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Dissociation Between Two Types of Skill Learning Tasks: The Differential Effect of Divided Attention*

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ABSTRACT

The proposed distinction between perceptual and conceptual skill-learning tasks was tested. Eighty participants were administered a cued recall task and two priming tasks, one perceptual (partial word-identification) and one conceptual (category production). Two skill-learning tasks were administered as well, one putative perceptual (mirror reading) and the other putative conceptual (Tower of Hanoi puzzle). Each task was performed by half of the participants under a full attention condition, and by the other half under a divided attention condition. Consistent with previous reports in the literature, divided attention did not interfere with the perceptual priming task, but did interfere with the conceptual priming and cued recall tasks. Dissociation was also observed for the skill-learning tasks. Divided attention did not affect either baseline performance or learning rate on the mirror reading task. However, on the Tower of Hanoi puzzle, divided attention did interfere with baseline performance, but contrary to prediction it did not interfere with learning rate. The differential effect of divided attention on the baseline performance in these two tasks was interpreted as supporting the distinction between conceptual and perceptual skill-learning tasks.

Implicit tests of memory are frequently divided into two major subtypes: priming or item-specific, and skill or procedural learning (Moscovitch, Goshen-Gottstein, & Vierzen, 1994; Squire & Zola-Morgan, 1991). Moscovitch et al. define these subtypes as follows: "Memory for the item typically is inferred from changes in the efficiency or accuracy with which the item is processed when it is repeated ... Procedural tests, on the other hand, are not concerned with acquisition of a particular item but rather with learning a general cognitive or sensorimotor skill ... Here, too, memory is inferred from changes in performance with practice" (p. 621).

In recent years priming has been further subdivided into perceptual and conceptual priming (Blaxton, 1992; Srinivas & Roediger, 1990). Partial word-identification is an example of a perceptual priming task (Biederman & Cooper, 1991; Hirshman, Snodgrass, Mindes, & Feenan, 1990) in which fragments of a word gradually appear on the screen and participants are told that their task is to attempt to identify the word as quickly as possible. The percent exposure to correct identification, ranging from 0 to 100, is automatically recorded. Priming is said to have occurred when the percent exposure required for the repeated words is significantly lower than for

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the non-repeated words. Category production is an example of a conceptual priming task (Srinivas & Roediger, 1990; Vakil & Sigal, 1997). In this task participants are presented with a word list consisting of non-frequent exemplars from different category names plus filler words, mixed together. At test, participants are read category names one at a time, and are requested to state the first eight category members that come to mind for each category name (without explicit reference to the list of words previously learned). Half of the category names were the primed categories (i.e., appeared at study), while the other half are new category names. Priming is said to have occurred when the number of non-frequent category members reported for the primed categories is significantly higher than the number for the non-primed categories.

In memory studies with normal participants, this distinction between perceptual and conceptual priming accounts for many findings, such as the level of processing effect. Whereas deep encoding affects conceptual priming but not perceptual priming, modality shift between study and test affects perceptual priming but not conceptual priming (Blaxton, 1989; Srinivas & Roediger, 1990). Divided attention (DA) manipulation was also used in several studies to distinguish between perceptual and conceptual priming. In a typical DA manipulation, participants are required to perform the task of interest simultaneously with a distracting task. Performance on the task of interest under this condition (i.e., DA) is compared to performance of the same task under full attention (FA) condition, that is, without simultaneously performing the distracting task. In the present study we used the same distracting task used by Russo and Parkin (1993), which was the tone-monitoring task. In this task three tones (high, medium, and low pitch) are played on a tape recorder. The tones are presented in random order at a quasi-random rate. Participants are asked to call out each tone (i.e., high, medium, or low) upon presentation, while simultaneously performing the task of interest. Several studies have consistently demonstrated that DA manipulations that do not disrupt the (overt or covert) identification of the study stimulus have little or no effect on perceptual priming (see Mulligan, 1998, for review). However, the effect of DA on conceptual priming depends on the attentional load of the distracting task. Conceptual priming interference occurs in a high-strength (Mulligan & Hartman, 1996), but not in a low-strength, DA task (Insingrini, Vazou, & Leroy, 1995; see Mulligan, 1997, for discussion).

