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Specificity and Transfer of Learning

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Abstract

Knowledge is often highly specific to the conditions of acquisition, so there is limited transfer of learning from training to testing. A series of studies is reported examining specificity and transfer of learning in three very different tasks, including digit data entry, speeded aiming, and time production. These studies address a variety of theoretical issues, including those involving mental practice, variability of practice, and task integration. Despite these differences across studies, they converge on the conclusion that specificity and transfer of learning are not mutually exclusive. That is, significant specificity can occur even when participants appear to transfer their learning from training to testing. Furthermore, the studies show that the extent of transfer and its direction (i.e., positive or negative) is largely dependent on the definition of transfer employed, the baseline level during training (i.e., start or end of training), and the dependent measure used to assess performance (e.g., initiation time or execution time).

1. Introduction

We would like to believe that humans are adaptive and can easily apply previously learned information to new situations. However, research has shown that learning is often highly specific, and a number of theoretical explanations have been proposed to explain such specificity effects, including, for example, the theories of identical elements (Singley & Anderson, 1989; Thornidke, 1906), encoding specificity (Tulving & Thomson, 1973), transfer appropriate processing (Morris, Bransford, & Franks, 1977; Roediger, Weldon, & Challis, 1989), and procedural reinstatement (Healy, 2007; Healy, Wohldmann, & Bourne, 2005a). One purpose of our own research program has been to explore ways of promoting generalization of knowledge and skills. The focus of the present chapter, however, is on the issue of how to determine whether learning is specific or whether instead there is transfer of learning between training and testing. After reviewing some critical definitions and contrasts and then discussing general issues involved in measuring transfer, we summarize the results of three sets of empirical studies examining specificity and transfer. These studies involve very different tasks requiring different sets of cognitive processes (digit data entry, speeded aiming, and time production), and they focus on very different theoretical issues (differences between mental and physical practice, possible advantages of variable practice, and integration of primary and secondary tasks into a single functional task). Nevertheless, the empirical studies converge because each one leads to the same conclusion, namely that specificity and transfer of learning are not mutually exclusive, they can coexist in the same data set, and whether or not there is evidence for specificity or transfer depends on the measure used to assess these constructs.

2. Definitions and Contrasts

2.1. Transfer and retention

Transfer of learning is highly related to retention of learning. In both cases, performance is assessed both during learning itself and during testing after learning is completed, with the test often occurring after a delay. In the case of pure retention, the same tasks are examined during training and testing, whereas in the case of transfer different tasks are examined during training and testing. Naturally, previous studies that have included assessments of both pure retention and transfer have typically shown better performance at test when pure retention is assessed (i.e., when the training task matches the testing task) than when transfer is assessed (i.e., when the training and testing tasks differ) (see, e.g., Schneider, Healy, Barshi, & Kole, 2011).

For assessments of transfer, when the two tasks are closely related "near transfer" is evaluated, whereas when they are more distantly related "far transfer" is evaluated. Thus, depending on the similarity between the tasks used during training and testing, there can be a continuum of evaluations ranging from pure retention to far transfer. Most research on transfer has focused on tasks that are highly similar to the training tasks, but many current studies (see Morrison & Chein, 2011, and Tang & Posner, 2009, for reviews) have examined transfer for tasks that are quite different from the training tasks, in an effort to see whether general skills or abilities, such as those involving working memory or attention, can be trained.

2.2. Transfer and specificity

Related to issues of transfer of training are those concerning specificity of training. The effects of training might be highly specific to the training task or might instead be generalizable to different tasks, even those that are related to the training task only remotely. That is, specificity of training would be evident when there is little transfer, whereas generality of training would be evident under conditions demonstrating transfer, especially far transfer. The typical method used to assess specificity is to compare performance at test on old and new tasks, where old tasks were the ones used during training and new tasks were introduced for the first time on the test. This comparison of old and new tasks might be made within subjects if the subjects are given both tasks during the tests. Alternatively, different groups of subjects could be compared that are given only a single task at test, with the groups differing in whether or not the task at test is the same as at training. In that case, test performance for the same group is compared to test performance for the switch group, with specificity indicated by an advantage for the same group relative to the switch group.

3. Measuring Transfer

3.1. Baseline level

To assess transfer, performance during testing needs to be compared to some baseline level. The baseline level used could be derived from either performance during training itself, performance during a pretest occurring before training, or performance by a control group of participants given no training, depending on the experimental design. Positive transfer (or facilitation) would be evident when performance at test is better than the baseline level, whereas negative transfer (or interference) would be evident when performance at test is worse than the baseline level. When the baseline used involves performance during training itself, the question arises when during training should the baseline be measured. If the baseline is measured at the start of training and compared to performance at the start of testing, any change from training to testing would be considered transfer, whether positive or negative. Such a measure would be relatively lax and might reflect situations in which transfer is only partial rather than complete. On the hand, a stricter measure of transfer would occur by measuring the baseline at the end of training and comparing it to performance at the start of testing, as is typically done to measure retention. In that case, the question is whether what was learned during training is fully transferred to the testing situation.

3.2. Dependent measures

A complex task has many different components that can be measured in different ways. These dependent measures might not agree with respect to the issue of whether or not there is transfer of training. For example, accuracy and speed of responses might show different patterns, reflecting a possible speed-accuracy tradeoff (see, e.g., Healy, Kole, Buck-Gengler, & Bourne, 2004; Pachella, 1974). The assessment of whether or not there is transfer might yield different results depending on which dependent measure is chosen. For example, it is possible that positive transfer would be evident with an accuracy measure at the same time as negative transfer would be evident with a response time measure (or vice versa). Even two different response time measures might yield conflicting evidence about transfer. For example, total response time can be broken down into multiple components, with a measure that reflects the time to initiate a response yielding different results with respect to transfer than a measure that reflects subsequent movement. In fact, as summarized below, results from our studies on speeded aiming yield different conclusions about the presence of transfer when examining these components (initiation time and movement time), separately (Wohldmann & Healy, 2010).

Finally, as mentioned previously, for the same task and the same dependent measure, transfer could involve stimuli or responses that are highly similar to the learned stimuli or responses (near transfer) or it could involve stimuli or responses that are quite dissimilar from the learned stimuli or responses (far transfer). Again, as summarized below, our studies on speeded aiming assessed both near and far transfer, although in this case the same conclusions were reached on the basis of both of those assessments (Wohldmann & Healy, 2010).

4. Empirical Studies

Many studies show specificity of learning, with little transfer from training to testing (e.g., Healy, Wohldmann, Parker, & Bourne, 2005b). However, some studies show conditions that do promote transfer of learning, and in fact transfer of learning can under some circumstances be superior to pure retention (Wohldmann, Healy, & Bourne, 2008a). Furthermore, transfer of learning can be promoted in some cases by varying the practice regimen. However, the benefits of variable practice appear to be limited to certain conditions that are not well understood (Healy, Wohldmann, Sutton, & Bourne, 2006; Wohldmann, Healy, & Bourne, 2008b). We review here three different lines of investigation examining specificity and transfer of learning using a variety of tasks and procedures. These tasks include digit data entry, speeded aiming, and time production, and the theoretical issues they address include mental practice, variability of practice, and task integration. These studies, thus, vary in many respects but together lead to some general conclusions about the assessment and measurement of specificity and transfer.

4.1. Digit data entry: Mental practice

Motor imagery, or mental practice, is defined as covert movements in the absence of any overt movements, and a number of studies have demonstrated the effectiveness of such practice on subsequent physical performance (e.g., Decety & Jeannerod 1995; Driskell, Copper, & Moran, 1994). Previous research, however, left many questions unanswered regarding the effectiveness of mental practice. For example, from an applied perspective, what are the conditions under which motor imagery can be used to learn a motor skill, and do mental and physical practice differ with respect to skill learning and retention? In addition, and most relevant to the present focus on specificity and transfer, can motor imagery be used to improve a general motor skill, resulting in transfer that extends beyond the particular information presented during the learning phase? Furthermore, is transfer of learning from mental practice to a physical test comparable to or different from retention of learning from physical practice to a physical test? From a theoretical perspective, what type of mental representation is formed and strengthened through motor imagery, and does that representation differ from one formed through physical practice?

Wohldmann, Healy, and Bourne (2007, 2008a) attempted to address those questions in a series of experiments using a task that involved digit data entry developed by Fendrich, Healy, and Bourne (1991). In this task, subjects are presented with four-digit number sequences, one at a time, and they are asked to type each number before pressing the spacebar or enter key, which ends a trial and begins the next. In most of the previous studies, no visual feedback was provided so subjects could not see their typed responses as they were being made.

