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The effect of constant versus varied training on transfer in a cognitive skill learning task: The case of the Tower of Hanoi Puzzle

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ABSTRACT

The differential effect of constant versus variable training conditions on acquisition and transfer has been demonstrated primarily in perceptual motor skills. In the present study, this effect was tested on 84 young adults using a cognitive skill learning task — the Tower of Hanoi Puzzle. The advantage of this task is that it allows testing the effect of the two training protocols on transfer by separately analyzing accuracy of the task solution, speed of reaching the correct solution and time planning before beginning to solve the task. Participants were divided into two groups. The "constant training" group practiced the task for 10 consecutive trials with identical configuration in terms of the "start" and "end" peg; followed by an 11th trial with a new configuration of the task (i.e., transfer). The "varied training" group practiced for 10 consecutive trials with different configurations, followed by a new configuration. As predicted, the constant training group yielded a higher cost when transferring to a new configuration of the task compared with the varied training group. These findings support the notion that varied training leads to the development of a schematic representation of the task solution, thus transfer is facilitated. These results have important implications in terms of the optimal learning conditions for adults while coping with cognitive problem-solving tasks.

The factors that enable transfer following skill acquisition have been studied extensively in learning and memory literature (Speelman & Kirsner, 2001). Baldwin and Ford (1988) view transfer as the primary issue in skill learning research. In fact, Schmidt and Bjork (1992) claim that transfer is a better index of learning than the acquisition process itself. In many cases, the goal of skill learning is to enable transfer of variations of the acquired skill in real life situations such as the work setting (Holladay & Quinones, 2003). Another example is when children learn to solve mathematical problems at school, the teacher hopes that they will apply these skills to similar problems that were not necessarily practiced in class (Hatano & Inagaki, 1986; Verschaffel, Luwel, Torbeyns, & Van Dooren, 2009). The issue of transfer has been studied for over a century (for historical reviews see Adams, 1987; Baldwin & Ford, 1988). Most theories of transfer ascertain the requisite of certain similarity between the learned and new task, either in terms of stimuli and responses (Osgood, 1949) or shared action production rules (Singley & Anderson, 1989).

Hatano and Inagaki (1986) and Schmidt and Lee (2011) claim that although transfer is typically expected following training, there are cases in which there is no need or expectation to transfer the skill to other situations (Schmidt and Lee give the examples of archery and bowling). Other researchers however, do not accept this dichotomy and stress the need for constant training at the early phase of skill acquisition in order for varied training to yield the advantage expressed by better transfer (Lai & Shea, 1998, 1999; Lai, Shea, Wulf, & Wright, 2000; Shea, Lai, Wright, Immink, & Black, 2001).

Several researchers have attempted to identify the factors affecting the generalizability of acquired skills. Schmidt (1975), for example, proposed the "schema theory of discrete motor skill learning". Schmidt and Lee (2011) view schema as a rule learned during the acquisition process. "The rule is a relationship between all the past environmental outcomes that the person produced and the values of the parameters that were used to produce those outcomes. This rule is maintained in memory and can be used to select a new set of parameters for the next movement situation – even a novel variation – that involves the same motor program" (p. 371).

Schmidt (1975) recommends engaging in varied training to enable the development of schema that would yield better transfer ("e.g., jump over an object in as many ways as possible" p. 257). Constant training reinforces a rigid and specific sequence of actions without requiring an understanding of the abstract solution or representation of the task. However, adopting a particular sequence of actions during varied training would not be effective. Instead, varied training would lead (intentionally or unintentionally) to a search for a more generalized

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solution or rule that could be applied to a range of variations of the task. The variety of tasks encountered are presumed to yield a schema, i.e. a more abstract representation of the motor skill, which would enable better transfer of the learned skill (Green, Whitehead, & Sugden, 1995; Schmidt, 1975). In other words, if a problem schema is not developed during practice and the participant fails to notice the similarity between the examples and the subsequent novel task, transfer abilities are limited (Chen, 1999).

