor skill learning and retention.

Method: A 2 x 2 design was used in the present study. Reward and variability each had two levels: reward or no reward, variable or blocked training schedule. The Maze Drawing Task, a computer task required participants to control the target cursor and stay in the maze for as long as they can, were designed and used. Each participant was assigned to one of the four conditions of the Maze Drawing Task. Four questionnaires were administered to measure possible influential factors such as handedness, duration and quality of sleep, and personality traits.

Results: The results showed that rewarding feedback and variability of training schedule improved task performance, yet only reward led to a better learning effect. Neither of reward and variability enhanced motor skill retention.

Conclusions: We propose that reward and variable training schedule are insufficient to affect motor skill retention, even though reward can improve learning effect.

Introduction

What can help people get better at motor skill learning? Many studies suggest that motor skill learning is improvable through manipulations such as offering rewarding feedback or practice with a varied training procedure. Previous research has supported that rewarding feedback can lead to enhancement of learning effect during procedural tasks through reinforcement of good performance (Abe et al., 2011; Wächter, Lungu, Lui, Willingham, & Ashe, 2009; Orand, Ushiba, Tomita, & Honda, 2012). Wu et al. (2015) observed that faster learning and improvement of performance on motor learning tasks can be associated with higher motor variability. Moreover, it has been demonstrated learned motor skills are better retained when reward and variability are provided. For example, rewarding positive feedback during a training session has been shown to increase retention, even when tested in the absence of reward (Galea, Mallia, Rothwell & Diedrichsen, 2015). Variable training schedule has also been shown to affect motor skill retention, such that greater variability during initial training, as opposed to consistent presentation of information, leads to greater retention and greater generalization of a task to other domains (e.g., Batting, 1972; Shea & Morgan, 1979).

Yet, the interaction between rewarding feedback and the variability of a training scheduled remains elusive. In the present experiment, we aimed to examine the interaction between rewarding feedback and a variable training schedule in a motor skill learning process. We designed a two-part study to investigate how feedback and training schedule interact to strengthen or hinder motor skills learning and retention.

To examine the relationship between these variables, participants completed a maze-drawing experiment on two successive days. The effect of learning was assessed during the first session, and the retention of motor skill was assessed during the second visit. We predicted that

(1) both reward and variability will improve the performance at training session; (2) reward and variability can improve the learning effect; and (3) reward and variability will both help motor skill retention.

Additionally, it is possible that certain personality traits may affect constructs such as reward responsiveness and motivation to achieve one's goals (Carver & White, 1994), which may mask our findings. As such, all participants completed the Behavioral Inhibition System / Behavior Approach System (BIS/BAS) questionnaire to investigate any possible correlation between personality traits and the effect of reward and variability on the retention of a learned motor skill. As for the correlation between personality traits and the effects of reward and variability, we hypothesized that the impact of reward and variability will be positively correlated with drive level, and level of reward responsiveness will be related to the effect of reward.

Methods

Participants

A total of 55 healthy college students (26 Females, Mean age = 19.47±1.60; see Table 1 for mean age and gender distribution of each condition) participated in this experiment for course credit (Table 1). All participants were recruited through a version of the SONA system adapted by the University of Iowa Department of Psychological and Brain Sciences. All subjects reported normal or corrected-to-normal vision and hearing, and were all right-handed.

		Feedback	
		Rewards	No Reward
Training Schedule	Variability	N = 13 6 Female, 7 Male Mean Age = 19.62±2.60	N = 16 6 Female, 10 Male Mean Age = 19.19±1.17
	Blocked	N = 13 6 Female, 7 Male Mean Age = 19.38±1.12	N = 13 8 Female, 5 Male Mean Age = 19.69±1.49

Table 1. Gender, mean age, and the number of participants in each group.

Participants were excluded if they had any history of orthopedic or neurological disorders, or if they had any right-hand motor deficits. Following completion of the first session, participants were informed to not consume any alcohol or allergy medication prior to the second visit. Moreover, participants were asked to have an adequate night's sleep, as much research has observed a negative relationship between cognitive performance and low sleep quality/duration (Van Dongen, Maislin, Mullington, & Dinges, 2003; Benitez & Gunstad, 2012). All participants gave informed consent at the beginning of their first visit and the study was approved by the University of Iowa Institutional Review Board.

Materials

The task program was developed with and run using MATLAB. Four questionnaires were administered: (1) an eligibility screener to assess handedness, pre-existing orthopedic or neurological conditions, consumption of alcohol or other medications, and the availability of a two-day commitment; (2) the Edinburgh Handedness Inventory to assess handedness; (3) the

BIS/BAS Scales to assess personality traits; and (4) a sleep quality questionnaire to assess the participant's quality and duration of sleep.

