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Limited generalization with varied, as compared to specific, practice in short-term motor learning

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ABSTRACT

The schema theory of learning predicts that varied training in motor learning should give rise to better transfer than specific training. For example, throwing beanbags during practice to targets 5 and 9 ft away should better generalize to targets 7 and 11 ft away, as compared to only throwing to a target 7 ft away. In this study, we tested this prediction in a throwing task, when the pretest, practice, and posttest were all completed within an hour. Participants in the varied group practiced throwing at 5 and 9 ft targets, while participants in the specific group practiced throwing at 7 ft only. All participants reliably reduced errors from pretest to posttest. The varied group never outperformed the specific group at the 7 ft target (the trained target for the specific group). They did not reliably outperform the specific group at 11 ft, either. The numerically better performance at 11 ft by the varied group was due, as it turned out in a subsequent experiment, to the fact that 11 ft was closer to 9 ft (one of the two training targets for the varied group) than to 7 ft (the training target for the specific group). We conclude that varied training played a very limited role in short-term motor learning.

1. Introduction

Implicit learning in general relies on incremental improvements over time through feedback and practice. Motor learning research has focused on understanding the mechanisms in which new motor skills are acquired across different learning scenarios (for reviews, see Shapiro & Schmidt, 1982; Schmidt & Bjork, 1992). One of the leading theories, the schema theory, suggests that motor skills are learned through the development of motor schemas that can be generalized to other similar scenarios.

Using the schema theory as a foundation, much of this literature details ways in which motor learning can be optimized. One idea in the general schema theory literature that has recently received increased attention is that variability introduced during practice can improve later performance (Boutin & Blandin, 2010; Breslin, Hodges, Kennedy, Hanlon, & Williams, 2010; Breslin, Hodges, Steenson, & Williams, 2012; Feghhi, Abdoli, & Valizadeh, 2011; Jones & Croot, 2016). The schema theory suggests that practicing different but similar tasks during the same training session should improve learning and long-term retention. For example, a trainee could alternate between shooting a basketball from the free throw line and the three-point line, controlling for shooting angle. While shooting from the three-point line may be more difficult because of the increased distance, the trainee can utilize the same movement plan used at the free-throw line while using a different force. This type of practice, in theory, allows for the trainee to develop a generalized motor program over time that includes a range of forces that are applicable to both the trained target distances and untrained distances (Adams, 1971; Schmidt, 1975). One can contrast between a session that practices shooting to two distances (varied practice) to a session that focuses on shooting to just one distance (specific practice) using the same number of throws. Based on the schema theory, trainees in a varied practice condition should generalize not only to distances located between the two practiced distances (e.g., between the three-point and free-throw lines), but also to a range outside of the practiced distances (e.g., farther than the three-point line or closer than the free-throw line), better than a specific practice group that practiced at only one distance. Predictions based on the schema theory are in contrast with theories in other implicit types of learning. Particularly, in perceptual learning, learning is found to be very specific to the trained conditions (Fahle, 2005; Fahle & Poggio, 2002; Gibson, 1969; Sagi, 2011). Specificity in learning would predict that groups have limited generalization to untrained distances regardless of the practice scheme.

Kerr and Booth (1978) were among the first to empirically test the hypothesis that a varied type of practice would result in better generalization than a specific type of practice. In their experiment, grade-school student participants in the specific group practiced throwing to one target distance (e.g., 4 ft away) and those in the varied group practiced throwing to two target distances (e.g., 3 ft and 5 ft away)

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within the same number of practice trials. Kerr and Booth (1978) found that, after long-term physical education training at the students' school, the varied group performed better than the specific group at the exact distance that the specific group had practiced at. These advantages of varied practice have mostly been described to occur only after a long-retention period. Research on variability in short-term retention after a single practice session has mixed findings. Some researchers were unable to find advantages of varied practice in the short term (Feghhi et al., 2011; Schmidt, 1975; Schmidt & Bjork, 1992); some have found disadvantages (Shea & Morgan, 1979); while others have found benefits after short-term retention and practice (Gabriele, Hall, & Buckolz, 1987).