Numerous studies tested specific perceptual-motor tasks and confirmed that varied training results in better generalization of the learned skill than constant training. Heitman, Pugh, Kovaleski, Norell, and Vicory (2005) showed that varied practice of a pursuit rotor task (three different speeds) resulted in better transfer than specific (single speed) practice. Roller, Cohen, Kimball, and Bloomberg (2001) used visual displacement lenses to test the effect of varied versus constant training on adaption to visuo-motor discordance. Their results show that varied training (i.e. using multiple sets of lenses) yielded better increased adaptability to a novel visuo-motor situation than constant training (i.e. using one set of lenses). Green et al. (1995) showed that varied training for a forehand stroke with a racket resulted in better 'out of range' transfer than specific training. Yao, Cordova, De Sola, Hart, and Yan (2012) tested the effect of varied versus constant training on a real-life motor task, i.e. wheelchair propulsion. Consistent with previous findings, varied training (two speeds) resulted in greater improvement of propulsive efficiency than constant training (single speed). However, a critical review by Van Rossum (1990) found that empirical support for the "variability hypothesis" is not entirely solid. For example, several of the studies that claim to support this hypothesis did not demonstrate a learning effect in the first place. Thus, findings reported above in support of the "variability hypothesis" should be interpreted cautiously as the findings are not as conclusive as they may seem.

Previous studies have demonstrated the importance of distinguishing between perceptual-motor and cognitive skill learning tasks (Vakil & Hoffman, 2004). While the differential effect of type of training (i.e. varied vs. constant) on acquisition and transfer has been well studied in regard to perceptual-motor skills, literature on cognitive skills is very scarce. In a series of studies, Chen and colleagues (Chen, 2002; Chen & Klahr, 1999; Chen & Mo, 2004) addressed this question using a problem solving task called Luchins' Water Jar Problems. In this task, children are presented with three water jars with different capacities. Their task is to fill up one of the jars with a specific amount of water using these three jars. The researchers demonstrated that children trained with various versions of the task (e.g. different rules to solution) showed better transfer to a new version (e.g. untrained rule) of the task than those with less varied training, though the children given less varied training exhibited slower initial learning. In his review, Rohrer (2012) distinguishes between *blocked* and *interleaved* concept exposure, which resembles the distinction between *constant* and *varied* training, respectively. The advantage of interleaved over blocked exposure was demonstrated in a variety of tasks such as category induction learning and discrimination learning. In a more recent study, Rohrer, Dedrick, and Burgess (2014) showed the benefit of interleaved practice while learning mathematics.

Though, Schmidt's schema theory refers to a generalizable *motor* program or rule, the TOHP case presented in this study refers to a generalized *cognitive* program or rule. Consistent with the above definition of motor skill schema by Schmidt and Lee (2011), the cognitive schema is a rule or algorithm that can be applied to any configuration of the TOHP. In fact, computer scientists are often instructed to write an algorithm based on a recursive law as explained above for solving the TOHP.

Hence, unlike the literature on motor skill learning, the literature on the effect of learning procedure on transfer in cognitive skill learning is very limited. Findings on cognitive skill learning could have very important implications on the teaching methods used for all ages - from primary school to graduate school. The main goal of this study is to test the effect of training procedures, i.e. constant versus varied, on transfer in the Tower of Hanoi Puzzle (TOHP) a well-established cognitive skill learning task (Anderson, Albert, & Fincham, 2005; Beaunieux et al., 2006; Schiff & Vakil, 2015; Vakil & Hoffman, 2004). It is hypothesized that the "constant training" group would perform better at the acquisition phase than the "varied training" group. On the other hand, the "varied training" group will develop a more abstract solution which will facilitate transfer, therefore this group will more easily transfer to a new configuration than the "constant training" group.

The TOHP is a problem solving task that requires planning and subgoal management and is a non-verbal task that does not depend on prior knowledge such as mathematical background. Performance on the TOHP reflects various cognitive processes such as planning, problem solving, inhibition, self-regulation and monitoring (Strauss, Sherman, & Spreen, 2006). The use of the TOHP generates various measures of speed of solution, accuracy and planning time. Thus, this task enables testing the effect of the two training protocols on transfer by separately analyzing accuracy, speed and planning time.

As will be explained in more detail in the Procedure section, the task can be presented in six different configurations. The various configurations are at exactly the same level of difficulty (i.e., require the same number of moves to solution). Transfer from one configuration to another requires abstract representation abilities and flexible thinking that enable application of the same underlying principle.

1. Method

1.1. Participants

A total of 84 individuals participated in this study. In the "constant training" group: $n = 44$ (19 males), mean age 22.75 years (range 19–32 years, $SD = 2.82$), mean education 13.45 years ($SD = 1.34$). In the "varied training" group: $n = 40$ (17 males), mean age 23.63 years (range 18–32 years, $SD = 3.58$), mean education 13.91 years ($SD = 1.72$). The groups did not significantly differ in age, $t(82) = 1.25$, $p = .22$, or in education, $t(82) = 1.37$, $p = .17$. Participants were mostly undergraduate students at Bar Ilan University who participated in the experiment for class credit. The others were volunteers or participants who were paid for their participation. Written informed consent was obtained from all participants for a protocol approved by the Bar Ilan University Institutional Review Board.