After completion of the entire experiment for their first visit, participants were administered the Behavioral Inhibition System / Behavior Approach System (BIS/BAS) Scale (Carver & White, 1994). According to this theory, BAS directs the regulation of appetitive motives, which is the desire to reach for pleasant things. BIS, on the other hand, directs the regulation of aversive motives, which is the desire to escape from unpleasant things. Theoretically, individuals who exhibit high levels of traits related to BAS sensitivity would be more susceptible to rewarding feedback and such feedback would have a positive effect on them. There were four personality traits that can be measured with the BIS/BAS Scale: fun-seeking, drive, reward responsiveness, and inhibition (Carver & White, 1994b). Fun-seeking, drive, and reward responsiveness were linked to the BAS sensitivity, while inhibition level reflects traits related to sensitivity of the BIS (Carver & White, 1994a). This scale contains twenty-four statements, to which participants made their response on a 1-4 Likert scale (1 for "very true for me" and 4 for "very false for me"). In those twenty-four statements, four questions were about fun-seeking traits, four asked about drive, five measured reward responsiveness, seven were about inhibition, and the remaining three questions were fillers.

The sleep quality questionnaire was administered at the beginning of the second visit. This questionnaire addressed similar questions to the screener we gave our participants at the beginning of their first visit. For example, the questionnaire addressed the number of hours and quality of sleep the night before the second visit, and alcohol and medication consumption. We asked those questions in both days of visit to see if each participant had an intact cognitive function for both visits and whether there was any change occurred between those two visits.

Procedure

Our study used a 2 x 2 between-group design: the type of feedback participants received after trials which they performed well in (rewards or no reward), and the type of training schedule (variable or blocked). Participants would be assigned to one of the four conditions (rewarded variable, rewarded blocked, no-reward variable, no-reward blocked) upon their arrival (Table 1). This design allowed us to examine the interaction of reward and variability on motor skill learning performance and the retention of such skill.

For the first visit, each participant administered the Maze Drawing Task for about forty minutes (330 trials). The whole process of the first visit usually took about one hour. On the second visit, participants came back to the lab to complete the retention session (30 trials). After accomplishing all thirty trials, participants were given a debriefing form which revealed the goal and intention of this study and were rewarded with course credits. The second visit normally took about fifteen minutes.

The Maze Drawing Task

This was a computer task developed by Dr. Freedberg. In this computer-based task, participants used the mouse to control the position of a cursor. The goal was use mouse to guide the round shaped target along a maze path colored in red while the target fell from the top of the screen (Figure 1). Participants were asked to try to stay on the maze for as long as possible. What participants practiced in this task is the ability to execute precise control of the mouse with their right hand. All groups of participants had a pre-test session, a training session, a post-test session, and a retention session. In those four sessions, only the training session was manipulated with reward and variability and was different for every study group. The rest three sessions were the same for all groups and did not have any rewarding feedback or varied training schedule. Participants needed to finish the pre-test, the training, and the post-test session during their first visit. The pre-test session included 30 trials, the training session contained 270 trials in total, and the post-test session had another 30 trials.

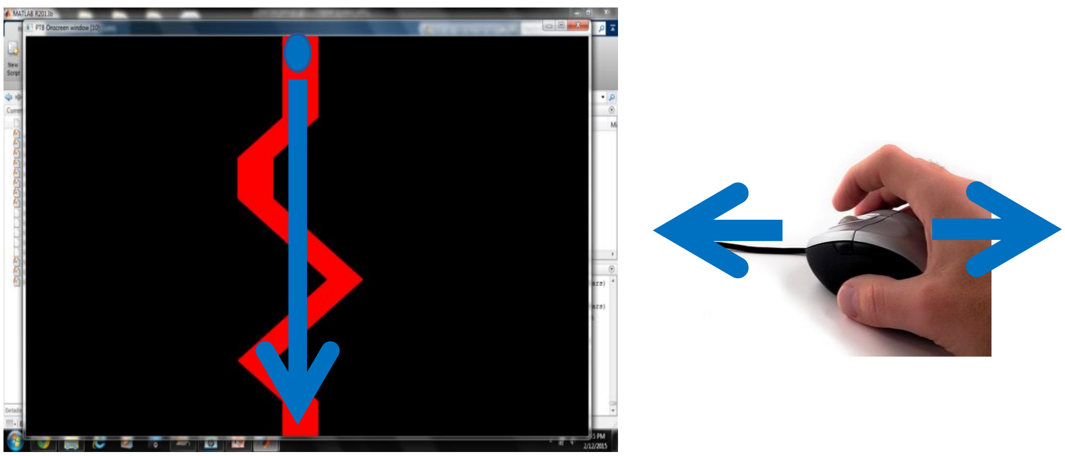

Figure 1. Participants used the mouse to guide the position of the cursor through the red path on screen.