Beyond varied and specific training, however, there has been some research to investigate varying sources of variability on short-term performance. The current study seeks to use Kerr and Booth's (1978) paradigm to investigate the extent to which variability from different sources can influence short-term performance at trained and untrained target distances in a simple motor learning task. There are many potential sources of variability that may influence how generalization manifests after varied and specific training schedules. In the following experiments, we investigated how variability affects motor learning acquisition in a novel throwing task with adult participants. The first goal of the study was to investigate whether there was an advantage of varied training after a short retention period in a throwing-for-accuracy task. Specifically, in the first two experiments, we explored whether varied or specific training could be responsible for generalization away from the trained distance(s). We then investigated the effect of variability from different sources, which were either directly or indirectly related to the task. Specifically, we looked at the effects of variability added as a result of giving a pretest and an increase in contextual interference introduced by switching hand throughout practice. Further, we investigated how knowledge of results may influence transfer performance. In general, the schema theory would predict that when variability is decreased within the methodological procedures one would see a decrease in generalizability to untrained distances, particularly within the specific practice group.

2. Experiment 1: Specific (7 ft) and varied (5 and 9 ft) training groups tested from 3 to 11 ft

2.1. Method

We recruited 60 participants from the UCLA human participant pool. All participants had normal or corrected-to-normal vision and two participants were left-handed. They threw a 9.05 oz. beanbag to various distances during a pretest, two practice blocks, and a posttest. During all throws, the participant threw the beanbag over their shoulder, with their back facing the targets, in order for the task to be sufficiently difficult. All target distances were marked on the ground from the participant's standing position. The targets ranged from 3 to 11 ft in two-foot increments (total of 5 distances). After each trial, a trained research assistant recorded the thrown distance by measuring the shortest distance from the beanbag to the nearest target line.

2.1.1. Pretest

During pretest, participants threw 12 beanbags (one at a time) to each of the five distances in a blocked design. The order of the five blocks was random. For each distance, participants only viewed once the distance that they aimed for at the beginning of the 12 trials and were given no visual or verbal feedback between trials. The research assistant would indicate when the participant could make their next throw. All throws were made with the participant's non-dominant hand. We chose to test the non-dominant hand to increase the general difficulty.

2.1.2. Practice blocks

Participants were randomly assigned to one of the two practice groups. During practice, the specific group ($N = 30$) aimed their throws for a target 7 ft away, while the varied group ($N = 30$) alternated (every 12 trials) between targets 5 ft and 9 ft away. Both groups completed 60 throws in each of the two practice blocks. Unlike in the pretest, participants were instructed to turn their head to view the result of each throw and were given explicit verbal feedback about the distance of each throw. After each practice block, participants took a five-minute break before continuing. Participants also switched between their hands every six trials in order to reduce fatigue of the tested hand and to retain their attention and interest. We explored how using only one hand throughout the entire experiment affected performance in the varied and specific groups in Experiment 4.

2.1.3. Posttest

After the second 5-minute break, participants began the posttest, which was identical in procedure to the pretest except that the sequential order of the five blocks was reversed.

2.1.4. Analyses

In order to assess learning for each group, we conducted analyses on pretest and posttest data using each set of the 12 individual test trials at each target distance. For each individual test trial, we calculated the signed and unsigned errors by taking the signed or unsigned difference between the target and the landing position. A positive signed error indicated an overthrow to the target. Using these individual errors, we calculated per participant, a constant error, an absolute error, and a variable error to run the analyses. A constant error (CE) is the mean of the individual signed errors. An absolute error is the mean of the individual unsigned errors. A variable error (VE) is defined as follows:

$$\mathrm{VE} = \sqrt{\frac{\sum (\mathrm{CE} - \mathrm{M_{CE}})^2}{\mathrm{N}}},$$

where N = 12, the total number of throws per condition per participant.

Here we focus on analyses using CE and VE, but will mention any notable findings in absolute error in Experiment 1 since Kerr and Booth (1978) found their primary effects between groups using absolute errors. The reason for focusing on CE and VE throughout is because it has been argued that absolute error is a combination of both CE and VE and therefore the CE and VE are all that is needed to understand the nature of the errors made (Schultz & Roy, 1973).

Our predictions were as follows. Errors were expected to decrease from pretest to posttest, if learning had occurred. Since longer distances are naturally more difficult, according to Weber's Law, errors were also expected to increase as the distance increases. Additionally, the varied group was expected to reduce errors more than the specific group, according to the schema theory.

2.2. Results

We first checked for any between-group differences in the pretest in CE. A 2(Group) × 5(Distance) ANOVA was conducted within pretest, and no group differences were found, as expected, $F\ (1, 58) = 0.001$, $p = 0.98$. There was no interaction between target distance and group either, $F\ (4, 232) = 0.98$, $p = 0.42$. As a result, we plotted the pretest performance in Fig. 1 by combining both groups together. A similar null group effect was found for VE, $F\ (1, 58) = 0.44$, $p = 0.509$.