1.2. Tasks and procedure

1.2.1. Tower of Hanoi Puzzle

Three pegs appeared on the screen, numbered 1to 3. Four disks were arranged on one of the pegs according to size with the largest disk at the bottom. Participants were instructed that the goal was to move the disks, using the keyboard, from the initial peg to another peg (determined by the task condition) in a minimum number of moves and as quickly as possible. They were also told that they had to adhere to the following rules: only one disk could be moved at a time, no disk could be placed on a smaller one, and the middle peg had to be used. Participants were not informed that a transfer task would follow the acquisition phase. The optimal solution for four disks requires 15 moves. The computer automatically recorded the number of moves required to solve the puzzle, time to solution, the average time per move, and time of first move.

During the acquisition phase, both the constant and varied training groups solved 10 consecutive trials of the TOHP. This was followed by a transfer phase - the 11th trial. However, the procedure in which the task was administered differed between the two groups. The TOHP can be played in six different configurations as determined by the initial peg and the final peg; 1 to 3, 1 to 2, 2 to 3, 3 to 1, 2 to 1, & 2 to 3.

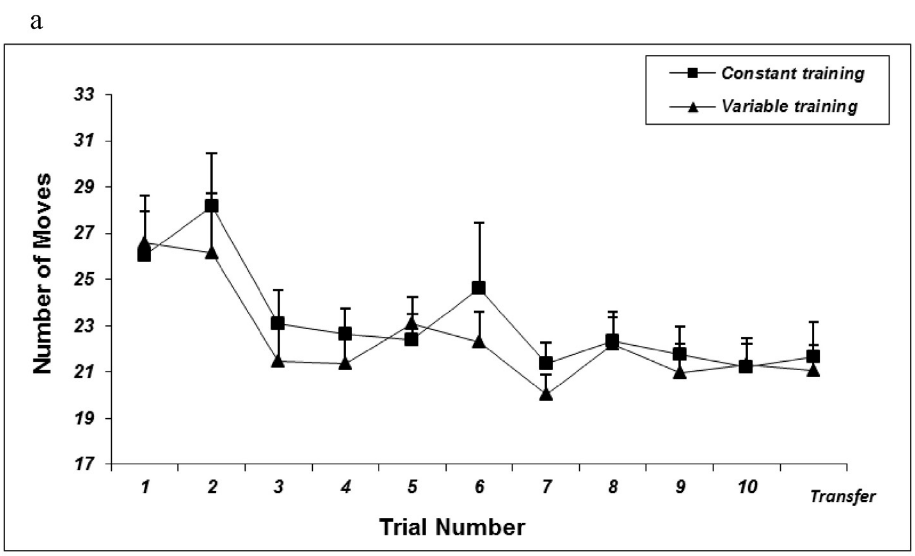
1.2.2. Constant training

During the acquisition phase, participants in this group were asked to solve *one* of the six configurations in which the TOHP could be played (e.g., 1 to 3), for 10 consecutive trials. In the transfer phase that followed (trial 11), participants were asked to solve one of the five remaining configurations of the TOHP not used in the acquisition phase, (e.g., 2 to 1).

1.2.3. Varied training

During the acquisition phase, participants in this group were asked to solve *five* of the above six configurations in which the TOHP could be played (e.g., 1 to 2, 2 to 3, 3 to 1, 2 to 1, and 2 to 3). Each one of these configurations was played twice, yielding a total of 10 consecutive trials. The trials were arranged in pseudo-random order that did not allow the same configuration to be played consecutively. In the transfer phase that followed (trial 11), participants were asked to solve the only configuration of the TOHP not used in the acquisition phase, (e.g., 1 to 3).

Four dependent measures were used to analyze performance on the TOHP - number of moves to solution, total time for solution, time per move, and time of first move. Each one of these measures reflects slightly different aspects of performance. *Number of moves* is a reflection of the accuracy of performance and the ability to avoid unnecessary moves. *Total time for solution* reflects performance speed. *Time per move* corrects the previous measure by taking into account the number of moves to solution that is confounded within the total time for solution. Finally, the *time of first move* is assumed to reflect planning time. Each one of these measures was used to analyze learning (i.e. trials 1–10), and transfer which was calculated as the percentage of the “cost” of transfer - i.e. ((trial 11 - trial 10)/trial 10) * 100. Mixed Analysis of Variance (2 X 10) was used to analyze learning, with Group (varied vs. constant training) as a between-subject factor and Learning Trials (1–10) as a within-subject factor. For the analysis of transfer the two groups (varied vs. constant training) were compared using *t*-test for independent samples.