In the two reward groups, participants were rewarded with facsimile money for their good performance at the training session (no rewards were given in the pre-test, the post-test, and the retention sessions). Good performance means successfully use the mouse to keep the target on the maze for a certain amount of time. If the target stayed in the maze longer than the threshold of reward, the participant would get a rewarding feedback, that is, gaining facsimile money. The amount of facsimile money they won through the whole training session would be added up as their final score. Participants would try to get as much money as possible. Since the effect of the number of rewarding feedbacks on such task is not the focus of this study, the reward threshold would be adjusted dynamically, depending on participant's previous performance. Also, the width of the maze would also adjust depending on their performance. Therefore, each participant in both reward groups would get the same amount of rewarding feedback. In contrast, participants in the no-reward groups would only receive a fixed amount of money points, despite how they performed in this task.

The six types of mazes used in this task are shown in Figure 2. In these listed mazes, mazes A, B, and C were used as practiced mazes and occurred in all sessions. Participants had their motor skill trained with only those three maze in the training session. Mazes D, E, and F were the generalization mazes. Participants had no practice on these three mazes, since they only occurred in the pre-test, post-test, and retention sessions. To success in the trials with mazes D, E, and F, participants had to apply the skills they learned from mazes A, B, and C in the training session to those novel mazes. We designed those generalization mazes in order to test whether retention of the motor skill trained with the practiced mazes can be applied to those three non-practiced novel mazes. All six mazes occurred five times for each of the pre-test, post-test, and retention sessions.

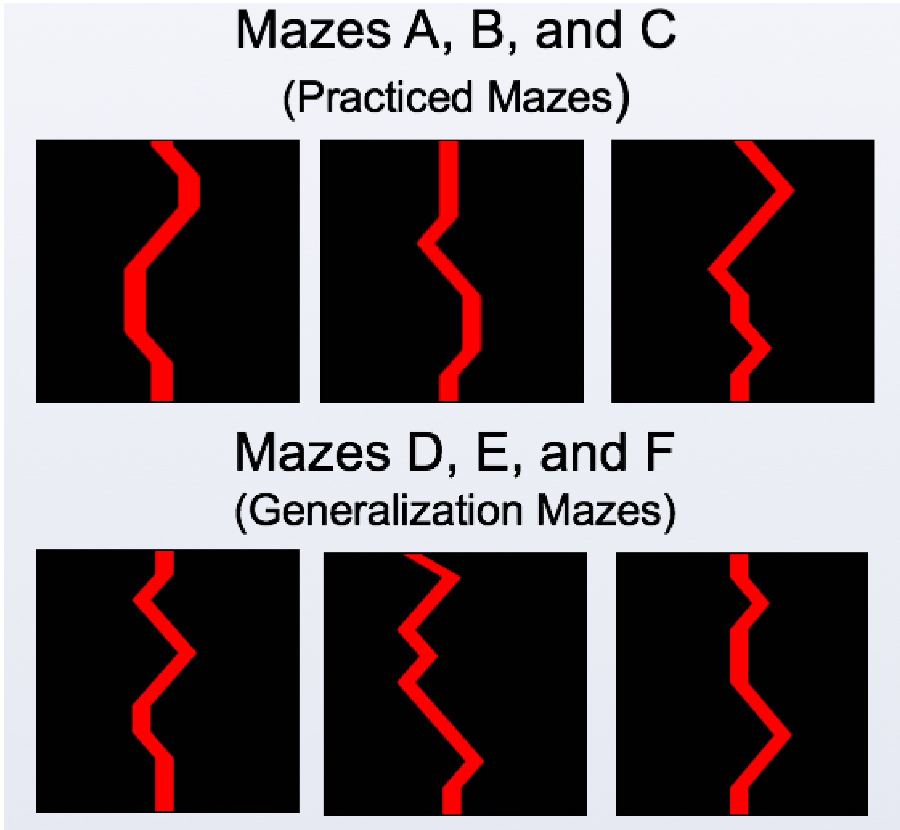

Figure 2. *Six types of mazes used in the Maze Drawing Task.*

The training schedule of the training session, as can be seen in Figure 3, was different for participants in the blocked groups when compared to the variability groups. The variability groups had three similar blocks with variable trials, which were comprised of a random mixture of three mazes, each maze was repeated ninety times. The blocked groups had three different blocks in the training session, each contained 90 trials with one of the three mazes (A, B, and C). These three blocks had six possible orders (ABC, ACB, BAC, BCA, CAB, and CBA), which made six kinds of training session with different block sequence. Such sequences were counterbalanced so that similar number of participants practiced in each kind of training session.