The nature of this task makes it well suited for the study of mental practice because it is a sequential task with both cognitive and motoric requirements that can be examined separately though different components of response time. More specifically, in addition to accuracy and total response time, response initiation time (which is the time that it takes to type the first digit of the four-digit number after the onset of the number) and response execution time (which is the average time to type the second, third, and fourth digits after typing the first) served as the main measures of performance. Previous studies have shown that initiation time primarily reflects the cognitive aspects of the task, such as encoding and planning, whereas execution time primarily reflects the motoric aspects (e.g., Buck-Gengler & Healy, 2001; Fendrich et al., 1991; Healy et al., 2004).

4.1.1. Wohldmann et al. (2007): Mental vs. physical practice. In one experiment, Wohldmann et al. (2007) examined the effectiveness of mental practice for skill learning and retention across a 3-month delay. During familiarization, right-handed subjects used their right hand to practice typing on the keypad 64 numbers five times each and were immediately tested on both old (presented during familiarization) and new (not presented during familiarization) numbers. One, and then 2 months later, subjects returned for refresher training during which time they were assigned to one of four experimental conditions. Subjects in the physical-same condition typed each four-digit number with their right hand, just as they did during familiarization. Subjects in the mental condition were given first-person motor imagery instructions. Specifically, they were asked to imagine, as vividly as possible, typing each number with their right hand while gripping a computer mouse to preclude finger movements. Those in the physical-switch condition were asked to type each number with their right hand on the key row, instead of on the keypad that was used during familiarization. Finally, subjects in the no-practice control condition performed tasks that were irrelevant to data entry. During this phase, the other groups of subjects practiced the same 64 numbers five times each as were practiced during familiarization. Finally 3 months after familiarization, subjects returned for a second typing test, again, which included both old and new numbers that all subjects typed on the keypad using their right hand.

Sequence learning was measured in terms of repetition priming, that is, faster or more accurate performance on old compared to new numbers. Retention was measured as the change in response times between immediate and delayed testing on old numbers, so no change would demonstrate perfect retention and an increase in response times would demonstrate forgetting of old numbers. Skill acquisition, or transfer (learning that extends beyond the practiced sequences), was measured as a change in response times between immediate and delayed testing on new numbers. In this case, a decrease in response times between the two tests would suggest transfer of learning.

For execution time, all subjects showed a repetition priming effect on the immediate test. That is, old numbers were typed significantly faster than new numbers, demonstrating specificity of learning. This effect did not depend on condition, which is important because the condition manipulation occurred during subsequent refresher training. However, there was not a difference between old and new numbers for initiation time.

Figure 1 shows the results for retention--execution and initiation times for *old* numbers as a function of test (immediate and delayed) and training condition. With respect to execution time subjects in the mental and physical-same conditions showed perfect retention of old numbers, suggesting that either mental or physical refresher training can be used to maintain sequences once they are learned. However, subjects in the no-practice and physical-switch conditions showed significant forgetting across the 3-month delay, suggesting that either no practice or practice with a different configuration hurts retention. With respect to initiation time, there was forgetting from the immediate to the delayed test, and that decline was larger in the physical-switch condition than in any of the other conditions.

Figure 1 also shows the results for skill acquisition—execution and initiation times for *new* numbers as a function of test (immediate and delayed) and training condition. For the measure of initiation time, there was no improvement across tests for any of the conditions, thus providing no evidence for skill acquisition by this measure. In contrast, for the measure of execution time, subjects in the mental and physical-same conditions showed significant improvement on new numbers, suggesting that either mental or physical refresher training can be used to improve the general skill of data entry. However, subjects in the no-practice and physical-switch conditions showed no improvement in the general skill of data entry. In fact, those in the physical-switch condition showed negative transfer on new numbers (i.e., faster times on the immediate than on the delayed test).

The findings from the physical-switch condition were curious, leading to the question of whether learning would be susceptible to interference when refresher training involved mental practice as was found when it involved physical practice. Previous research suggested that mental practice contributes to the acquisition of an effector-dependent representation, that is, learning to associate the effectors (in this case, fingers) with their assigned responses (Nyberg, Eriksson, Larsson, & Marklund, 2006). If this hypothesis were true, then mental practice with a response configuration different from that used during familiarization and final testing was expected to yield similar results as those found for subjects in the physical-switch condition.

4.1.2. Wohldmann et al. (2008a, Experiment 1): Switch response configurations. Thus, Wohldmann et al. (2008a), conducted a second study in which right-handed subjects practiced typing numbers with their right hand during familiarization and were immediately tested on both old and new numbers. One and then 2 weeks later, subjects returned for refresher training during which time they were assigned to one of two experimental conditions. Subjects in the physical condition typed each four-digit number with their right hand, and those in the mental condition imagined typing each number with their right hand while gripping a computer mouse to preclude finger movements. To examine effector dependence, all participants switched response configurations during refresher training, and the order of response configurations was counterbalanced across subjects. Specifically, half of the subjects were familiarized and tested on the key row but used the keypad during refresher training, and the remaining half were familiarized and tested on the keypad but used the key row during refresher training. Finally 3 weeks after familiarization, all subjects returned for a delayed test, which included some of the old and some new numbers that subjects typed with their right hand and with the configuration used during familiarization and the immediate test.

On the immediate test, for execution time, as was found previously, subjects showed a repetition priming effect such that old numbers were typed significantly faster than new numbers, again demonstrating specificity of learning. As in the previous experiment, this effect did not depend on condition. However, there was no repetition priming evident for initiation time.

Figure 2 shows the results for execution and initiation times as a function of test (immediate, delayed) and training condition for *old* numbers. For the measure of execution time, subjects in the mental condition showed perfect retention of old numbers, but those in the physical condition showed significant forgetting of old numbers. This forgetting was attributed to retroactive interference effects, forgetting of old motor movements due to rehearsing new movements between original learning and later testing. There was no significant forgetting, and there were no significant differences across conditions in retention for the measure of initiation time.

Figure 2 also shows the results for execution and initiation times as a function of test (immediate, delayed) and training condition for *new* numbers. For execution time, subjects in the mental condition showed a trend of general improvement in the skill of data entry, but those in the physical condition showed no such improvement. In contrast, there were no significant effects of either test or condition on initiation time.

The results of this experiment suggest that, at least in some situations, mental practice may actually be better than physical practice in terms of retention and transfer. Mental practice with a new configuration led to less forgetting and more positive transfer than did physical practice. There was also evidence that subjects in the mental condition were following instructions, ruling out this factor as a potential explanation for the results. That is, despite the instructions to use a new configuration and despite the fact that the configuration practiced during familiarization was occluded from view during refresher training, participants in the mental condition might have continued rehearsing with the original configuration learned during familiarization. Buck-Gengler and Healy (2001) found that it took significantly longer to type physically on the key row than on the keypad, and that same pattern was found in the physical condition of the present experiment. Thus, if participants in the mental condition were practicing mentally the correct response configuration, they should also have shown longer response times when practice involved the key row compared to the keypad, and that is exactly what was found, with the effect of response configuration roughly equivalent in the mental and physical conditions.

So, returning to the question of why, in this case, mental practice was more effective than physical practice, Wohldmann et al. (2008a) hypothesized that mental practice strengthens an effector-independent representation, whereas physical practice strengthens an effector-dependent representation.

4.1.3. Wohldmann et al. (2008a, Experiment 2): Switch hands. A final experiment included a stronger manipulation of effector dependence to provide further evidence for this hypothesis. Subjects were asked to use only their index finger for responding, and half of the subjects switched hands between the immediate and delayed tests, whereas the remaining half used the same hand during all phases. Varying hands is a more powerful and more direct manipulation of effectors than is varying response configurations.

More specifically, during familiarization, right-handed subjects practiced typing four-digit numbers five times each with either their right or left hand. As in the previous studies, subjects were then given an immediate typing test during which they used the same hand to type both old and new numbers. Next, during training, subjects were asked to type, either physically or mentally, the same numbers as were learned during familiarization, again, five times each, using either the same hand or the opposite hand. Subjects in the mental condition were, again, given first-person motor imagery instructions, and were required to grip a computer mouse to preclude finger movements. Those in the physical condition merely continued typing each number. Finally, a delayed typing test was given, which involved typing both old and new numbers with the same hand as was used during familiarization.

For execution times, all subjects showed a repetition priming effect on the immediate test, with old numbers being typed significantly faster than new numbers, demonstrating, again, specificity of learning. This effect did not depend on condition. In contrast, the repetition priming effect was not evident for initiation times.

Figure 3 shows the results for retention (i.e., on *old* numbers) in terms of both execution and initiation times. With respect to execution time, for participants who used the same hand throughout the experiment, perfect retention was evident and, in fact, response times improved between the two tests. Moreover, the benefits of mental practice on retention were similar to those of physical practice. In contrast, for participants who switched hands during training, response times improved between the immediate and delayed test for those in the mental condition but not for those in the physical condition, who showed instead signs of retroactive interference. The pattern of results for initiation time is different from that for execution time. For initiation time performance was actually better on the immediate test than on the delayed test, especially with mental practice when the same hand was used during training and testing, suggesting some forgetting, rather than improvement as a result of training.