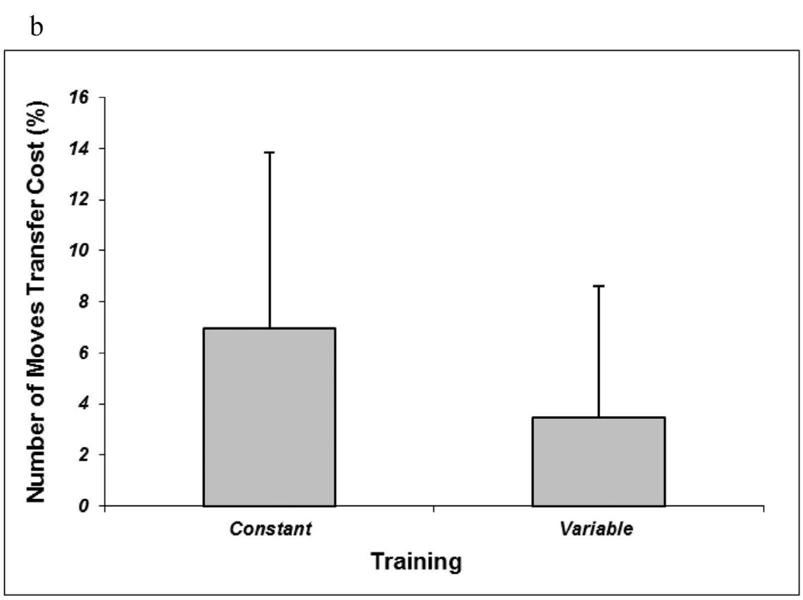


Fig. 1. a: Mean (and *SD*) number of moves to solve the TOHP as a function of the learning rates exhibited by the constant and varied training groups. b: Mean (and *SD*) number of moves to solve the TOHP indicating the percentage of cost of transfer from trial 10 to trial 11 as exhibited by the constant and varied training groups.

2. Results

2.1. Number of moves

2.1.1. Acquisition

As can be seen in Fig. 1a, overall the groups did not significantly differ in the number of moves required to solve the TOHP, $F(1, 81) = .61$, $p = .44$, $\eta^2 = 0.01$. The number of moves required to solve the TOHP decreased significantly across the 10 learning trials, $F(9, 729) = 4.69$, $p < .001$, $\eta^2 = 0.06$. The interaction between Group and Learning Trials did not reach significance, $F(9, 729) = .37$, $p = .95$, $\eta^2 = 0.01$, indicating that the groups' learning rates did not differ.

2.1.2. Transfer

The percentage of cost during transfer from trial 10 to the new configuration of the task on trial 11 did not significantly differ between the groups, $t(82) = .40$, $p = .69$, $\eta^2 = 0.02$ (see Fig. 1b).