Next, we compared CE between pretest and posttest, and conducted a 2(Group) × 2(Time) × 5(Distance) mixed ANOVA. We found the expected main effect of time, $F\ (1, 58) = 14.97$, $p < 0.001$, $\eta_p^2 = 0.21$, indicating learning. We also found that errors followed a significant negative linear trend across distances, $F\ (1,58) = 53.37$, $p < 0.001$, $\eta_p^2 = 0.48$, indicating the effect of Weber's Law since the

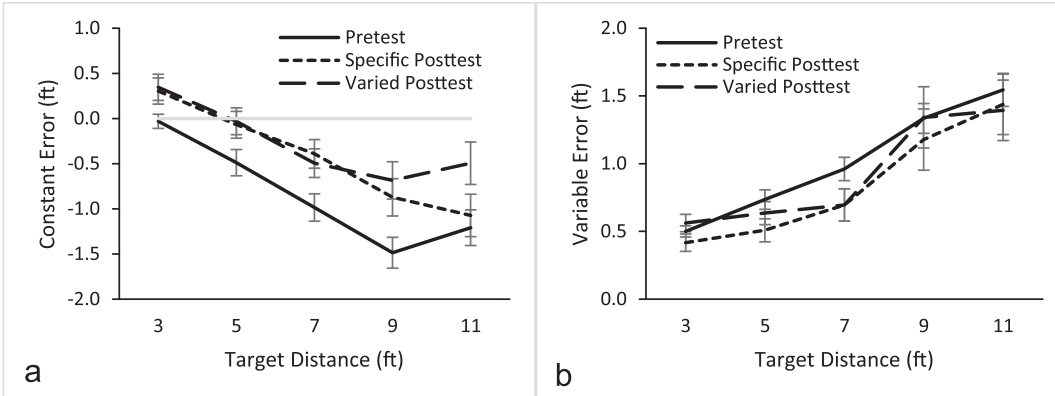

Fig. 1. Average constant error (a) and variable error (b) on pretest and posttest for the specific and varied groups in Experiment 1. Error bars represent standard errors about the mean in all figures. The gray reference line indicates zero constant error, as it does in all figures depicting constant errors. The pretest data were averaged between the two groups as they are in all figures, because no reliable difference could be found between the groups, as expected.

CE was more negative as a function of distance (Fig. 1a). Additionally, there were no differences in the slopes between the two groups, $F(1,58) = 0.23$, $p = 0.63$.

Using VE, we found only an effect of time, $F(1, 58) = 4.00$, $p = 0.050$, $\eta_p^2 = 0.07$, suggesting that the throwing consistency only slightly increased from pretest to posttest (Fig. 1b). We also found that errors followed a significant positive linear trend across distances, $F(1,58) = 113.89$, $p < 0.001$, $\eta_p^2 = 0.66$, suggesting that consistency of throws tended to decrease for longer distances. All other effects were not significant. Results using absolute error were consistent with findings from CE and VE analyses.

Looking at the data at 11 ft in Fig. 1a, one may suspect that the two groups performed differently. We, therefore, conducted a 2(Time) × 2(Group) repeated measures ANOVA using CE at 11 ft, and found an effect across time, $F(1, 58) = 5.25$, $p = 0.023$, $\eta_p^2 = 0.09$. However, this difference was not significant after a Bonferroni correction was considered ($p = 0.01$). Consistent with this null result, the time × group interaction did not reach significance either, $F(1, 58) = 3.15$, $p = 0.081$.

It should be noted, moreover, that any potential differences in posttest performance between the two groups could be due to the proximity of untrained distances rather than the practice schedule itself. For example, the 11 ft mark was closer to one of the two trained distances for the varied group (5 ft and 9 ft) than that for the specific group (7 ft). This issue is addressed in the next experiment. It should also be noted that we will continue to use ANOVA to analyze the data, while being aware that larger distances gave rise to larger variances. We did this for the following reasons. (1) Our critical hypothesis was never about comparing one test distance versus another. Instead, it was about comparing between the two training groups at a fixed distance. Therefore, the variable "distance" was never a main dimension of interest. (2) Using the distance measure, rather than any of their transformations in an attempt to conform to equal variance, would provide direct intuition as how participants performed.