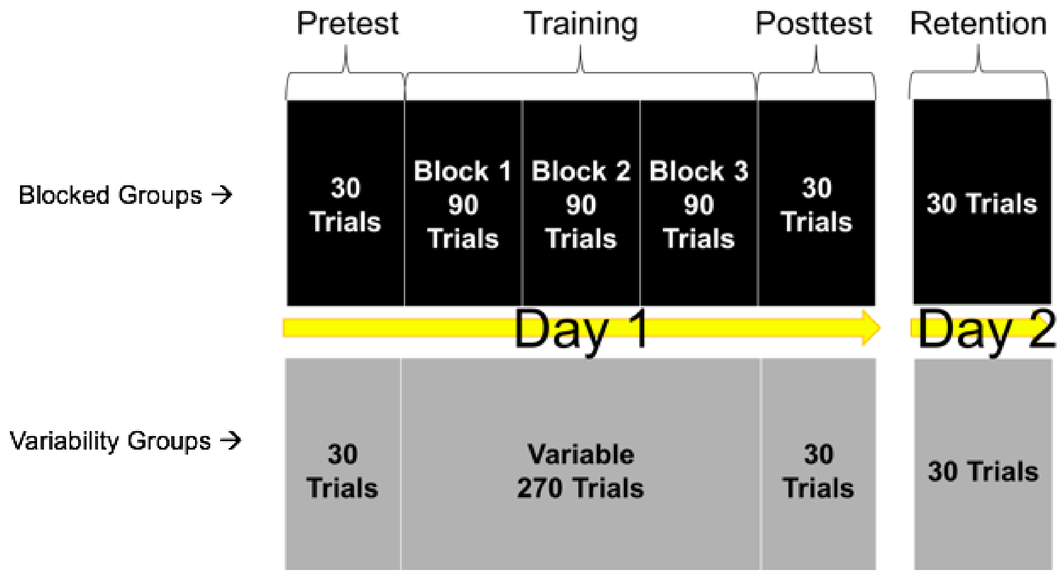

Figure 3. Training schedules of the blocked groups and the variability groups.

Results

Baseline

We used performance in the pre-test session as the baseline data. Since the manipulation of reward and variability was only applied to the training session, participants' performance in the pre-test session was not affected by those two variables. Therefore, the baseline performance should have reflected a participant's normal motor skill ability. The average percentage of time stayed on the maze path was compared across the groups. Results of the pre-test session showed no significant difference across all groups, $F(1,51) = 1.477$, $p = 0.23$. Such results indicated that participants in all four groups did not have much difference regarding normal motor skill ability (Figure 4).

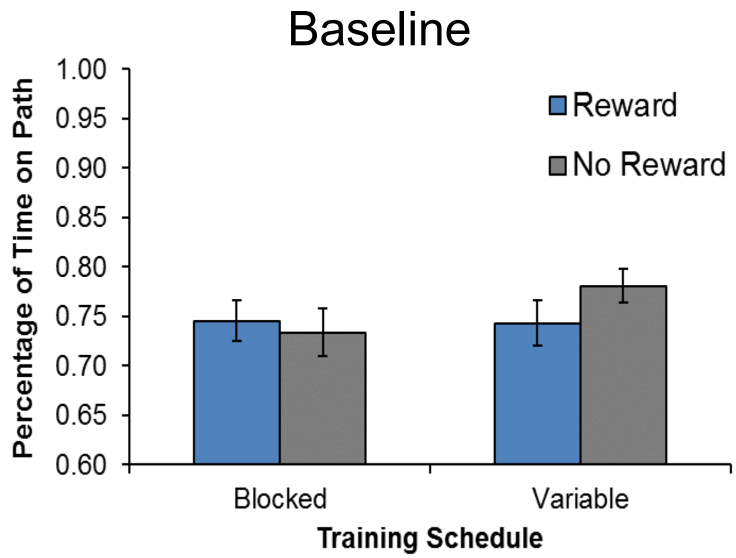

Figure 4. *Baseline performance average of each group. Notice that the group names here do not indicate task conditions. All groups should have the same non-manipulated condition in the pre-test session. Error bars represent standard error of the mean (SEM).*

Training

We analyzed the interaction of reward and variability with participants' performance in the training session (Figure 5). Consistent with our hypothesis, the number of finished blocks had a significant effect on performance, $F(2,102) = 17.749$, $p < 0.001$, $\eta_p^2 = 0.258$. The more blocks participants finished, the better their performance was. A significant difference was detected in both reward groups when compared to groups with no rewarding feedback, $F(2,102) = 3.887$, $p < 0.05$, $\eta_p^2 = 0.07$, which suggested that reward could help participants achieve better performance with practice. Moreover, the effect of variability is significant, $F(2,102) = 3.159$, $p < 0.05$, $\eta_p^2 = 0.058$. This finding indicated that a varied training schedule could improve performance in the training session. However, the interaction between reward and variability was not significant, $F(2,102) = 0.039$, $p = 0.96$. The interplay of those two variables might not make a difference on motor task performance.