2.2. Total time for solution

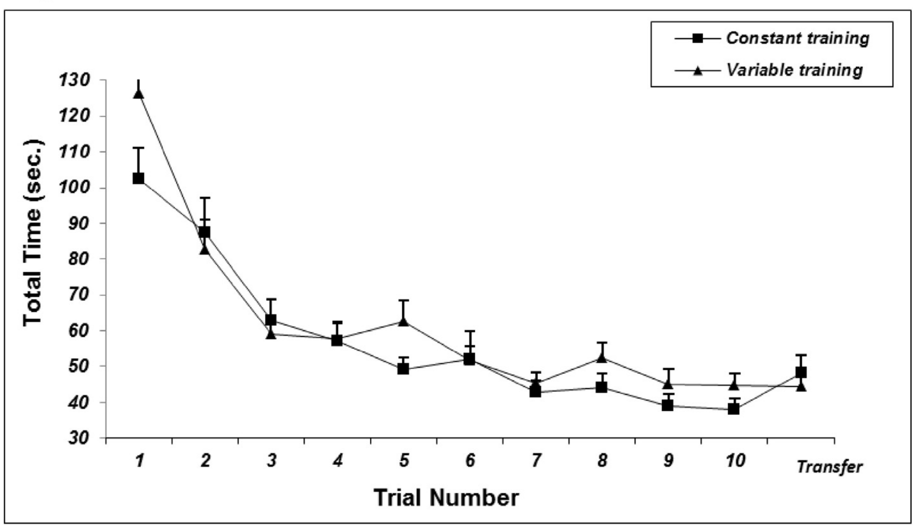
2.2.1. Acquisition

As can be seen in Fig. 2a, overall the groups did not significantly differ in the total time required to solve the TOHP, $F(1, 53) = .95$, $p = .33$, $\eta^2 = 0.02$. The total solution time decreased significantly across the 10 learning trials, $F(9, 477) = 42.52$, $p < .001$, $\eta^2 = 0.45$. The interaction between Group and Learning Trials did not reach significance, $F(9, 477) = .56$, $p = .83$, $\eta^2 = 0.01$, indicating that the groups' learning rates did not differ (see Fig. 2a).

2.2.2. Transfer

The constant training group displayed a significantly higher percentage of cost upon transfer from trial 10 to the new configuration of the task in trial 11, compared to the varied training group, $t(74) = 2.38$, $p < .05$, $\eta^2 = 0.07$ (see Fig. 2b).

a



b

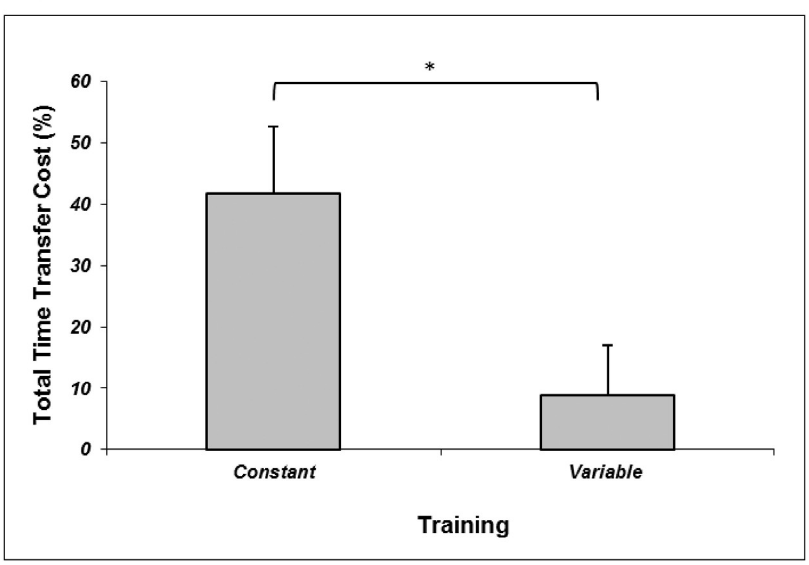


Fig. 2. a: Mean (and *SD*) total time to solve the TOHP as a function of the learning rates exhibited by the constant and varied training groups. b: Mean (and *SD*) total time to solve the TOHP indicating the percentage of cost of transfer from trial 10 to trial 11 as exhibited by the constant and varied training groups.

2.3. Time per move

2.3.1. Acquisition

The average time per move was less for the constant training group then for the varied training group, $F(1, 81) = 5.85$, $p < .05$, $\eta^2 = 0.07$. Time per move decreased significantly across the 10 learning trials, $F(9, 729) = 89.13$, $p < .001$, $\eta^2 = 0.52$. The interaction between Group and Learning Trials did not reach significance, $F(9, 729) = 1.49$, $p = .15$, $\eta^2 = 0.02$, indicating that the groups' learning rates did not differ (see Fig. 3a).

2.3.2. Transfer

The constant training group had a significantly higher percentage of cost upon transfer from trial 10 to the new configuration of the task in trial 11, compared to the varied training group, $t(80) = 4.18$, $p < .001$, $\eta^2 = 0.18$ (see Fig. 3b).

2.4. Time of first move

2.4.1. Acquisition

The constant training group spent less time on the first move compared to the varied training group. This difference was marginally significant, $F(1, 74) = 3.13$, $p = .08$, $\eta^2 = 0.04$. The time spent on the first move decreased significantly across the 10 learning trials, $F(9, 666) = 11.32$, $p < .001$, $\eta^2 = 0.13$. The interaction between Group and Learning Trials did not reach significance, $F(9, 666) = .33$, $p = .96$, $\eta^2 = 0.04$, indicating that the groups' learning rates did not differ (see Fig. 4a).