3. Experiment 2: Shifting training from 7 ft to 9 ft for a new specific group

The purpose of this experiment was to examine differences in learning when the distance between untrained and trained target distances between the two groups was equal. In order to test this, the specific group in this experiment used the target distance of 9 ft, while the varied group alternated their practice trials at 5 ft and 9 ft as before. At pretest and posttest, participants were tested at target distances of 9 ft, 11 ft, and 13 ft to investigate generalization from the trained distance. Sixty-nine new participants (35 in the specific group, 34 in the varied group) were similarly recruited in this experiment. All procedures were otherwise the same as in Experiment 1.

3.1. Results

We first analyzed the pretest data. A 2(Group) × 3(Distance: 9, 11, and 13 ft) ANOVA on the pretest errors revealed that the main effect of group was not significant in either CE, $F(1, 67) = 0.02$, $p = 0.90$; or VE, $F(1, 67) = 0.002$, $p = 0.961$, as expected.

A 2(Time) × 2(Group) × 3(Distance) repeated measures ANOVA using CE revealed that there was a main effect of time, $F(1, 67) = 57.26$, $p < 0.001$, $\eta_p^2 = 0.46$; and that errors across distances

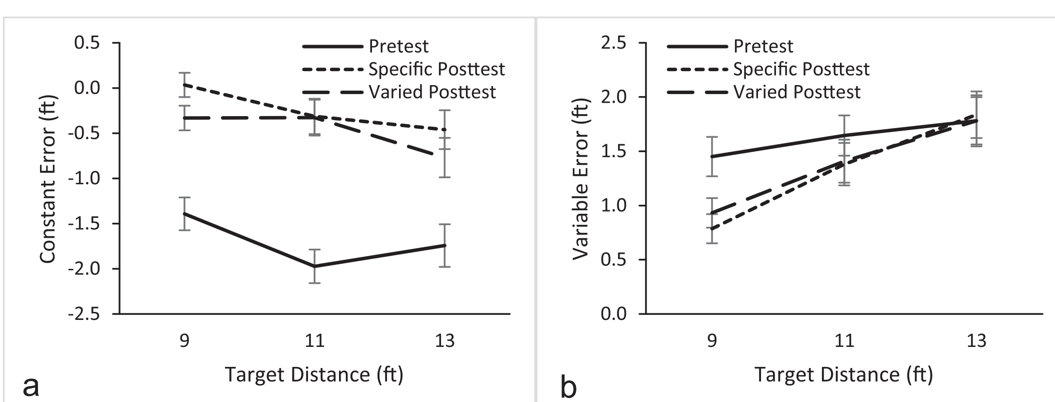

Fig. 2. Constant (a) and variable error (b) in Experiment 2 at pretest and posttest from the specific and varied groups.

followed a negative linear tread, F (1, 67) = 9.06, p = 0.004, η_p^2 = 0.12. All other effects were not significant (Fig. 2a).

Using VE revealed similar results. There was a main effect of time, F (1, 67) = 24.07, p < 0.001, η_p^2 = 0.26; and a positive linear trend across distances, F (1, 67) = 33.73, p < 0.001, η_p^2 = 0.34, as well as a time × distance interaction, F (2, 134) = 3.58, p = 0.031, η_p^2 = 0.05. These results suggested that both groups performed comparably, and the errors increased as the target distance increased, as in Experiment 1 (Fig. 2b).

Both groups similarly improved with practice. The specific group performed as well as the varied group at untrained distances that were equidistant to the nearest trained target in both groups. This suggests that participants could equally generalize performance to nearby untrained target distance regardless of practice schedule.

4. Experiment 3: Restricting pretesting to only 7 ft for both groups

One possibility of the observed transfer effects within the specific group could have been due to how we conducted pretesting. Because the pretest in Experiment 1 included throwing at all five target distances, this may have allowed for a varied-type of practice at all distances. This type of variability is directly related to the training task and the transfer tests. While a pretest was present in both groups, the possibility remains that this varied practice may have induced generalization to untrained distances within the specific group. To address this possibility, we ran the pretest in this experiment only at the 7 ft target distance for both groups.