The dissociation between perceptual and conceptual priming is further supported in neuropsychological studies. Although patients suffering from amnesia were shown to have perceptual and conceptual preserved priming effect (Cermak, Verfaellie, & Chase, 1995; Vaidya, Gabrieli, Keane, & Monti, 1995), patients afflicted with Alzheimer's disease were found to have preserved perceptual, but not conceptual, priming effect (Keane, Gabrieli, Fennema, Growdon, & Corkin, 1991; Monti, Gabrieli, Reminger, Rinaldi, & Wilson, 1996). Similar findings were reported with patients after closed-head injury, in which conceptual priming, but not perceptual priming, was impaired (Vakil & Sigal, 1997). Furthermore, for a patient with occipital lobe lesions, an opposite pattern has been observed, with impaired perceptual priming and preserved conceptual priming (Gabrieli, Fleischman, Keane, Reminger, & Morrell, 1995).

The present study addresses the question whether skill learning could be further subdivided into different subtypes. Patients with global amnesia have been shown quite consistently to possess preserved skill-learning ability for a large range of tasks. The mirror reading task (Cohen & Squire, 1980; Martone, Butters, Payne, Becker, & Sax, 1984) and the Tower of Hanoi puzzle (Cohen, Eichenbaum, Deacedo, & Corkin, 1985) are among the first tasks used in demonstrating normal skill learning in patients suffering from amnesia. In the mirror reading task, words are presented on the computer screen in mirror writing. Participants are asked to read the words aloud as quickly as they can because reading time is being recorded. The reduced reading time over repeated trials reflects skill acquisition. In the Tower of Hanoi task, three pegs appear on the screen. Five disks are arranged according to size, with the largest disk at the bottom of the left-most peg. Participants are told that the goal is to move the disks from the left-most peg to the right-most peg in a minimum number of steps, and that they must observe the following rules: Only one disk at a time may be moved, no disk may be placed on a smaller one, and the middle peg must be used. The optimal solution for five disks requires 31 moves. Learning is reflected by the reduced number of moves for solving the puzzle over the learning trials.

The fact that patients with amnesia are not impaired on all these tasks does not necessarily suggest that skill learning is a unitary system, but rather indicates that the brain regions affected in amnesia (i.e., medial temporal and diencephalon) are not involved in these tasks. The latter claim is consistent with findings regarding priming. Although the distinction between perceptual and conceptual priming is not useful in the dissociation between impaired and preserved memory ability in amnesia (both types of priming are preserved), it is nevertheless an important distinction. It accounts for many findings in memory studies with normal and patient groups other than those with amnesia (i.e., Alzheimer's disease and closed-head injury).

Various studies have implicated a dominant role for the basal ganglia in the regulation of skill learning. These claims are primarily based on studies of patients suffering from Parkinson's disease and Huntington's disease (for review, see Lawrence, Sahakian, & Robbins, 1998; Saint-Cyr & Taylor, 1992). However, other studies found that the performance of patients with Parkinson's disease on different skill-learning tasks (e.g., Tower puzzle) did not differ from that of normal controls (Morris et al., 1988). Thus, by contrast with patients with amnesia, results in all these groups are inconsistent. Several attempts have been made in the literature to resolve these conflicting findings. Some researchers have raised the possibility that heterogeneity of patient samples has contributed to inconsistent reports in the literature (e.g., Vakil & Herishanu-Naaman, 1998), while others have emphasized the heterogeneity of the skill-learning tasks (e.g., Harrington, Haaland, Yeo, & Marder, 1990).

We would like to propose that the distinction between perceptual and conceptual processes applied to priming could also be applied to skill learning. Confirmation of the distinction between perceptual and conceptual skill learning would make a theoretical as well as a diagnostic contribution. This distinction might help to resolve some of the conflicting findings about skill learning. In addition, it would lend further support to the transfer-appropriate-processing approach, emphasizing the importance of the mental processing required by the task. More specifically, this approach argues that dissociations among memory tasks are better understood in terms of the degree of similarity between cognitive processes at study and test than by assuming that different memory systems underlie different tasks (Blaxton, 1989).

Other researchers have previously distinguished between different types of skill-learning tasks. Moscovitch et al. (1994) distinguished between sensorimotor and rule-based skill-learning tasks. Gabrieli (1998) distinguishes between sensorimotor, perceptual, and cognitive tasks. However, these distinctions were based mainly on the descriptive requirements of the tasks and no operational criteria were offered for the classification of the different skill-learning tasks. Our suggested distinction between perceptual and conceptual skill learning offers a two-fold advantage. First, it is consistent with the dissociation that already exists in priming, and second, it enables application of the same criteria used in the literature to distinguish between perceptual and conceptual processes (e.g., effect of depth of processing and DA).