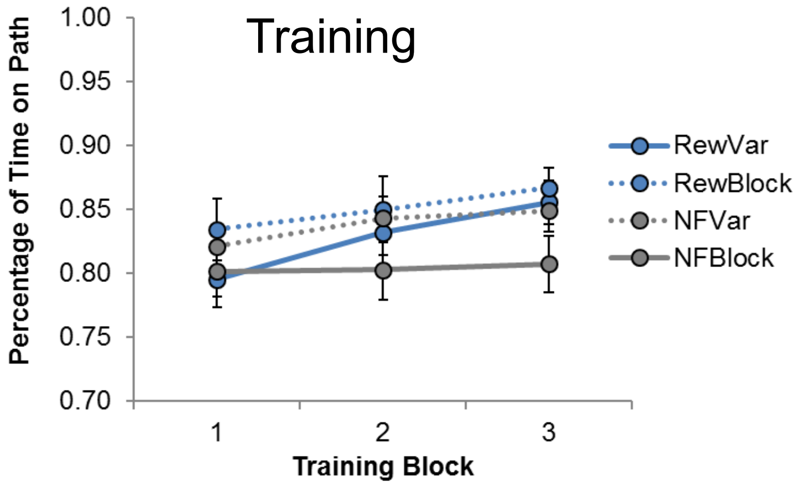

Figure 5. Performance of the training session. RewVar = Reward and Variable, RewBlock = Reward and Blocked, NFVar = No Feedback (reward) and Variable, NFBlock = No Feedback and Blocked. Error bars represent SEM.

Learning and Retention

The motor skill was learned through four sessions of the Maze Drawing Task (Figure 6, left graph). A significant difference was detected when comparing the performance on trials with practiced mazes in three testing sessions to each other (pre-test, post-test, and retention), $F(2,102) = 136.21$, $p < 0.001$, $\eta_p^2 = 0.728$. Such difference between performance in each session illustrated that the learning effect occurred after training, since the performance was the worst in the pre-test session, but improved significantly in the post-test session which followed the training session. In addition, reward also had a significant interaction with testing sessions, $F(2,102) = 4.40$, $p < 0.05$, $\eta_p^2 = 0.08$. This suggested that reward could improve the learning of motor skill. There were no significant results when analyzing the interaction between reward and variability, indicated that their interplay did not make a difference on motor skill learning, $F(2,102) = 1.70$, $p = 0.19$.

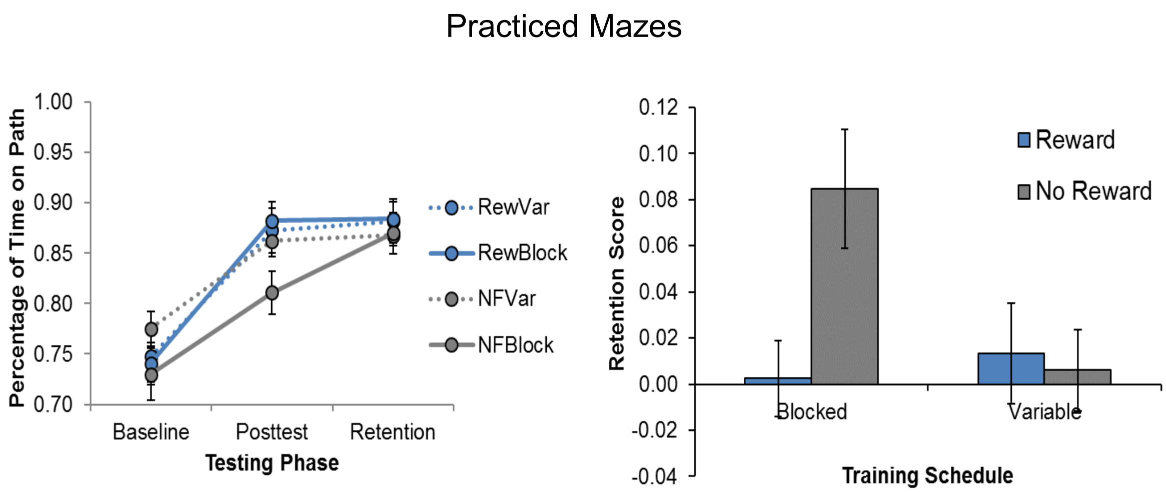

Figure 6. Learning and retention performance of the practiced mazes. Error bars represent SEM.
Left graph: Performance of each group in three test sessions
Right graph: Retention score of each group