We recruited 61 new participants (31 in the specific group, 30 in the varied group). This experiment had the same procedure and trained target distances as Experiment 1, but consisted of a pretest of 12 trials at 7 ft only. In order to obtain the most straightforward effect at 7 ft in both groups, we pseudo-randomized the order of posttest target distances. All posttests started with the set of 12 trials at 7 ft, followed by 5 and 9 ft (randomly ordered), then by 3 and 11 ft (randomly ordered). This setup ensured that participants in the specific group only had experience throwing at 7 ft before posttests at other distances.

4.1. Results

CE and VE on pretest at 7 ft were similar between groups, CE: t (59) = 0.67, p = 0.51; and VE: t (59) = 0.17, p = 0.87.

Using CE at posttest, a 2(Group) × 5(Distance) repeated measures ANOVA again found that errors followed a negative linear trend across distances, F (1, 59) = 24.81, p < 0.001, η_p^2 = 0.30, but no group differences were found (Fig. 3a).

Using VE, we found that errors followed a quadratic relationship across distances, F (1, 59) = 13.78, p < 0.001, η_p^2 = 0.19. We also found a main effect of group, F (1, 59) = 4.64, p = 0.035, η_p^2 = 0.07. This result suggested that the varied group had overall greater consistency than the specific group. The interaction effects were not significant.

5. Experiment 4: Practicing with only one hand instead of two hands

In this experiment, we investigated hand switching as one specific form of varied practice. More generally, changing the learning context during a practice session may allow for better reconsolidation and relearning of the next relevant trial. Contextual interference interrupts blocked learning through interleaved or random schedules of tasks that are more or less related to the tested task. By using a random or interleaved practice schedule, contextual interference is thought to promote deeper processing of the interleaved tasks and/or promote forgetting and thus strengthens learning in the subsequent trials of the same task (Barreiros, Figueiredo, & Godinho, 2007; Battig, 1979; Lee & Magill, 1985; Shea & Zimmy, 1983). Boutin and Blandin (2010) also suggest that while the change of context between practice trials is greater when the interleaved tasks are unrelated as compared to when they are related, completely dissimilar tasks may not benefit from contextual interference. Therefore, the degrees of relatedness between interleaved tasks seem to be important for learning (Hall & Magill, 1995). Thus, switching hands between throws may induce greater contextual interference than switching between different target distances. The schema theory would predict that greater contextual interference would decrease performance in the short-term, while increasing performance in the long-term.

In Experiment 4, we examined the effects of reducing the contextual interference induced by switching hands. In the previous experiments, all participants, regardless of practice schedule, periodically switched the hand used for throwing during practice. We did this to both reduce fatigue in the tested hand and to keep the attention of the participant throughout the experiment. In all experiments up to this point, participants switched their throwing hand every six trials regardless of their group assignment. Thus, if participants practice using only one hand throughout the experiment and are subsequently tested on that same hand, the schema theory would predict reduced transfer to untrained distances in both groups. In order to test this prediction, 35 participants (16 in the specific group, 19 in the varied group) used their non-dominant hand for all practice trials. All other procedures were the same as in Experiment 1.

5.1. Results

A 2(Group) × 5(Distance) ANOVA on the pretest errors revealed no between-group differences in either CE, F (1, 33) = 0.03, p = 0.867, or VE, F (1, 33) < 0.001, p = 0.944, as expected.

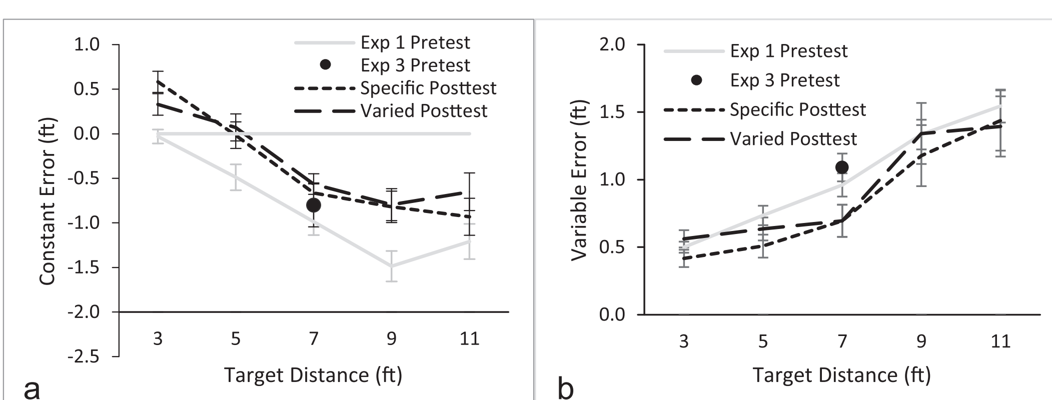

Fig. 3. Average constant (a) and variable error (b) on posttest for specific and varied groups in Experiment 3 (with limited pretest), as compared to pretest scores in Experiment 1.