As reported above, previous studies have shown that DA could distinguish between perceptual and conceptual priming tasks (Mulligan, 1997). However, as pointed out by Mulligan, it is important to control for strength of the DA task, which, if not sufficiently demanding, would fail to interfere with the conceptual task. Five tasks were administered in the present study: two priming tasks, two skill-learning tasks, and a cued recall task. One-half of the participants were administered the tasks under FA and the other half under DA. We chose priming tasks that are well documented in the literature, one of which is perceptual (i.e., partial word-identification, Biederman & Cooper, 1991; Hirshman et al., 1990), and the other conceptual (i.e., category production, Graf, Shimamura, & Squire, 1985; Srinivas & Roediger, 1990). The putative perceptual (i.e., mirror reading) and conceptual (i.e., Tower of Hanoi puzzle) skill-learning tasks were chosen primarily based on the tasks' requirements. Mirror reading requires analysis and learning at the surface level (i.e., visuospatial transformation of the letters), as demonstrated in a recent fMRI study (Poldrack, Desmond, Glover, & Gabrieli, 1998). By contrast, the Tower of Hanoi puzzle is classified by Moscovitch et al. (1994) as a rule-based procedural task, which requires the acquisition or application of sequential patterns or rules. This task involves strategic processes such as monitoring, planning, developing, and testing hypotheses.

Various findings with the Tower of Hanoi puzzle suggest that it resembles other conceptual tasks. First, there are several indications that conceptual priming is tied to the frontal lobes (Gabrieli et al., 1996; Vakil & Sigal, 1997). The Tower of Hanoi puzzle is also known to be sensitive to the functioning of the frontal lobes (Lezak, 1995). Furthermore, the category production task, just like other conceptual tasks, was reported to benefit from deep encoding (Blaxton, 1989; Vakil & Sigal, 1997). Although not a typical manipulation of deep processing, performance on the Tower of Hanoi puzzle improved when participants went through active as compared to passive training (Vakil, Hoffman, & Myzlik, 1998).

In the present study, DA was used as an external and objective criterion to further validate the distinction between perceptual and conceptual skill learning, just as it distinguishes between perceptual and conceptual priming. To the best of our knowledge, this is the first exploratory study that attempts to distinguish systematically between different skill-learning tasks. Thus, as an exploratory study, we chose to apply the DA manipulation to those tasks for which other evidence already indicates that the one is probably mediated by perceptual processing (i.e., mirror reading) and the other by conceptual processing (i.e., Tower of Hanoi puzzle). Should the findings with DA appear to be consistent with this a priori categorization, then DA could be used as an additional criterion to classify other skill-learning tasks, the nature of whose underlying processes is not as clear.

The two priming tasks were administered in order to confirm that the DA task used in the present study (i.e., tone monitoring, Russo & Parkin, 1993) is at optimal strength to distinguish between known perceptual and conceptual priming tasks. In other words, DA is expected to affect performance on the conceptual priming task (i.e., category production), but not on the perceptual priming task (i.e., partial word-identification). Likewise, we expected DA to interfere with the explicit task (i.e., cued recall). Accordingly, it is predicted that DA will affect performance on the Tower of Hanoi puzzle but not the mirror reading task. The rationale for these predictions is that tasks that are assumed to require substantial cognitive resources, such as working memory, are more vulnerable to additional attentional demands, while tasks that are assumed to require analysis at the surface level are less vulnerable. Such a finding will be interpreted as supporting the distinction between conceptual and perceptual skill-learning processes.

METHOD

Participants

Eighty students (39 males and 41 females) from Bar-Ilan University (Israel) participated in this study. Ages ranged from 18 to 38 ($M = 23.12$, $SD = 2.94$), and education ranged from 12 to 18 ($M = 13.80$, $SD = 1.5$) years of schooling. Participants had no history of mental illness, alcoholism, brain injury, or drug abuse.

Tasks and Procedure

Participants were tested individually in one session. Five tasks were administered: two skill-learning tasks, Tower of Hanoi puzzle and mirror reading, two priming tasks, category production and partial word-identification, and a cued recall task. Each participant was assigned to one of four alternative task orders: (1) Mirror reading, category production, Tower of Hanoi puzzle, and partial word-identification; (2) Tower of Hanoi puzzle, partial word-identification, mirror reading, and category production; (3) Mirror reading, Tower of Hanoi puzzle, partial word-identification, and category production; (4) Partial word-identification, category production, mirror reading, and Tower of Hanoi puzzle. Each task was performed by half of the sample under FA condition and by the other half under DA condition. The exact assignment of participants was done in a pseudo-random order, so that two of the tasks were administered under FA and two under DA, for each participant. The assignment of participants (i.e., FA or DA) in the cued recall task was the same as in the category-production task.