Observed results for the retention of learned skills was inconsistent with our predictions. This surprising finding regarding retention score for the practiced mazes is detailed in Figure 6, right. Retention score reflected how well participants retained their motor skill learned during the first visit. Retention score was calculated with the following formula:

$$\text{Retention score} = \left(\frac{\%\,Time\ on\ path\ day\ 2 - \%\,time\ on\ Path\ Day\ 1\ Post{-}test}{\%\,Time\ on\ path\ pre{-}test}\right)$$

Thus, a positive retention score meant participants had better performance in the second visit compared to their first visit. A negative score, on the opposite, indicated a worse performance in the second visit when compared to the first visit. Results showed that there was a significant interaction between reward and variability, $F(1,51) = 5.092$, $p < 0.05$, $\eta_p^2 = 0.09$. What led to this finding was that the no-reward blocked group (NFBlock) had a much higher retention score than the other three groups as shown in the right graph in Figure 6. Moreover, reward and variability did not make a difference when analyzed separately. This finding illustrates that reward and variability might be insufficient to improve motor skill retention.

The same analysis was run with performance in trials with the generalization mazes. The findings were quite similar to the results of practiced mazes (Figure 7). The learning effect was still significant, $F(2,102) = 99.604$, $p < 0.001$, $\eta_p^2 = 0.661$, and rewarded feedback groups also had significantly better learning results when compared to non-rewarded feedback groups, $F(2,102) = 7.104$, $p < 0.005$, $\eta_p^2 = 0.122$. In contrast to the training mazes, we observed a significant sessions x reward x training interaction, $F(2,102) = 4.606$, $p < 0.05$, $\eta_p^2 = 0.083$, and the reward blocked group performed better at the post-test session than other groups, especially the no-reward and blocked group (Figure 7, left graph). This suggests that reward and blocked training schedule might improve a participant's ability to learn novel mazes. Nevertheless, such improvement did not lead to a good retention score since all groups performed similar in the retention session (Figure 7, left graph). Interestingly, the right the no-reward blocked group had the best retention score (Figure 7, right). Analysis on the retention score of the generalization mazes revealed a significant interaction between reward and variability, however, such impact of interaction was negative, $F(1,51) = 16.13$, $\eta_p^2 = 0.240$. Similarly, the reward groups had significantly worse performance when compared to no-reward groups, $F(1,51) = 7.09$, $p < 0.01$, $\eta_p^2 = 0.122$. Such results indicate that reward and variability might lead to worse retention of motor skills.