2.4.2. Transfer

The constant training group had a significantly higher percentage of cost upon transfer from trial 10 to the new configuration of the task in trial 11, compared with the varied training group, $t(75) = 3.56$, $p < .001$, $\eta^2 = 0.15$ (see Fig. 4b).

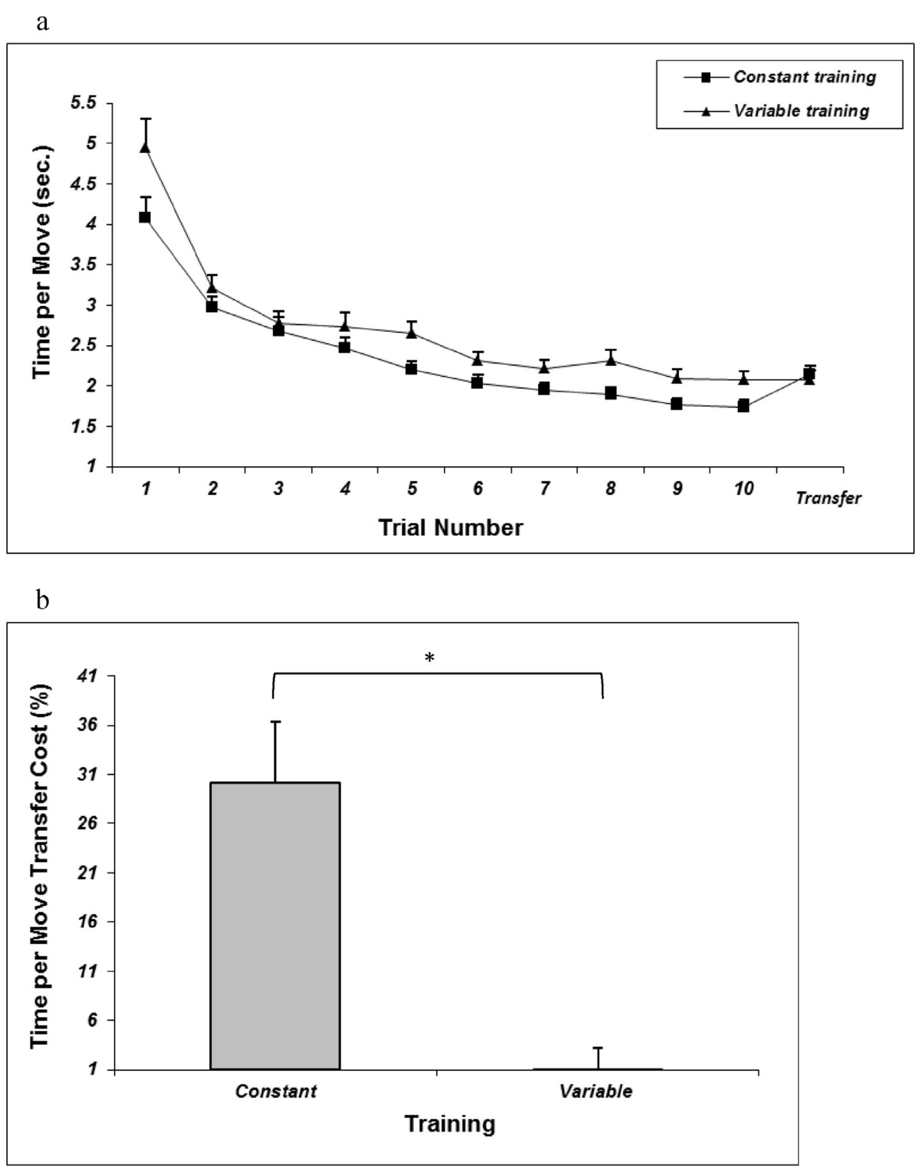


Fig. 3. a: Mean (and *SD*) time per moves to solve the TOHP as a function of the learning rates exhibited by the constant and varied training groups. b: Mean (and *SD*) time per moves to solve the TOHP indicating the percentage of cost of transfer from trial 10 to trial 11 as exhibited by the constant and varied training groups.

3. Discussion

Varied training is presumed to lead to the development of an abstract representation (or schema) of the learned skill (Chen, 1999; Schmidt, 1975). Several studies have demonstrated that varied training leads to better transfer than constant training in a wide range of perceptual-motor tasks (Green et al., 1995; Heitman et al., 2005; Roller et al., 2001; Yao et al., 2012). However, as mentioned above, Van Rossum (1990) showed that the empirical support for the "variability hypothesis" is not as conclusive as it seems.