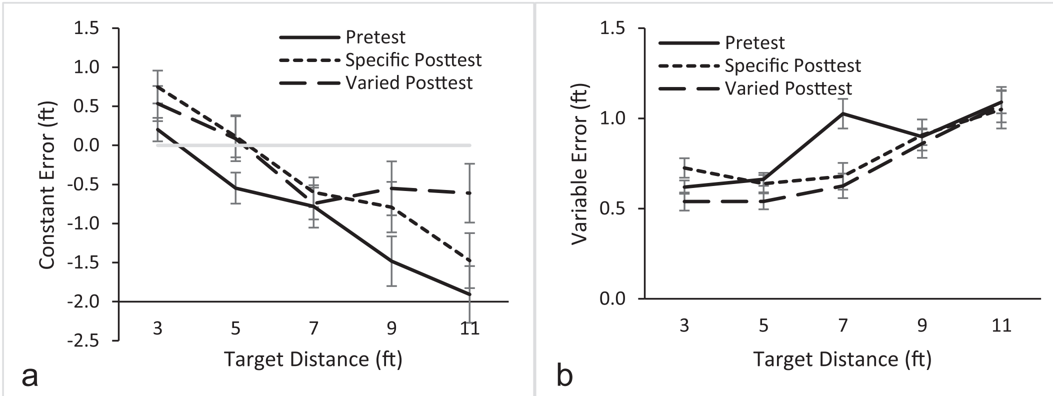

Fig. 4. Average constant (a) and variable error (b) on pretest (collapsed across group) and posttest for the specific and varied groups in Experiment 4 (one-hand training).

A 2(Time) × 2(Group) × 5(Distance) repeated measures ANOVA using CE suggested that there was a main effect of time, F (1, 33) = 10.98, p = 0.002, $\eta_p{}^2$ = 0.25; and a significant negative linear trend across distances, F (1, 33) = 93.43, p < 0.001, $\eta_p{}^2$ = 0.74. All other effects were not significant (Fig. 4a).

Using VE, we found a main effect of time, F (1, 33) = 6.82, p = 0.013, $\eta_p{}^2$ = 0.17; and a positive linear trend across distances, F (1, 33) = 94.18, p < 0.001, $\eta_p{}^2$ = 0.74. We also found a group × distance interaction, suggesting differential learning across target distances, F (1, 33) = 7.85, p = 0.008, $\eta_p{}^2$ = 0.19 (Fig. 4b). Post-hoc analyses between groups at each distance found no significant effects between groups after correcting for multiple comparisons. There was also a time × distance interaction, F (4, 132) = 6.66, p < 0.001, $\eta_p{}^2$ = 0.17, most likely due to the relatively higher VE on pretest at 7 ft in both the specific (M = 1.02, SE = 0.12) and varied group (M = 1.03, SE = 0.11) than at other distances during pretest. No group effects were found.

6. Experiment 5: Reducing visual feedback

The quality of feedback given to the participant during task trials is a central part of the schema theory (Schmidt, 1975; Schmidt & Bjork, 1992). When learning a motor skill that tests for accuracy, it is helpful to receive feedback in order to adjust bodily parameters to get closer to the desired outcome. Visual feedback has been shown to be particularly important for tasks that require accuracy (Adams, 1971; Adams, Gopher, & Lintern, 1975; Salmoni, Schmidt, & Walter, 1984). Along with explicit knowledge of results, visual feedback can be a rich source of information that facilitates learning (Newell, 1974; Schmidt & Wrisberg, 1973). In real world settings, participants have detailed viewings of the environment and can also gain additional implicit feedback about untrained conditions. For example, while shooting a basketball from the three-point line, trainees can also see how far away the free-throw line is in relation to the three-point line, in addition to the visual knowledge of the basket's relative location. Thus, they may implicitly learn about the force needed to shoot at closer targets through feedback made about errors. This may potentially help them to transfer their skill to the free-throw line.