Figure 3 also shows the results for skill acquisition (i.e., on *new* numbers) for both execution and initiation times. In terms of execution time, for participants who used the same hand throughout the experiment, skill learning was evident. There were no differences in transfer effects for the two types of practice. In contrast, for participants who switched hands during training, larger improvements were found between the immediate and delayed test for those in the mental condition than for those in the physical condition. Again, the results for initiation time are different from those for execution time. By that measure, there is a modest improvement in performance from the immediate to the delayed test as a result of training for all conditions except, surprisingly, the condition with mental practice when the same hand was used during training and testing.

The results of this experiment provided further support for the claim that, in some situations, mental practice may actually be better than physical practice with respect to its benefits on retention and transfer. The findings support the idea that mental practice strengthens an effector-independent representation, whereas physical practice strengthens an effector-dependent representation, and only the effector-dependent representation suffers from retroactive interference caused by training with different effectors than those used in familiarization and testing.

In addition to these theoretical implications, the results of this study have important practical applications. Specifically, they demonstrate that, when the opportunity to practice physically is precluded, mental practice can be used to maintain performance, perhaps even when practice involves different effectors. This might be particularly relevant to recovery of movements, such as relearning to walk after a stroke.

Moreover, this research suggests that, in some ways, mental practice can be superior to physical practice!

Along with these important theoretical and practical implications are two notable methodological implications concerning the assessment of transfer. First, the last two experiments reviewed here, showing that mental practice was superior to physical practice, seem to violate an assumption discussed earlier and verified in previous studies (e.g., Schneider et al., 2011) that measures of pure retention yield higher levels of performance than measures of transfer. In these experiments, retention and transfer were both measured by comparing performance on the delayed test to that on the immediate test. When old numbers were examined, we labeled the assessment "retention" because the same stimulus sequences occurred during training and testing, whereas when new numbers were examined, we labeled the assessment "skill acquisition" because different stimulus sequences occurred during training and testing. However, because testing involved physical typing in each case, the conditions involving physical practice can be viewed as assessing pure retention, whereas the conditions involving mental practice can be viewed as assessing transfer. We found that when practice involved a switch either in response configurations or in hands, mental practice was superior to physical practice, so that, according to this view, the measure of transfer actually yielded more improvement than did the measure of pure retention. These novel results are due in part to the fact that the determination of whether pure retention or transfer is being measured depends not only on the task itself (in this case, mental or physical typing), but also on the stimuli encountered (in this case, old or new numbers) and on the effectors used to make the responses (in this case, either the keypad or the key row response configuration or the right or left hand). In the final experiment, performance was best (i.e., execution time was fastest) when there was a correspondence on the delayed test along all three dimensions (task, effectors, and stimuli; i.e., physical-same old). Nevertheless, changing the task from mental to physical typing helped rather than hurt performance when there was a switch in effectors. Hence, any evaluation of transfer needs to keep in mind all three dimensions of possible change (task, effectors, stimuli), and when considering only one of the dimensions pure retention is not necessarily better than transfer.

Second, in these experiments, repetition priming, retention, and skill acquisition were all clearly evident only for one of the two response time measures examined, execution time. The other response time measure, initiation time, did not show a consistent or interpretable pattern of results. Initiation time, which is reaction time, or the time to enter the first keystroke after the stimulus is displayed, is the longest component of the response. It has been shown to reflect primarily cognitive processes such as encoding (Healy et al., 2004). In contrast, execution time is the average time to enter the remaining keystrokes after the first (i.e., Keystrokes 2-4) and has been shown to reflect primarily motor processes. Finding a different pattern of results, including differences in transfer, between the two response time measures sheds light on the processes underlying these effects. Because transfer was clearly evident only for execution time, not for initiation time, the implication is that transfer occurs only for the motor processes, not for the cognitive processes such as encoding.

4.2. Speeded aiming: Variability of practice

In a recent study (Wohldmann & Healy, 2010), we set out to define better the conditions under which variable practice is effective for learning a new motor skill. The task involved finding and moving to target digits along the circumference of what looks sort of like a circular clock face (see Figure 4). Subjects must first place the screen cursor on the start location marked with an X, and a target digit appears above it. Next they move to the target along the circumference of the circle and then back to the X, after which another target appears. To study learning of a new skill, we made this task more difficult by programming the mouse so that it was horizontally reversed. That is, when subjects moved the mouse to the left, the cursor on the screen moved to the right, and vice versa.

4.2.1. Healy et al. (2006), Wohldmann et al. (2008b): Vary mouse reversals and number of targets. In earlier research using this task, subjects practiced with the horizontally reversed mouse used in the present study or instead with a mouse reversed vertically rather than horizontally, with a mouse reversed in both directions, or with a normal mouse (Healy et al., 2006; see also Healy, Wohldmann, & Bourne, 2011). Subjects trained with one mouse reversal and were then tested with the same or a different mouse reversal. There were large improvements in performance as a result of training, and those improvements were well retained across a 1-week retention interval, with no forgetting across that interval. Nevertheless, there was little or no positive transfer from training with one mouse reversal to testing with another mouse reversal, with negative transfer evident in some cases, even when training involved using a mouse reversed in both directions and testing involved using a mouse reversed in only one direction (i.e., whole-part transfer). Furthermore, training on a variety of mouse reversals yielded no better performance than did training with the single mouse reversal used in testing, contrary to previous demonstrations of the advantages for variable practice (e.g., Schmidt & Bjork, 1992; Wulf & Schmidt, 1997). However, in a later study (Wohldmann et al., 2008b) variable practice was shown to be beneficial for the same speeded aiming task when instead of varying the mouse reversal used during training (which was the horizontal reversal in every case), the number of target locations was varied. Practice with four target locations was compared to practice with only two target locations, and for new targets at test the more variable practice condition (four training target locations) did yield better performance than the less variable practice condition (two training target locations), at least in terms of one measure of performance. Likewise by that performance measure, transfer of training was evident because subjects' performance at the start of testing on untrained targets was better than performance at the start of training for other participants given those same targets at that time. Specificity of training was evident as well, though, because subjects were faster at test on trained than on untrained targets.

Wohldmann et al. (2008b) speculated that the crucial difference between the results of the earlier study by Healy et al. (2006) and those of their subsequent study was that different mouse reversals were used in the earlier study, with the target locations fixed, whereas different target locations were used in the subsequent study, with the mouse reversal fixed. Thus, it was proposed that variable practice helps test performance and that training in a given condition transfers to testing in other conditions only when the same schema (Schmidt, 1975) (i.e., generalized motor program, which in this case applies to a given mouse reversal) is used during training and testing.

4.2.2. Wohldmann and Healy (2010): Vary number of movements. In our more recent study (Wohldmann & Healy, 2010), we manipulated the practice regimen by training subjects on a varied number of target digits for which the number of movements practiced during training differed. More specifically, there were three training conditions. Subjects in the D1 (training on one diagonal) condition practiced moving either to targets 1 and 5 or to targets 3 and 7. Note that the movements required to return from the target back to the X are the same as those required to reach the opposite target along the same diagonal axis (e.g., returning from the 1 involves the same movement as moving to the 5). So, subjects in this condition practiced only two movements during training. Subjects in the D2 condition (training on two diagonals) practiced moving either to targets 1 and 7 or to 3 and 5. So in this condition, subjects practiced the movements required to reach all four diagonal targets, considering both instructed and return movements, even though only two of the targets were included in the training set. Subjects in the control condition practiced moving to all 8 targets. To examine transfer of learning, all targets were included during testing. This experiment also allowed us to examine the question of whether return movements (those required to return from a target to the start position) or only instructed movements (those required to reach a target) contribute to learning.

As in the studies involving mental practice, our measures of learning involved looking at different components of response time. Specifically, we examined *movement time*, which is the time that it takes subjects to reach the target digit after having left the center starting X, and assesses motor learning. In contrast, *initiation time*, which in this case is the time that it takes subjects to leave the center starting X once the target digit has appeared, assesses both finding the target and planning the movement (see Healy et al., 2011).