Studies testing the effect of varied versus constant training on transfer of cognitive skills are very erratic. Chen and colleagues (Chen, 2002; Chen & Klahr, 1999; Chen & Mo, 2004) are among the few researchers who addressed this issue, though their research involved children only. Using the Luchins' water jar problem solving task, Chen demonstrated similar findings to those obtained with perceptual-motor tasks. That is, varied training led to better transfer than constant training. Rohrer (2012) and Rohrer et al. (2014) showed better transfer under interleaved versus blocked exposure in various tasks such as category induction, discrimination and mathematics learning.

Thus, the main goal of this study was to test the "variability hypothesis" on a cognitive skill learning task with young adults using the TOHP. The TOHP is a well-established cognitive skill learning task (Anderson et al., 2005; Beaunieux et al., 2006; Vakil & Hoffman, 2004). One of the advantages of this task is that it enables generation of measures of accuracy, speed and planning time of the task. Such findings on cognitive skill learning could have very important implications on the teaching methods all the way from primary school to graduate school.

In the present study we trained two groups of young adults on the TOHP, one with varied training and the other with constant training. The hypothesis that the "constant training" group would perform better at the acquisition phase than the "varied training" group was confirmed only when time per move was measured (and a tendency was shown for time of first move). Thus, constant training has an advantage over varied training only in terms of performance speed but not in terms of accuracy or planning time. In terms of transfer, three out of the four