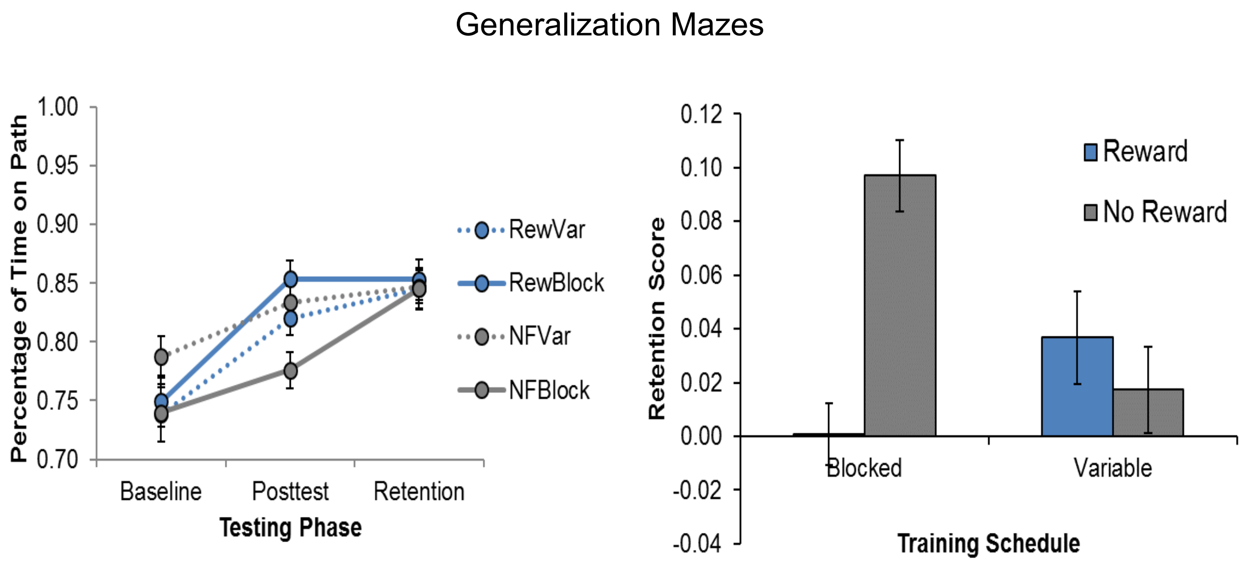

Figure 7. Learning and retention performance of the practiced mazes.
Left graph: Performance of each group in three test sessions
Right graph: Retention score of each group

Personality Traits

No differences were found between the four groups regarding the four personality traits measured with the BIS/BAS Scale (Figure 8). However, contrary to our prediction of the positive correlation between personality traits and retention, no such correlation was found. Instead, the correlations between the four personality traits and retention score were negative for most groups, except for the no-reward blocked group (Figure 9).

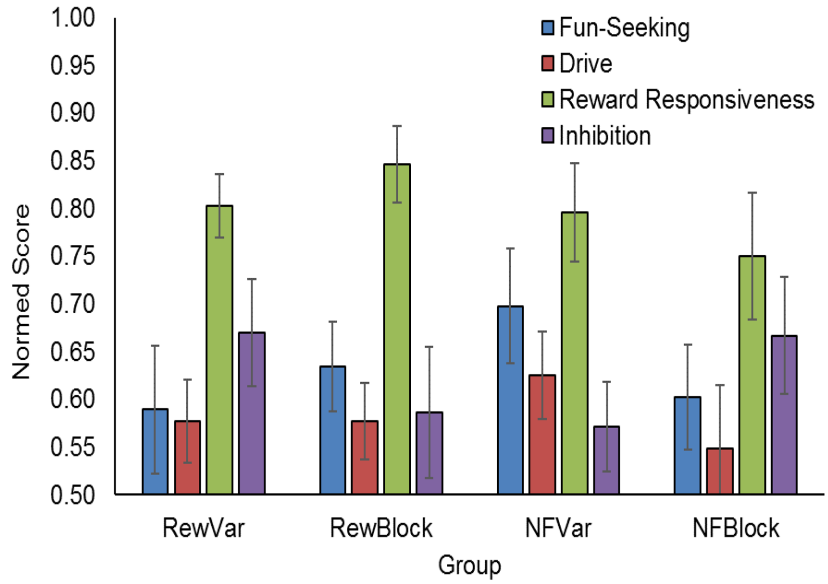

Figure 8. *Average scores of each group on four personality traits.*

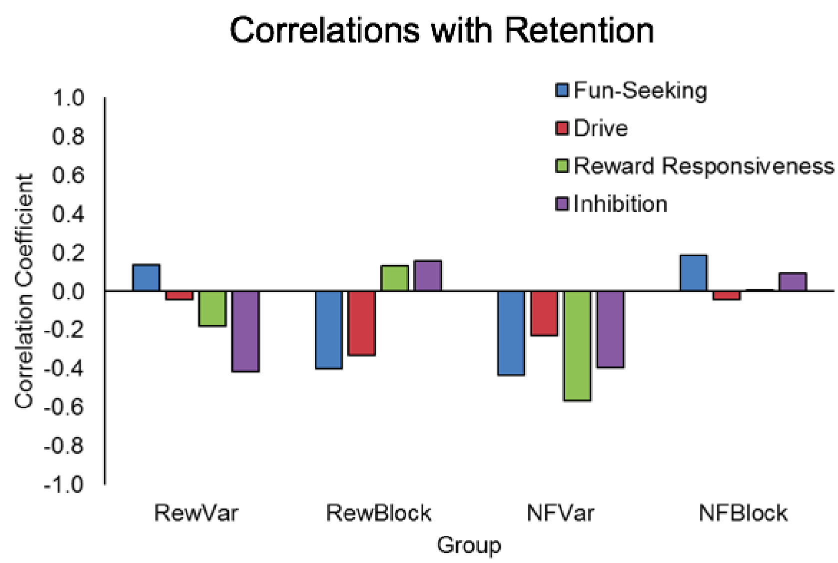

Figure 9. *The correlations between trait scores and retention scores for practiced mazes.*