We evaluated transfer of learning in three ways, in the first two of which we looked only at performance on the diagonal targets and evaluated the possibility of an advantage for D1 and D2 relative to the control condition, which could be attributed to learning during the training phase. First, response times (RTs) to diagonal targets at the start of *training* in the control condition were compared to those on new diagonal targets at the start of *testing* in D1 and D2. So for all subjects, the targets being practiced were new, and were evaluated in the context of the full set of eight targets. We call this measure "partial transfer" because the advantage in this case is only relative to performance at the start of learning. Second, RTs to diagonal targets at the start of *testing* in the control condition were compared to those on new diagonal targets at the start of testing in D1 and D2. So for the control condition, the targets were well learned, but for the experimental conditions, the targets were new. We call this measure "full transfer" because the advantage in this case is relative to performance after the end of learning. Third, we examined what we called "specificity" of learning by comparing RTs at test on old targets (those also presented during training) to RTs at test on new targets. An advantage for old relative to new items would suggest both that learning is specific and that transfer is not complete.

For movement time, we found that partial transfer was evident in both of the experimental conditions (see the top left panel of Figure 5). The overall effect of condition was significant, with slower movement times for the control condition than for either D1 or D2. Planned analyses comparing each of the experimental conditions, separately, to the control condition yielded significant differences, showing partial transfer in both D1 and D2. Nevertheless, movement times in the D1 condition were significantly slower than those in D2 condition, demonstrating more transfer for D2 than for D1. This result supports the hypothesis that variable practice (with a variation in the number of trained movements rather than in the number of trained targets) promotes transfer and that return movements (in addition to instructed movements) contribute to learning.

For the measure of initiation time (see the top right panel of Figure 5), however, the overall effect of condition was not significant, suggesting no partial transfer for either experimental condition by that measure. Because of this finding, there was no need for an assessment of full transfer in this case.

For movement time, we assessed full transfer by looking at the start of testing in all conditions (see the bottom panel of Figure 5), and we found significant transfer only in the D2 condition. That is, the effect of condition was significant, with longer movement times for D1 than for either D2 or the control condition. Again, planned analyses comparing D1 and D2 separately to the control condition showed differences between D1 and the control condition, but not between D2 and the control condition.

All of the transfer results described to this point involve responses to diagonal targets because training in the D1 and D2 conditions involved diagonal targets exclusively. In addition to this assessment of "near transfer," we also assessed "far transfer" by examining responses to new targets along the major (horizontal, vertical) axes. The results for far transfer yielded the same pattern in every case as did those for near transfer (i.e., for both partial and full transfer in terms of both movement time and initiation time measures), implying that the transfer benefits extend not only to similar movements but also to more dissimilar movements that were not practiced in any way (i.e., neither as instructed nor as return movements).

With respect to the measure of specificity, in which we examined RTs on old and new diagonal items during the test, both experimental conditions showed faster RTs on old targets than on new targets, this old-new difference was found for both initiation time and movement time, and the difference persisted throughout the entire testing session. Although the old-new difference in movement time was smaller for D2 than for D1, it was significant in each case, thereby documenting specificity of training and suggesting that instructed movements contribute more to learning than do return movements.

In summary, the results for movement time suggest that variability of practice (practicing four movements compared to only two) promotes superior transfer; subjects in the D2 condition showed both partial and full transfer, whereas those in the D1 condition showed only partial transfer. In contrast, the results for initiation time suggest no benefits from variable practice; no transfer was found, not even partial. However, during testing, subjects in both experimental conditions showed an advantage for old targets practiced during training, suggesting specificity of learning. Specificity was complementary to transfer in this case, because specificity was larger when transfer was smaller (for D1 than for D2). Taken together, these findings show that both specificity and transfer of learning can be found in the same data set.

4.3. Time production: Task integration

We have also explored transfer and specificity in a task that is largely cognitive, with essentially no motor components (Wohldmann, Healy, & Bourne, in press). In particular, we use a time production task that involves learning to produce intervals of time expressed in arbitrary units rather than seconds, with 1 unit equal to 783 ms so that we could examine learning of a new skill, as opposed to practicing a skill that is already familiar. For example, subjects were told to hit the space bar on the computer console after a fixed number (e.g., 32) units had passed, with feedback provided as the way to learn how long was a specific unit. Making temporal judgments of this type involves processes that are context dependent and influenced by attentional requirements that are present during the time interval to be estimated.

Our previous research has demonstrated clearly that changing secondary task requirements between training and testing, even when eliminating them, results in severe specificity of learning. Our initial study on this topic (Healy et al., 2005b) included an experiment in which subjects trained on time production either with no secondary task or with the difficult secondary task of counting backwards through the alphabet by three's (e.g., M J G). We found that subjects improved in their accuracy of time production during training and that they retained that skill across a 1-week delay when the secondary task conditions were the same during training and testing (i.e., no secondary task at both times or the alphabet task at both times). However, when the secondary task conditions differed at training and testing (i.e., the alphabet task at training but no secondary task at testing or no secondary task at training but the alphabet task at testing), then performance at the start of testing was no better than at the start of training, implying that subjects could not transfer anything they learned during training. It was surprising to find this lack of transfer despite the fact that the primary time production task was held constant during training and testing; there was a change only in the secondary background task that the subjects conducted as the produced time intervals passed. More surprising was the finding that removing the secondary task during testing after having been present during training, a shift in task requirements that should have made performing the time production task easier, also resulted in some negative transfer. We explained the strong specificity observed in this situation by proposing that subjects integrate the time production task and the alphabet task into a single functional task, rather than treat each task separately (see Hsiao & Reber, 2001; Rah, Reber, & Hsiao, 2000; Schmidtke & Heuer, 1997, for similar theoretical conclusions about dual task processing; but also see Ruthruff, Van Selst, Johnston, & Remington, 2006, for a different conclusion). A subsequent study of ours manipulated in separate experiments either the characteristics of the primary time production task or the characteristics of the secondary alphabet task to provide support for this functional task principle (Wohldmann, Healy, & Bourne, 2010).

4.3.1. Wohldmann et al. (in press, Experiment 1): Equal pacing. The purpose of our more recent study was, again, to explore the conditions that promote specificity and transfer of learning, and, in particular, to test how changes in task requirements affect transfer. In two experiments, along with the primary time production task, subjects were required to perform a concurrent secondary task that required counting stimuli rather than units of time. Specifically, during training, while waiting for time to pass, subjects counted small and large circles that appeared on the screen (visual) or high- and low-pitched tones that were played (auditory). They either had to keep one total count (easy) or two separate counts (difficult). During testing, there were eight transfer conditions. All subjects switched secondary tasks. In some cases, the new task involved the same modality but a switch in the level of difficulty (*same modality*); in other cases the new task involved switching modalities but maintaining the same level of difficulty (*switch modality*). In Experiment 1, the pacing of the secondary task was equivalent for all conditions. This constraint was imposed intentionally to facilitate transfer of learning. Thus, for example, training on the easy auditory task and testing on the easy visual task merely involved changing the type of item to be counted, not the number of items to be counted, for a particular interval of time. Likewise, the difference between the easy and difficult secondary tasks, regardless of modality, merely involved keeping track of either one or two running totals, but the number of items to be counted was the same. The secondary tasks used here all involved explicit counting to ensure that subjects used a counting procedure for that task. One question of interest was whether subjects would also use a counting procedure for the primary time production task. Because of the pacing of the stimuli and the duration of the temporal units, there was not a simple mapping of the number of stimuli to the number of elapsed units. If the primary and secondary tasks were integrated, then using a counting procedure for the secondary task should encourage a counting procedure to be used for the primary time production task based on the secondary-task stimuli but to preclude a simple procedure involving just counting the stimuli as the main basis for the primary time production task.

Performance on the time production task was measured in terms of proportional absolute error, which is the absolute difference between the produced interval and the specified interval divided by the specified interval. This measure provides a normalized assessment of error magnitude. As in the study of motor skill (Wohldmann & Healy, 2010), we examined two types of transfer. First, we compared proportional absolute error on the time production task at the *start* of training to that at the start of testing. We referred to this as the "Block 1 analysis," and it can be thought of as analogous to the partial transfer measure of Wohldmann and Healy (2010). Second, we compared proportional absolute error at the *end* of training to that at the start of testing, which we referred to as the "Block 6 analysis," and it can be thought of as analogous to the full transfer measure of Wohldmann and Healy (2010).

The results in Experiment 1 for the Block 1 analysis of the time production task are summarized in Figure 6. Switching secondary tasks between training and testing had a facilitative effect. That is, there was a significant decrease in proportional absolute error between the start of training and the start of testing, regardless of whether the change in secondary task requirements involved a switch in the modality (switch modality) or a switch in the level of difficulty (same modality). This finding provides evidence for partial transfer. In contrast, by the Block 6 analysis, also evident in Figure 6, switching secondary task requirements between the end of training and the start of testing led to a significant increase in proportional absolute error on the time production task, indicating a lack of full transfer. In sum, by one analysis of transfer (Block 1), we found positive transfer (or facilitation) and by another (Block 6) we found negative transfer (or interference).