Thus, participants who performed the Partial Word-Identification task under FA performed the mirror reading task under DA and vice versa. One group consisted of 20 male and 20 female participants, whose ages ranged from 19 to 30 ($M = 23.35$, $SD = 3.03$), and education ranged from 12 to 18 ($M = 14.13$, $SD = 1.65$) years of schooling. The other group consisted of 19 male and 21 female participants, whose ages ranged from 18 to 32 ($M = 22.90$, $SD = 2.87$), and education ranged from 12 to 17 ($M = 13.53$, $SD = 1.28$) years of schooling. The groups did not differ significantly either on age, $t(78) = .68$, $p > .05$, or educational level, $t(78) = 1.82$, $p > .05$.

Similarly, participants who performed the Tower of Hanoi puzzle under FA performed cued recall and category production tasks under DA and vice versa. One group consisted of 18 male and 22 female participants, whose ages ranged from 19 to 32 ($M = 23.20$, $SD = 2.88$), and education ranged from 12 to 17 ($M = 13.63$, $SD = 1.37$) years of schooling. The other group consisted of 21 male and 19 female participants, whose ages ranged from 18 to 30 ($M = 23.05$, $SD = 3.04$), and education ranged from 12 to 18 ($M = 14.03$, $SD = 1.61$) years of schooling. The groups did not differ significantly either on age, $t(78) = .23$, $p > .05$, or educational level, $t(78) = 1.20$, $p > .05$.

Partial Word Identification (Perceptual Priming Task)

This task was based upon a program written for a PC computer. Although the version used in the present study was composed in Hebrew (Vakil & Sigal, 1997), similar forms of this test can be found in the literature (Hirshman et al., 1990). This type of test has been found to induce perceptual priming (Biederman & Cooper, 1991; Hirshman et al., 1990). Participants were told that they would first see an × on the screen to focus their attention. Then, they would see fragments of a word gradually appearing on the screen. They were told that their task was to attempt to identify the word as quickly as possible. The increase in number of fragments of the word continued until the participant responded verbally, at which point the experimenter pressed a computer key, thereby freezing the process. If a participant incorrectly identified a word, s/he was told so, and the gradation process continued until the word was correctly identified. In this case the computer automatically registers error occurrence. Percent exposure to correct identification, ranging from 0 to 100, was automatically recorded. Following correct identification of the word, the full word was presented on the screen for 1 s. This task was performed for five trials, with each trial consisting of 10 words. Five of the words in each trial were repeated and five were non-repeated words. Over the five trials, this yields a total of 30 words, five of which appeared on each trial (the repeated words) and 25 non-repeated words (five new words on each of the five trials). Priming is said to have occurred when the percent exposure required for the repeated words is significantly lower than for the non-repeated words.

Category Production (Conceptual Priming Task)

Two sets of 28 words were constructed as two versions of the acquisition list. The initial and final three items were fillers used to counteract primacy and recency artifacts. The body of the list consisted of six exemplars from three category names (i.e., 18 words) plus four words as fillers, mixed together. The category exemplars were predetermined by a pretest as non-frequent exemplars for these category names (i.e., not being one of the eight most commonly supplied) (Vakil & Sigal, 1997). The words were presented at a 5-s rate, printed in uppercase letters 15 mm high. Participants were asked to read each word aloud. After a 5-min delay in which they read magazines, participants were read six category names one at a time, and were requested to state the first eight category members that came to mind for each category name (without explicit reference to the list of words previously learned). Out of the six category names, three category names were the primed categories (i.e., appeared at study), while the other three were new category names. After participants either supplied eight exemplars for the prior category or failed to produce a new exemplar for the current category, a new category was then attempted. There was no set time limit. The three categories were used to generate 18 words in the study phase that constituted primed words for one-half of the participants, but served as unprimed categories for the other half, and vice versa.

Cued Recall

An attempt was made in this task to make the explicit task as similar as possible to the implicit task of category production. Thus, a list of 28 words was also presented here to the participants at a 5-s rate. The initial and final three items were fillers used to counteract primacy and recency artifacts. The body of the list consisted of six exemplars from three category names (i.e., 18 words) plus four words as fillers, mixed together. After a 5-min delay in which they read magazines, participants were given the three categories' names, one at a time, and asked explicitly to recall as many words as possible of the previously presented category members.