Discussion

The present study examined the impact of rewarding feedback and variability of training schedule on motor skill learning and retention. Our main findings demonstrated that rewarding feedback can lead to a better learning effect, yet both reward and variability did not help the retention of motor skills. These results support some of our initial predictions, such that participants tended to achieve better performance in the training session and a greater learning effect with the help of rewarding feedbacks. Variable training schedule improved performance in training session, but it did not make a difference in the learning of motor skill. Such findings illustrate that reward and variability both have positive impacts on task performance in the training process, but only rewarding feedback is associated with better learning effect. As for retention, however, the findings were near opposite of our prediction. Neither rewarding feedback nor variable training schedule improved retention. On the contrary, participants in the no-reward blocked group had much better retention scores compared to three other groups, suggested that rewarding feedback and variability of training schedule may impair the retention of a learned motor skill.

Moreover, unlike what we hypothesized, correlations between four personality traits and retention was negative for all groups except for the no-reward blocked group. This finding reflects the possibility that less positive influence brought forth by personality traits during the learning process might be associated with the occurrence of reward and variability. It is possible that personality traits detected by the BIS/BAS Scales could be linked with worse performance when reward and variability occurred, since those four traits could be associated with negative traits, which could have a negative effect on behavior (Carver and White, 1994a). For example, the fun-seeking trait included elements of impulsiveness, which could lead to less desired reaction in response to reward. On the other hand, it was also possible that personality traits might not be a sufficient predictor of the impact of reward and variability in the motor task used in the present study.

Although we provided some evidence for the positive impact of reward on learning effect, there were still many weaknesses and limitations in this study that might restrict us properly understanding the interaction between variability and reward. For instance, our sample size was possibly underpowered. Previous research illustrated that individual differences on learning paths could be a factor that affects motor skill learning (Golenia et al., 2014). Because of our small sample size, the results might be more vulnerable to noise brought by such differences, therefore making it harder to detect the effect of our manipulation.

In addition, the sample in the present study was not very diverse—all participants were undergraduate students of the University of Iowa with similar age and demographic background. According to Henrich et al. (2010), people with different age and culture background could have significant differences even in performance of some simple cognitive tasks, yet most published research samples are derived from western, educated, industrialized, rich, and democratic (WEIRD) societies. Thus, our findings would probably not be convincing enough to be applied to people other than young students of a U.S. university. However, countless studies have demonstrated rather decent external validity (generalizations) from a sample size of college students. The choice of sample should be based on the research question: if generalization was not the aim of the study design, then generalization should not be a concern (Gächter, 2010). Although a small sample size might decrease the chance of detecting significant results, the goal of the present study was not to increase external validity, but to establish sufficient internal validity.

Another weakness of this study would be short training and testing time. As previously mentioned, the time participants spent on the Maze Drawing Task in the first visit was about forty minutes, and the thirty trials in the retention session only took about six minutes to finish.

The two visits were usually conducted within 24 hours. Previous research had suggested that motor skill learning process could have two distinct stages (Kami & Sagi, 1993; Karni et al., 1998). A fast improvement stage could trigger an improvement of skill acquisition in a limited training time (less than an hour), while the post-training gain and retention of motor skill should take a longer time (more than one day) to be evident. Moreover, motor skill training with a long training period and more repeated training sessions would lead to a strengthened retention of trained skills (Lohse, Wadden, Boyd, & Hodges, 2014; Grau-Sánchez, Ramos, Duarte, Särkämö, & Rodríguez-Fornells, 2017). In the present study, although our results showed that learning effect did occur across test sessions in such a short training schedule, the retention did not have a chance to get enhanced before the second visit.

Despite the weaknesses of this study, these findings can provide some insight for better understanding learning and retention of new motor skills. For example, adding rewards in the motor skill learning process can help people get a better learning effect, yet rewarding feedbacks and variability may not lead to an improvement of skill retention. Such suggestion might have potential to be applied for clinical rehabilitation or athletic training, in which reward and variability may be unnecessary for improvement of their physical training or the relearn process of motor function. More training can have a strong positive effect on enhancing learning effect of motor skills even without any reward or varied training schedule (Karni et al., 1998).

More relevant studies could be designed based on the present study to further address the nature of motor skill learning and retention. For instance, future studies may use various types and magnitudes of reward and levels of variability in motor skill learning tasks. Moreover, the present study only examined the learning effect and retention of a small movement with right wrist. Thus, learning and retention of motor skills trained with tasks requiring more movement could be intriguing. Some example tasks can be throwing beanbags, basket shooting, or toys similar to the perplexus ball. Such tasks require much larger and more skillful movements than just moving a mouse, which may highlight information and mechanism of motor skill learning regarding more body parts.

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