4.3.2. Wohldmann et al. (in press, Experiment 2): Unequal pacing. In Experiment 2, the pacing of the visual and auditory stimuli was not equivalent. Specifically, the pacing of the stimuli was the same within, but not between, modalities. Thus, when the secondary task modality did not change between training and testing, the number of stimuli to be counted did not change (only whether subjects had to keep track of one or two totals). In contrast, when the secondary task modality changed between training and testing, the number of stimuli to be counted also changed. This change in pacing presumably made it difficult to rely on the same counting strategy for time production in the two experimental phases.

As in Experiment 1, by the Block 1 analysis of transfer, there was a significant decrease in proportion absolute error between the start of training and the beginning of testing in Experiment 2, reflecting positive transfer (see Figure 7). The amount of positive transfer was greater for subjects who maintained the same modality between training and testing (same modality) than for those who maintained the same level of difficulty (switch modality). This finding indicates that switching pacing is more important for transfer than switching level of difficulty. In contrast, by the Block 6 analysis of transfer (again see Figure 7), there was a significant increase in proportional absolute error between the end of training and the beginning of testing, reflecting negative transfer. Again, as was true for the Block 1 analysis, by this Block 6 analysis, there was a larger increase in proportional absolute error for subjects who switched modalities than for those who maintained the same modality between training and testing, indicating that switching pacing is more important for transfer than switching level of difficulty. This is an important finding in the context of how time production is thought to work because models of time production emphasize attentional resources (e.g., Brown & Boltz, 2002; Zakay & Block, 1997), and there is a larger change in the required attentional resources when difficulty is switched than when modality is switched (even when the change in modality is coupled with a change in pacing). This fact is illustrated by the finding that difficulty had a larger impact during training than did modality in both experiments, even in Experiment 2, in which the two modalities differed with respect to pacing, and hence, in the number of stimuli that had to be counted.

In addition to the separate Block 1 and Block 6 analyses of transfer, an overall transfer index was computed that included both Blocks 1 and 6 of training. This index was a ratio of the difference between Block 1 of training and Block 1 of testing to the difference between Block 1 of training and Block 6 of training. In other words, this index provides a measure of how much was gained (or lost) from training to testing as a proportion of how much was gained during training. This index is equal to (or greater than) 1 given full transfer, equal to (or less than) 0 given no transfer, and between 0 and 1 given partial transfer. In both Experiment 1 and Experiment 2, the average transfer index was between 0 and 1, indicating partial transfer in each case. By this index, in agreement with the separate Block 1 and Block 6 analyses, the amount of partial transfer in Experiment 2 was larger when there was a switch in difficulty then when there was a switch in modality, thereby implying that pacing was more important than attentional demands in determining the amount of transfer. This finding is consistent with the hypothesis that the primary and secondary tasks are integrated and that the procedures used as a basis for the primary task of time production involve a counting strategy that depends on the rate at which the secondary task stimuli are presented.

Thus, both Experiments 1 and 2 demonstrated partial transfer of learning for the time production task. Neither demonstrated full transfer. Again, as was true for the study of motor skill (Wohldmann & Healy, 2010), we found specificity of learning and transfer of learning in the same data set. In fact, we found both negative transfer and positive transfer in the same data set depending on the analysis we made.

5. Conclusions

The studies reviewed here address issues involving mental practice, variability of practice, and task integration. The first set of studies (Wohldmann et al., 2007, 2008a) used a digit data entry task to explore differences between mental and physical practice and found that mental practice can be as effective as physical practice for learning a skill. Indeed, in some cases mental practice showed better retention and transfer than physical practice when retroactive interference was elicited by switching either response configurations or hands. The explanation for the advantage of mental practice is that it uses an effector-independent representation, whereas physical practice uses an effector-dependent representation. The second set of studies used a speeded aiming task to explore the possibility of variability of practice improving transfer. An initial study (Healy et al., 2006), which varied the number of mouse reversals, found no evidence for improvements due to variable practice, whereas a subsequent study (Wohldmann et al., 2008b), which varied the number of targets with a single mouse reversal, did find evidence for improvements due to variable practice. Likewise, a more recent study (Wohldmann & Healy, 2010), which varied the number of movements, found evidence for improvements due to variable practice. These results support the proposal that variable practice helps transfer only when the same schema (Schmidt, 1975) is used during training and testing. The third set of studies (Wohldmann et al., in press) used a primary time production task with a secondary counting task to explore task integration, varying secondary task modality, difficulty, and pacing. The findings support the hypothesis that primary and secondary tasks are integrated, so that the procedures used for time production depend on the pacing of the secondary task stimuli.

With respect to specificity and transfer, taken together, the findings from these three sets of studies have important implications for researchers who examine learning and memory of knowledge and skills. The findings imply that specificity and transfer of learning are not mutually exclusive and can coexist in the same data set. Specificity can be found even when participants appear to transfer what they have learned to subsequent performance. Depending on the definition of transfer (partial, full, an old-new difference), and the measure used to assess it (e.g., initiation time, movement time) different amounts and directions of transfer may be evident. In fact, positive transfer (or facilitation) can be found when comparing initial testing to initial training even when negative transfer (or interference) is shown when comparing initial testing to final training. These are especially important findings given that many experiments in cognitive psychology use a single measure of transfer (e.g., based on total response time as the dependent variable), rather than examining multiple measures (e.g., on component response times), and because transfer is not always defined in the same way across studies. For example, if we had used only the commonly reported old-new difference as our index of transfer in the speeded aiming study, the conclusion would have been that learning is highly specific. There would have been no appreciation of the benefits of prior practice on subsequent testing, as reflected in our measures of partial transfer. Similarly, if we had used only the commonly reported measure of total response time in our studies on mental practice and speeded aiming, we would likely have shown little to no transfer, as the measure of initiation time, which did not show transfer, is the largest component of total response time. Moreover, if we had used only the Block 1 analysis of transfer or the overall transfer index in our study of time production, the conclusion would have been that some positive transfer occurs, but there would have been no appreciation of the fact that performance suffered, reflecting negative transfer, when making the transition between training and testing, as evident in the Block 6 analysis. This conclusion that the direction and extent of transfer depends on the measures used to assess it could help explain why there has been little consensus about the conditions under which durability, specificity, and transfer of learning occur.

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Author Notes

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Figure Captions

Figure 1. Execution time (top panel) and initiation time (bottom panel) on the digit data entry task as a function of training condition, test, and number type in Experiment 2 of Wohldmann, Healy, and Bourne (2007). Top panel was adapted with permission from Figure 2 of Wohldmann et al. (2007).

Figure 2. Execution time (top panel) and initiation time (bottom panel) on the digit data entry task as a function of training condition, test, and number type in Experiment 1 of Wohldmann, Healy, and Bourne (2008a). Top panel was adapted with permission from Figure 1 of Wohldmann et al. (2008a).

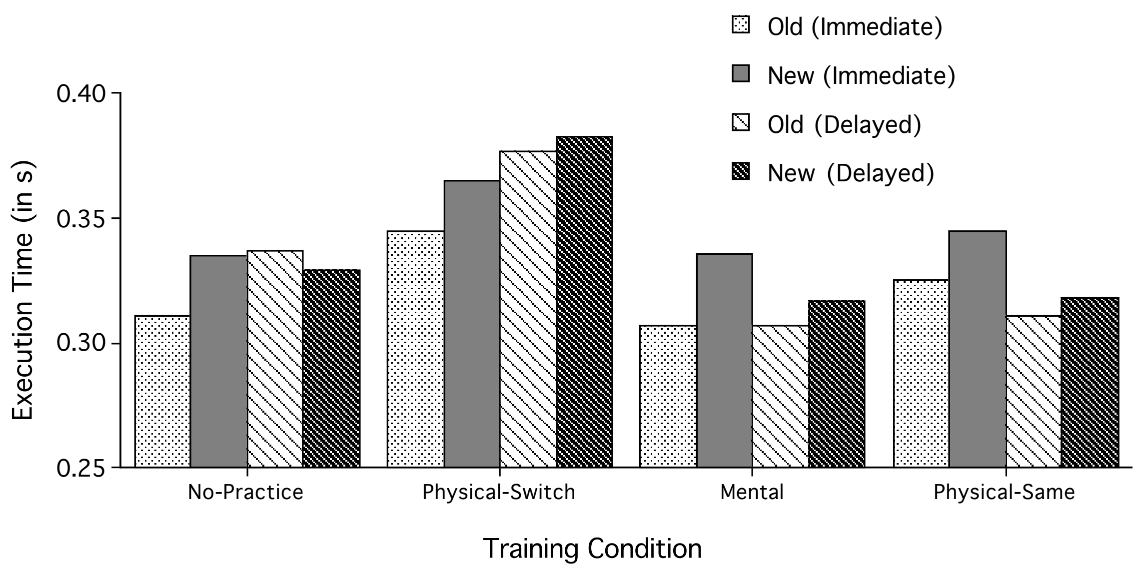
Figure 3. Execution time (top panel) and initiation time (bottom panel) on the digit data entry task as a function of training condition, test, and number type in Experiment 2 of Wohldmann, Healy, and Bourne (2008a). Top panel was adapted with permission from Figure 2 of Wohldmann et al (2008a).