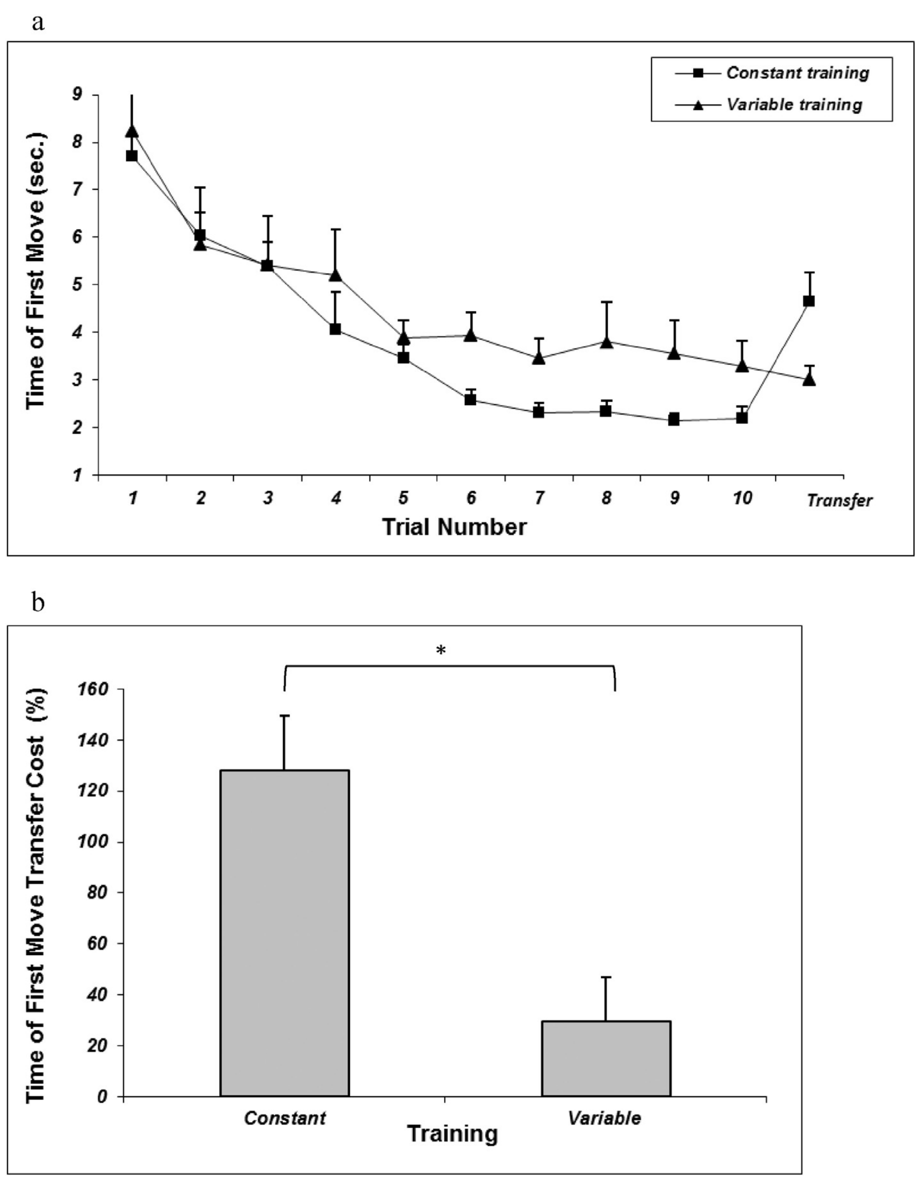


Fig. 4. a: Mean (and *SD*) time of first moves to solve the TOHP as a function of the learning rates exhibited by the constant and varied training groups. b: Mean (and *SD*) time of first moves to solve the TOHP indicating the percentage of cost of transfer from trial 10 to trial 11 as exhibited by the constant and varied training groups.

performance measures (i.e., *total time for solution*, *time per mo*ve and *time of the first move*) confirmed our prediction that the constant training group would yield a higher cost when transferring to a new configuration of the task compared to the varied training group. In terms of number of moves to solution, the groups were not dissociable. Our interpretation of these findings is that although participants were instructed to solve the puzzle in a minimum number of moves and as quickly as possible, they tended to focus more on the former than on the latter, resulting in a speed-accuracy trade-off. Note, that although a classic speed-accuracy trade-off would be when accuracy is improved and speed is degraded (or vice versa) the results of this study can be viewed as a form of trade-off. This occurs because the constant training group chose (intentionally or unintentionally) to perform the TOHP at a slower pace though as accurately as possible, thus trading speed for accuracy. Thus, the disadvantage of the "constant training" group in the transfer phase were evident in the measures that are dependent on speed and planning time but not in those that are dependent on accuracy (number of moves to solution).

One of the methodological limitations of this study is that our sample consists of participants that received class credit for their participation and the others who were paid for their participation. Also, in future research it is recommended to include at least early and late retention and transfer tests.

In summary, accuracy as measured by the number of moves to solve the TOHP did not distinguish between the groups either at the learning or the transfer phases. The measures based on time performance speed and planning time did distinguish between the groups (although the distinction was more pronounced in transfer than in acquisition). Thus, as predicted, varied training has an advantage in terms of transfer in a cognitive task as well. This supports the notion that varied training generates a more schematic and abstract representation which enables better transfer to a similar task (Green et al., 1995; Schmidt, 1975).

Lin, Fisher, Winstein, Wu, and Gordon (2008) have shown that transcranial magnetic stimulation (TMS) pulses to cortical motor areas (M1) interfered with motor skill learning under random condition. However, when retention of the motor skill learned under variable condition was tested, stimulation to the dorsolateral-prefrontal cortex (DLPFC), but not to primary motor cortex (M1), caused interference (Kantak, Sullivan, Fisher, Knowlton, & Winstein, 2010). Similarly, TMS to the DLPFC, but not M1, interfered with delayed transfer (outside-range target) of the task (Kantak, Sullivan, Fisher, Knowlton, & Winstein, 2011). Accordingly, it would be interesting in future studies to investigate whether TMS stimulation to the DLPFC would interfere with the retention and transfer of a cognitive skill learning task, such as the TOHP, as it interfered with a motor skill learning task.

Thus, retention and transfer of a skill learned under the varied training condition are dependent on the adequate functioning of the frontal lobes and primarily the DLPFC. Several studies have demonstrated the association between intelligence, and specifically fluid intelligence, and DLPFC function (Duncan, 1995; Kane & Engle, 2002). Accordingly, it could be predicted that transfer of a learned skill would be compromised among individuals with lower compared to higher fluid intelligence. It could be further predicted that when frontal lobe functioning has not yet fully developed, for example in young children (Huttenlocher & Dabholkar, 1997; Schiff & Vakil, 2015; Sowell, Delis, Stiles, & Jernigan, 2001), or has deteriorated due to aging (Raz, Gunning-Dixon, Head, Dupuis, & Acker, 1998; Sowell et al., 2003) or has been compromised as a result of traumatic brain injury (Avants et al., 2008), the effect of varied training on transfer would be compromised. This hypothesis should be tested in future research within relevant populations. Along this line, it is predicted that neuroimaging studies would demonstrate that performance of the TOHP under varied training would lead to greater frontal lobe activation than under constant training. These results have important implications in terms of the optimal learning conditions for adults while coping with cognitive problem solving tasks, such as in college. In other words, the findings emphasize the importance of practicing on a wide range of exemplars of the learned material in order to facilitate transfer.

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