In the experiments so far, all five targets were visibly marked on the ground during the entire experiment. Thus, while turning to receive visual feedback during practice, participants might have implicitly learned information about distances other than those for which they were directly aiming because these targets were visually available to them. By eliminating the visual feedback and reducing the knowledge of results, we wondered whether this would result in an increase of errors due to the increased uncertainty about each throw. We also wondered whether training would become more specific to the trained distances and should reduce the amount of transfer to untrained distances.

To address these possibilities, 30 participants (16 in the specific group, 14 in the varied group) were recruited to run through the same procedures as Experiment 1, except that during practice participants were not allowed to turn around to view the results of their throw and were only provided qualitative verbal feedback ("too far," "too short," or "right on target" after each throw). As in pretest and posttest, participants were instructed during practice to view the target distance (but not the results of any trial) after every 12 trials in both groups (corresponding to when the varied group alternated distances). Although direct visual feedback was eliminated, participants could still view all five targets after every 12 trials.

6.1. Results

A 2(Group) × 5(Distance) ANOVA on the pretest errors revealed no between-groups differences, as expected, in either CE, F (1, 28) = 0.39, p = 0.537, or VE, F (1, 28) < 0.001, p = 0.994.

A 2(Time) × 2(Group) × 5(Distance) repeated measures ANOVA using CE suggested no significant effects other than a negative linear trend across distances, F (1, 28) = 21.48, p < 0.001, $\eta_p{}^2$ = 0.43. These results suggest that little learning occurred in either group (Fig. 5a).

Using VE, we only found a positive linear relationship across distances, F (1, 28) = 77.97, p < 0.001, $\eta_p{}^2$ = 0.74, a main effect of time, F (1, 28) = 10.29, p = 0.003, $\eta_p{}^2$ = 0.27. Visual feedback appeared to have played little role in terms of affecting between-group differences. Across both groups, reduced feedback appeared to have prevented improvement of CE from pretest to posttest, while still improving upon consistency of throws (Fig. 5).

7. Discussion

In the current set of experiments, we found generalization effects of a simple throwing task to untrained distances regardless of practice schedule. Both practicing at one distance (7 ft) and practicing at two distances (5 ft and 9 ft) facilitated transfer to novel target distances in a relatively short acquisition and retention time. In Experiment 1, those participants who practiced at 5 ft and 9 ft performed slightly better at 11 ft than those who only practiced at 7 ft. When the specific group moved their practice distance to 9 ft in Experiment 2, both groups improved similarly at 11 ft and 13 ft. This effect suggested that generalization is limited to proximity in distance to the trained distances, and is not due to varied or specific practice schedules. In this sense, we could consider such generalization as local generalization in that transfer of learning extended to distances nearby the trained targets (2 ft), but not beyond.

This pattern of results was reminiscent of the classic results in

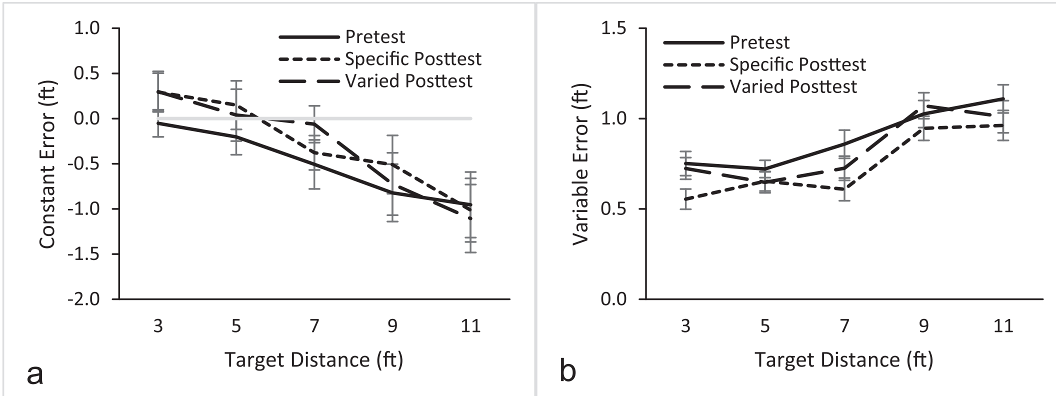

Fig. 5. Average constant (a) and variable errors (b) on pretest (collapsed across group) and posttest for specific and varied groups in Experiment 5 (reduced feedback).

perceptual learning, whose hallmark feature was the so-called stimulus specificity (see e.g., Fahle, 2005 for a review). As an example, in motion discrimination learning, participants determined whether two motion directions were the same or different (Ball & Sekuler, 1987). After training, the participants substantially improved their discrimination ability. However, when the average test direction was rotated away from the trained direction by 90° and beyond, learning did not transfer. This has been termed direction specificity of motion discrimination learning. Yet, even in this classic example of specific learning, there was still partial transfer to an average direction 45° away from the trained direction. This means that there was always limited (or local) generalization around the trained stimulus attributes.