Figure 4. Circular stimulus display. The target in the display shown is 1.

Figure 5. Movement time (top left panel) and initiation time (top right panel) for the first block of training in the control condition and the first block of testing in the experimental conditions (D1 and D2) in the study by Wohldmann and Healy (2010). Movement time for the first block of testing in the control condition and in the experimental conditions (D1 and D2) in the study by Wohldmann and Healy (2010) (bottom panel).

Figure 6. Proportional absolute error on the time production task for the switch modality and same modality conditions on the first and last blocks of training (Training B1 and B6) and the first block of testing (Testing B1) in Experiment 1 of the study by Wohldmann, Healy, and Bourne (in press).

Figure 7. Proportional absolute error on the time production task for the switch modality and same modality conditions on the first and last blocks of training (Training B1 and B6) and the first block of testing (Testing B1) in Experiment 2 of the study by Wohldmann, Healy, and Bourne (in press).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New (Immediate)
Old (Delayed)
New (Delayed)
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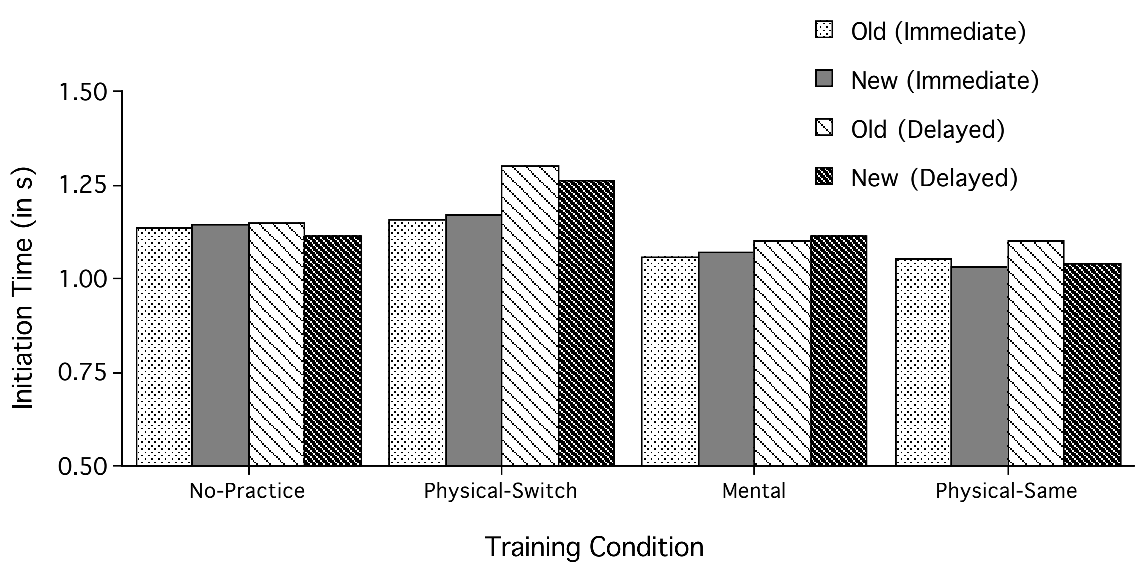
0.35
0.30
0.25
Execution Time (in s)
No-Practice
Physical-Switch
Mental
Physical-Same
Training Condition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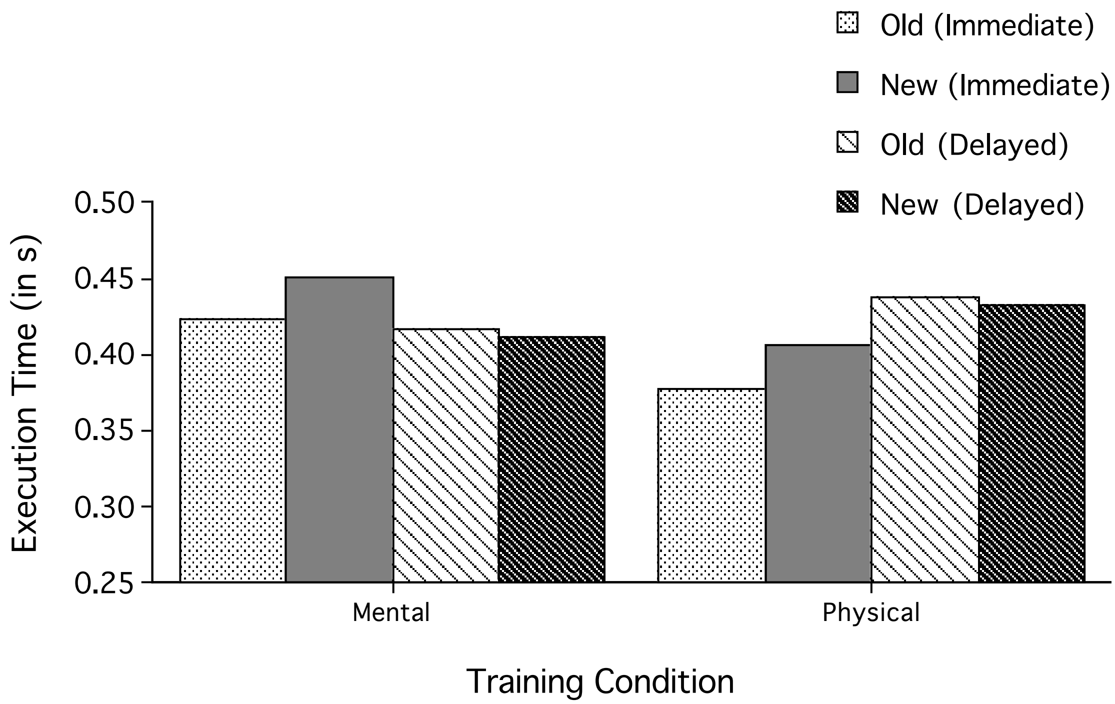
New (Immediate)
Old (Delayed)
New (Delayed)
1.50
1.25
1.00
0.75
0.50
Initiation Time (in s)
No-Practice
Physical-Switch
Mental
Physical-Same
Training Condition

Figure 1


Old (Immediate)
New (Immediate)
Old (Delayed)
New (Delayed)
Execution Time (in s)
0.50
0.45
0.40
0.35
0.30
0.25
Mental
Physical
Training Condition