Mirror Reading

The structure and procedure of this task were very similar to those of the partial word-identification task. Words appeared on the computer screen in mirror writing. Participants were asked to read the words aloud as quickly as they could. Each presentation contained three words – a triad. As soon as the three words were read correctly, the experimenter pressed the spacebar, reading time was recorded by the computer, and then the next triad appeared. The task was administered for five consecutive trials. Ten triads were presented in each trial (i.e., 30 words), of which five were repeated triads and five were non-repeated triads. Over the five trials, this yields a total of 30 triads (90 words), five of which (15 words) appeared on each trial (the repeated triads) and 25 (75 words) were non-repeated triads (five new triads on each of the five trials).

Tower of Hanoi Puzzle

Three pegs appeared on the screen, numbered 1–3. Five disks were arranged according to size, with the largest disk at the bottom of the left-most peg (# 1). Participants were told that the goal was to move the disks from the left-most peg (# 1) to the right-most peg (# 3) in a minimum number of steps and that they had to keep the following rules: Only one disk at a time could be moved, no disk could be placed on a smaller one, and the middle peg had to be used. The optimal solution for five disks requires 31 moves. The computer automatically measures the number of moves required to solve the puzzle. This task was administered five times consecutively.

Divided Attention Task

This task is the same DA used by Russo and Parkin (1993). In this task, three tones (high, medium, and low pitch) are played on a tape recorder. The tones are presented in random order at a quasi-random rate, so that the time lapse between any two consecutive tones varied from 6 to 9 s. Following 13 practice trials, participants were asked to call out each tone (i.e., high, medium, or low) upon presentation, while simultaneously performing one of the above tasks. They were told to concentrate on both tasks. The tone-monitoring distracter was used at the study phase for the category production and cued recall tasks. However, for the other tasks (i.e., Tower of Hanoi puzzle, mirror reading, and partial word-identification), because there is no natural break between the study and test phases, the tone-monitoring distracter was used throughout the entire task. The implications of such a procedure are discussed later on.

RESULTS

Preliminary analysis indicated that the order of task presentation did not have a significant effect on performance. To determine whether DA had a differential effect on the perceptual priming and conceptual priming tasks, results of the priming task will be reported, followed by those of the skill-learning tasks.

Partial Word-Identification (Perceptual Priming Task)

Mean percent exposure required for identification of repeated and non-repeated words for the FA and DA groups across learning trials is presented in Figure 1. A mixed-design ANOVA for repeated measures was conducted to test the effects of group (FA and DA), learning trials (trials 1–5), and repetition (repeated and non-repeated words). The former is a between-subjects factor and the latter two are within-subjects factors. Attentional load (i.e., FA vs. DA groups) did not have a significant effect on performance, $F(1, 78) = .08$, $p > .05$, $\eta^2 = .001$, observed power = .06. Overall, a significant decrease was found over learning trials, in percent exposure required for the identification of words $F(4, 312) = 57.85$, $p < .001$, $\eta^2 = .43$, observed power = 1.00. The significant repetition effect, $F(1, 78) = 1381.54$, $p < .001$, $\eta^2 = .95$, observed power = 1.00, indicates that less percent exposure was needed for identification of repeated as compared with non-repeated words. The only interaction to reach significance is the Learning trials × Repetition, $F(4, 312) = 100.92$, $p < .001$, $\eta^2 = .56$, observed power = 1.00. Follow-up analysis revealed that decrease in percent exposure from first to fifth trial reached significance with the repeated (i.e., priming) words, $F(1, 78) = 308.94$, $p < .001$, $\eta^2 = .80$, observed power = 1.00, but not with the non-repeated words, $F(1, 78) = 1.48$, $p > .05$, $\eta^2 = .02$, observed power = .22. This result indicates that only item-specific (i.e., priming) learning occurred and it did not transfer to new items. Attentional load did not affect differential learning rate, $F(4, 312) = 2.27$, $p > .05$, $\eta^2 = .03$, observed power = .66. The non-significant triple interaction, Attentional load × Learning trials × Repetition, $F(4, 312) = 1.73$, $p > .05$, $\eta^2 = .02$, observed power = .53, indicates that identification of repeated and non-repeated words was affected by attentional load to the same extent over the learning trials.