Given that the central theme of the current study was whether varied training induced more generalization than specific training, the overall results were completely consistent with the learning specificity in perceptual learning, as follows. Regardless of training schedule, learning transferred locally within 2 ft, but not beyond. If we use another common finding in perceptual learning as a guide here, we can well explain our data. The common finding in perceptual learning is: transfer was on average between 0% and 100%, and not beyond 100%. In other words, performance at a novel test distance (e.g., 11 ft) should be expected to be poorer than at the trained target distance (e.g., 9 ft). To illustrate, we can look again at the results from Experiment 1 in Fig. 1. At the most difficult target, 11 ft, the varied group outperformed the specific group probably because this distance was closer to one of their trained targets than was the specific group's trained target. At 5 ft, 7 ft, and 9 ft, the two groups performed comparably, probably because local transfer of the varied group from both 5 ft and 9 ft facilitated this group's performance at 7 ft, the trained target for the specific group. Similarly, it could be that local transfer of the specific group from 7 ft facilitated this group's performance at 5 ft and 9 ft. Incidentally, we comment that, although Kerr and Booth (1978) found that their varied group outperformed (not just matched) the specific group at the latter's trained target (equivalent here 7 ft), we could not find such result in our study.

Therefore, in Experiments 3 and 4, although we found a small advantage for the varied group over the specific group, particularly at 11 ft, this could be explained just as well by the local generalization of specific learning as by the reduced pretest. Additionally, results across all experiments were generally consistent, suggesting that these manipulations of variance associated with our methodology did not have a significant effect. We believe it is fair to say that the evidence was not overwhelming for a varied training advantage. Instead, our data were largely consistent with the hypothesis that motor learning in beanbag throwing was specific and only generalized to nearby distances, regardless of training schedule. This local generalization is closely analogous to the classic perceptual learning and, in fact, in visual object recognition (see e.g., Liu, 1996). Nevertheless, there have been recent developments in visual perceptual learning that indicated generalizable learning (Ahissar & Hochstein, 1997; Rubin, Nakayama, & Shapley, 1997; Liu & Vaina, 1998; Liu, 1999; Xiao et al., 2008). These new developments are conceptually consistent with the schema theory. Our future studies in motor learning will apply these newly developed techniques in perceptual learning to investigate the extent to which motor learning can generalize.

Our results also logically support the schema theory even though they do not support findings from Kerr and Booth (1978). Both groups generalized to untrained target distances 2 ft away from their trained distance(s). Improved performance at untrained distances, especially in specific group, suggests that participants indeed formed a generalized motor program that they used to improve at untrained distances. Kerr and Booth (1978) focused on transfer to distances located between the varied groups' trained distances (and at the specific group's trained distance) and did not test shared untrained distances. Some research suggests that, as in Kerr and Booth (1978), the advantage of the varied group only manifests after a long retention period. However, these studies have also suggested that after a short-term retention period, specific group should perform better at their trained distance than the varied group does at that same distance, which we also did not find. In a separate paper, we explore this same motor learning task in a set of long-term experiments to investigate the role of variability of practice schedule on generalization over the course of weeks (Willey & Liu, in press).

In conclusion, the current set of experiments shed light on the generalizability of specific and varied practice groups in short-term motor learning. While the focus of the current paper is on motor learning, it would be beneficial to carry out similar experiments within other types of learning domains, which would arguably use different parameters and feedback to acquire proficiency. The extent to which variable practice can influence different types of learning and how parameters of a given task interact with varied and specific practice schedules in short-term and long-term learning are still open questions that should be addressed. The current set of studies investigated differences in performance as a result of specific and varied training schedules in a simple motor task. We additionally manipulated task parameters in order to investigate how they might interact with varied and specific practice schedules. We found that variability during training had a limited effect on performance and generalizability. As these experiments have demonstrated, both types of practice groups were able to generalize to nearby distances and any benefit of a varied group over a specific group may be limited to how proximal untrained target distances are to trained target distances. Future studies could investigate the range of generalization to untrained distances in relation to the range of trained distances.

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