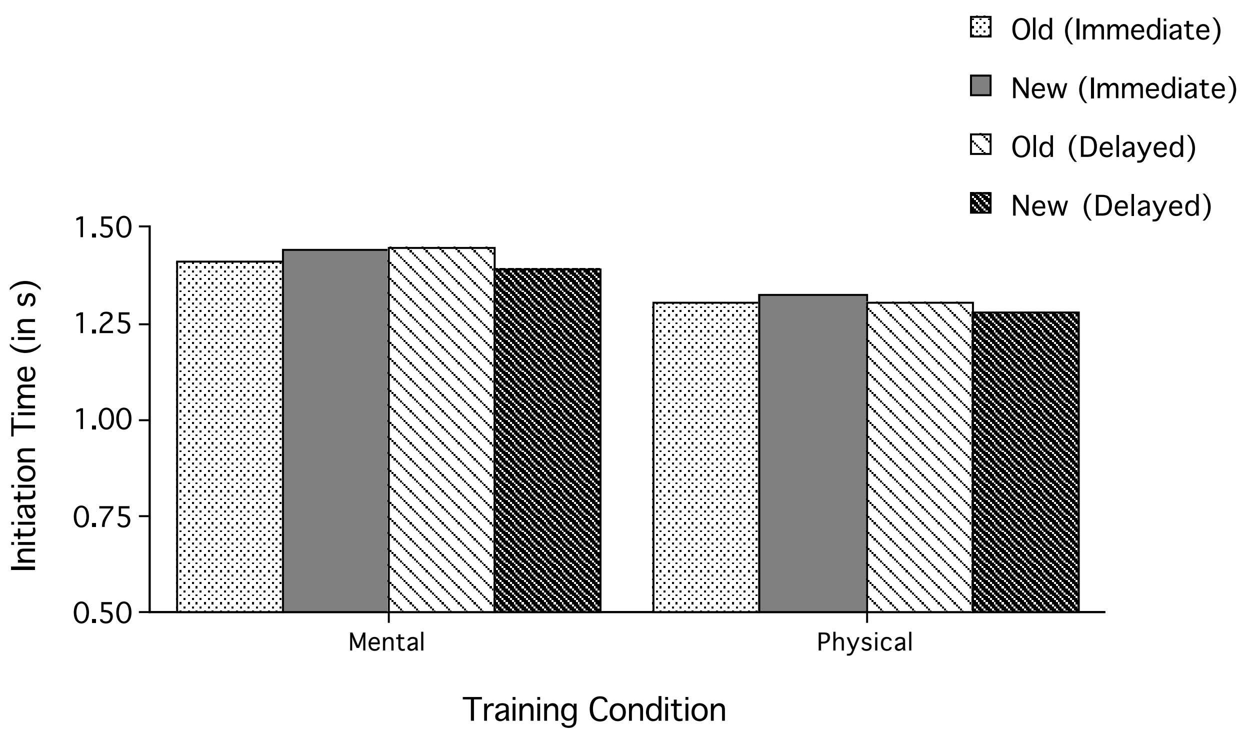
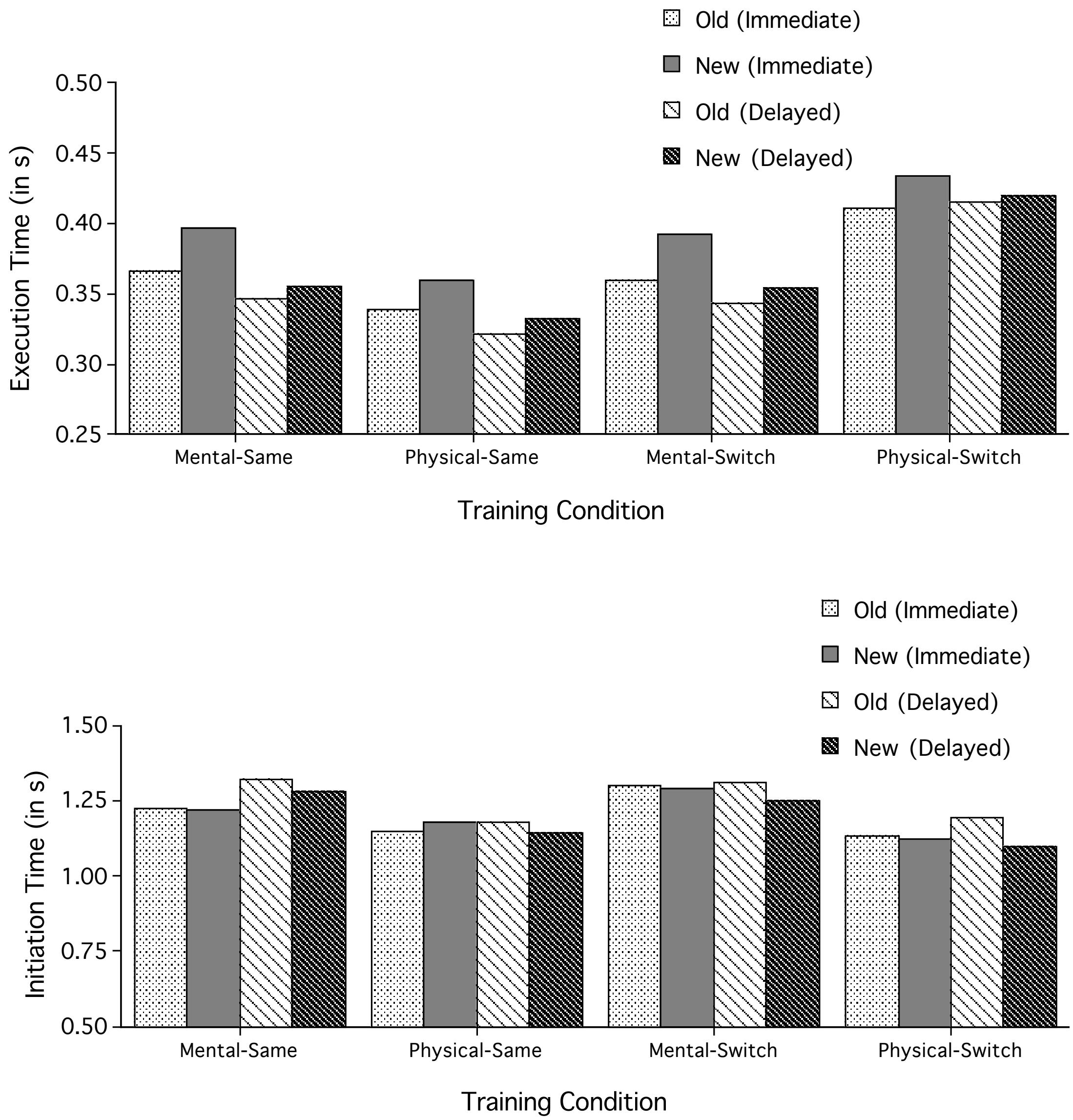

Old (Immediate)
New (Immediate)
Old (Delayed)
New (Delayed)
Initiation Time (in s)
1.50
1.25
1.00
0.75
0.50
Mental
Physical
Training Condition

Figure 2


Old (Immediate)
New (Immediate)
Old (Delayed)
New (Delayed)
Execution Time (in s)
0.50
0.45
0.40
0.35
0.30
0.25
Mental-Same
Physical-Same
Mental-Switch
Physical-Switch
Training Condition
Old (Immediate)
New (Immediate)
Old (Delayed)
New (Delayed)
Initiation Time (in s)
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1.25
1.00
0.75
0.50
Mental-Same
Physical-Same
Mental-Switch
Physical-Switch
Training Condition

Figure 3

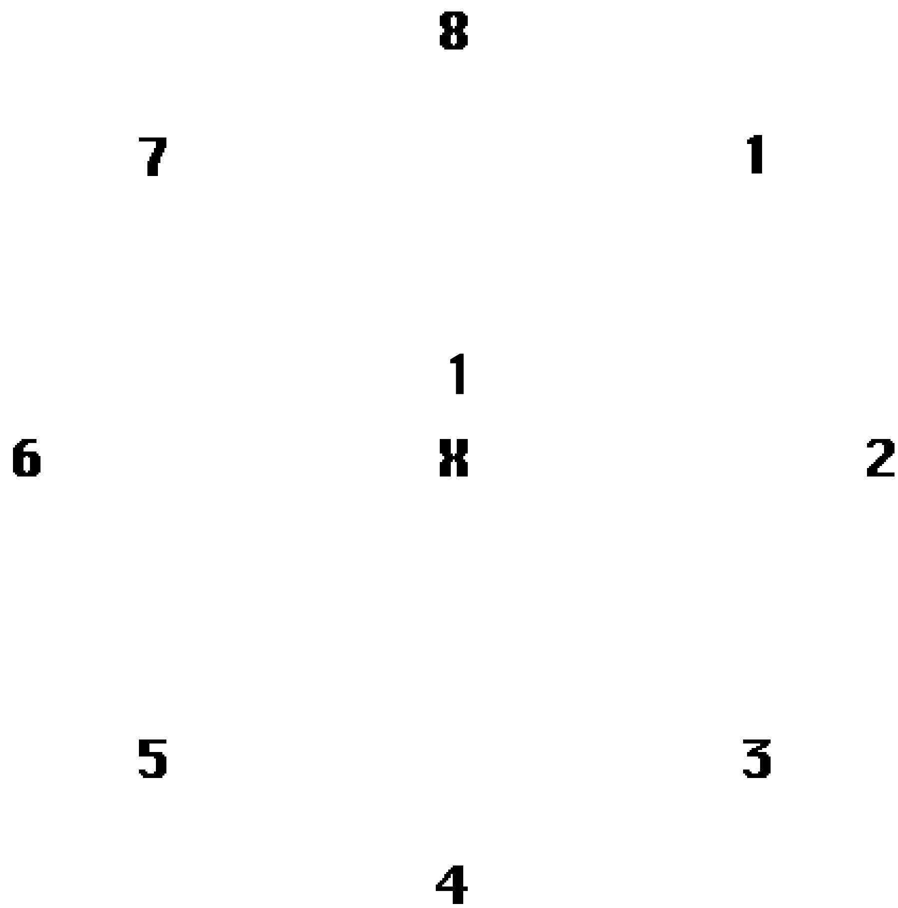

Figure 4

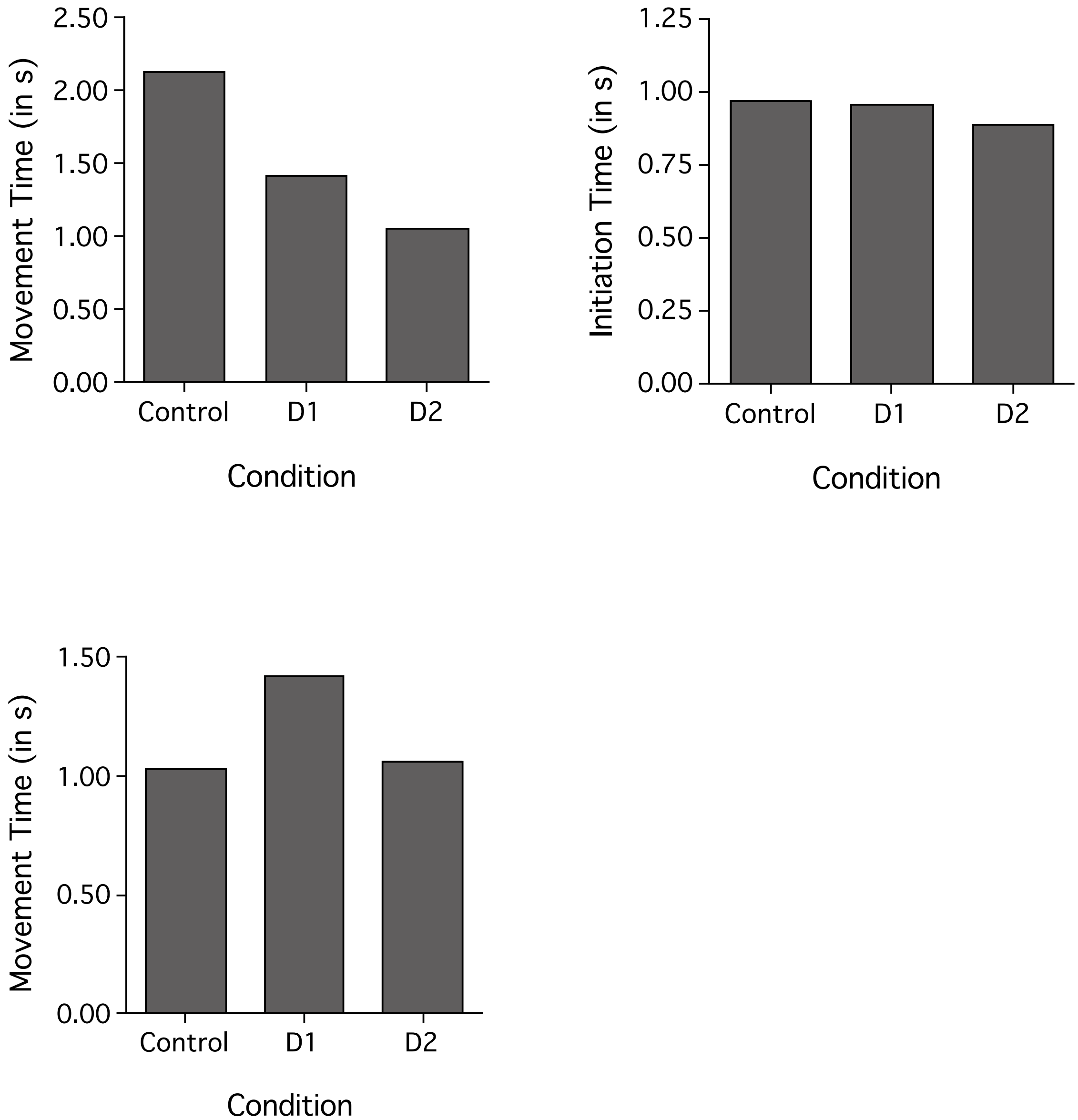
2.50
2.00
1.50
1.00
0.50
0.00
Movement Time (in s)
Control
D1
D2
Condition
1.25
1.00
0.75
0.50
0.25
0.00
Initiation Time (in s)
Control
D1
D2
Condition
1.50
1.00
0.50
0.00
Movement Time (in s)
Control
D1
D2
Condition

Figure 5

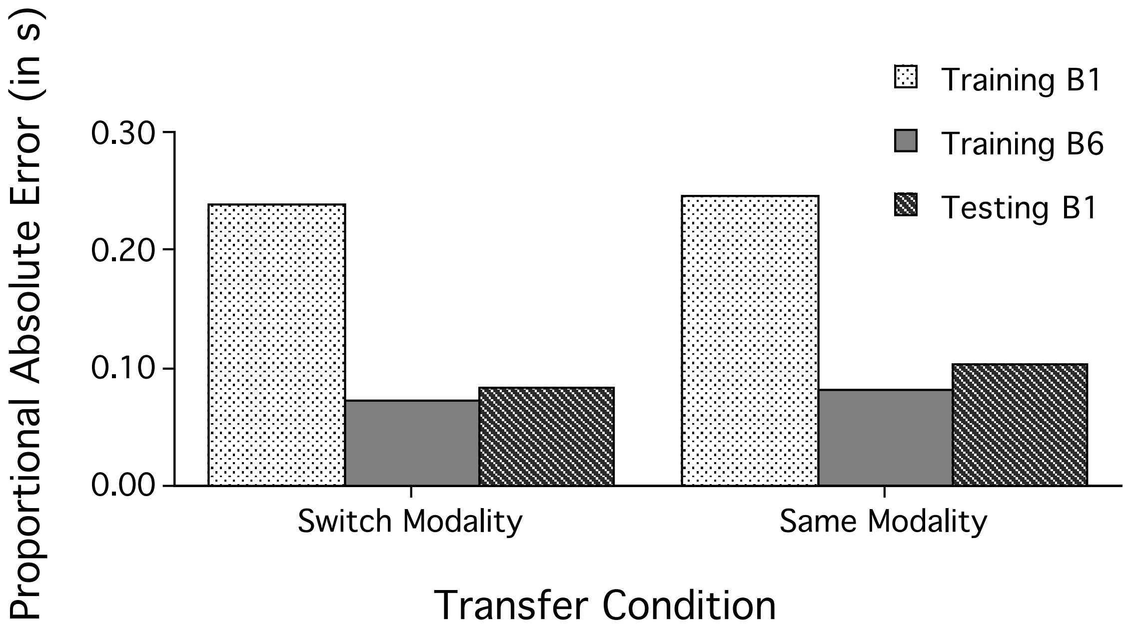
Proportional Absolute Error (in s)
0.30
0.20
0.10
0.00
Training B1
Training B6
Testing B1
Switch Modality
Same Modality
Transfer Condition

Figure 6

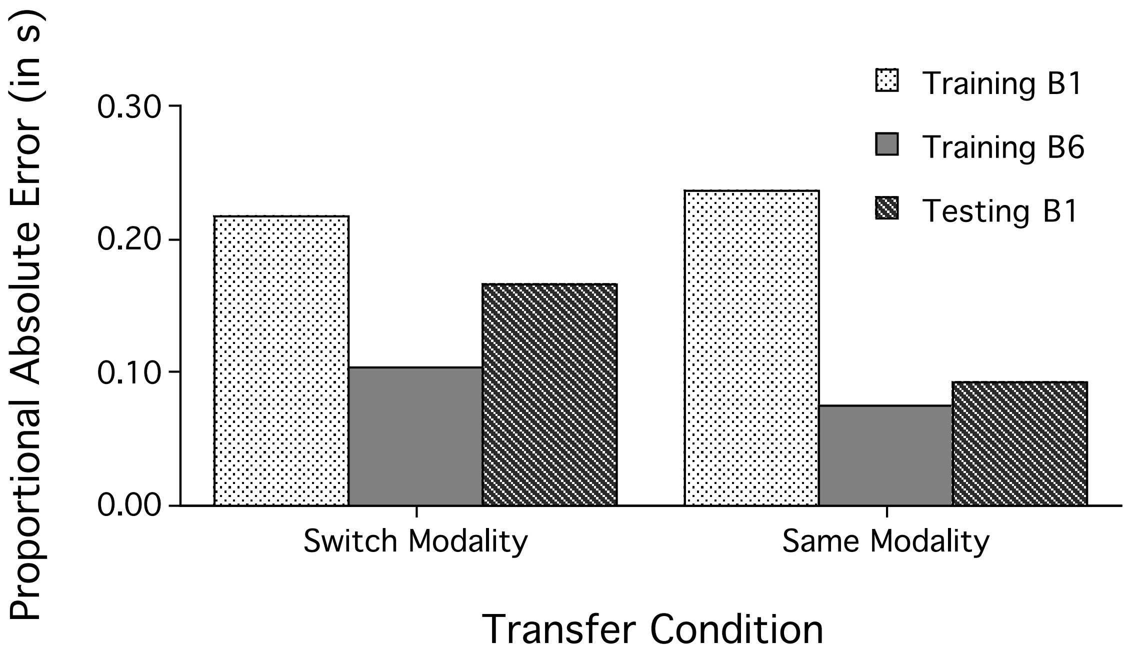
Proportional Absolute Error (in s)
0.30
0.20
0.10
0.00
Training B1
Training B6
Testing B1
Switch Modality
Same Modality
Transfer Condition

Figure 7