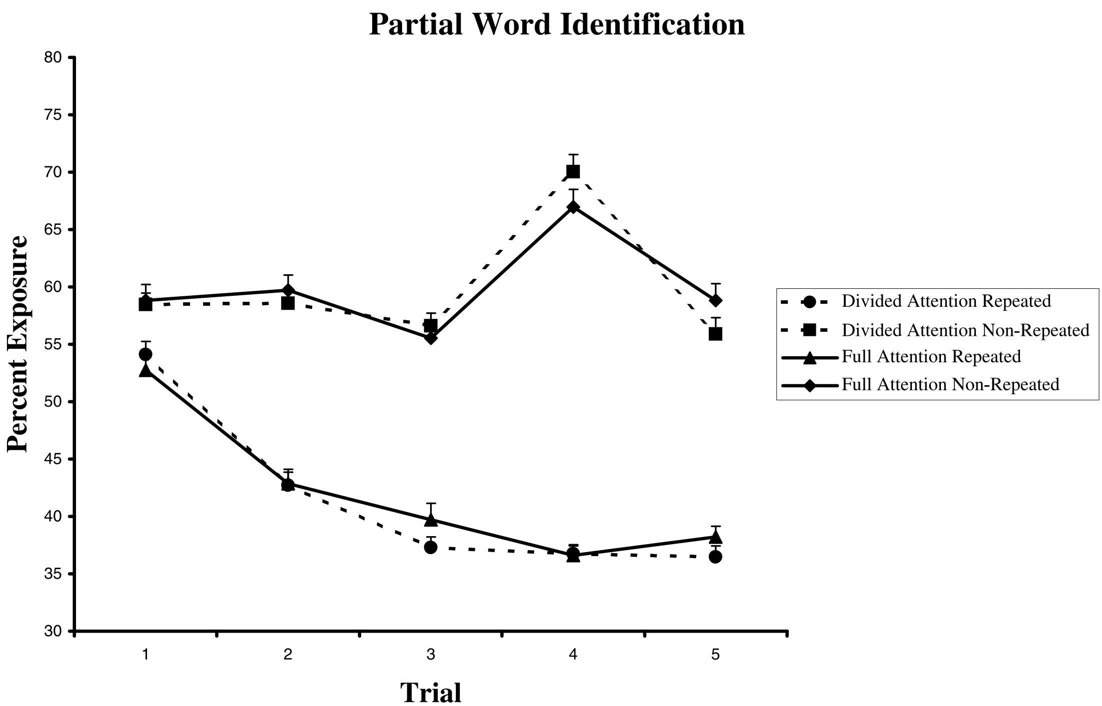

Fig. 1. Mean (and standard errors) percent exposure required for identification of repeated and non-repeated words for the FA and DA groups across learning trials.

Category Production (Conceptual Priming Task)

In this task, priming was measured as the difference between the number of non-frequent category members reported by participants for the primed and non-primed categories. The difference score under FA and DA ($M = 1.83$ and $-.05$, respectively) was significantly different, $t(78) = 4.31$, $p < .001$. Actually, the priming effect was totally eliminated under DA. Thus, as expected, the same DA task that had no effect on the perceptual priming task did have an effect on the conceptual priming task.

Cued Recall

The group under DA produced significantly fewer words than the group under FA ($M = 5.25$, $SD = 2.56$; $M = 8.4$, $SD = 3.88$, respectively), $t(78) = 4.35$, $p < .001$.

Mirror Reading

Mean reading time for each group across trials is presented in Figure 2. A mixed-design ANOVA for repeated measures was conducted to analyze the effects of group (FA and DA), repetition (repeated and non-repeated words), and learning trials (trials 1–5). The former is a between-subjects factor and the latter two are within-subjects factors. The main effect for group did not reach significance, $F(1, 78) = .08$, $p > .05$, $\eta^2 = .001$, observed power $= .06$, indicating that DA did not interfere with the learning rate of either the repeated or the non-repeated words. Repeated words were read faster than non-repeated words, $F(2, 78) = 88.52$, $p < .001$, $\eta^2 = .53$, observed power $= 1.00$. Overall, reading time improved across learning trials, $F(4, 312) = 13.95$, $p < .001$, $\eta^2 = .15$, observed power $= 1.00$. The only interaction that reached significance is the Repetition $\times$ Learning trials, $F(4, 312) = 10.74$, $p < .001$, $\eta^2 = .12$, observed power $= 1.00$. As can be seen in Figure 2, this result indicates that the learning rate (i.e., reduced reading time) is steeper for the repeated words as compared to the non-repeated words. Follow-up analysis revealed that the decrease in reading time from the first to the fifth trial reached significance for both the repeated words, $F(1, 78) = 43.27$, $p < .001$,

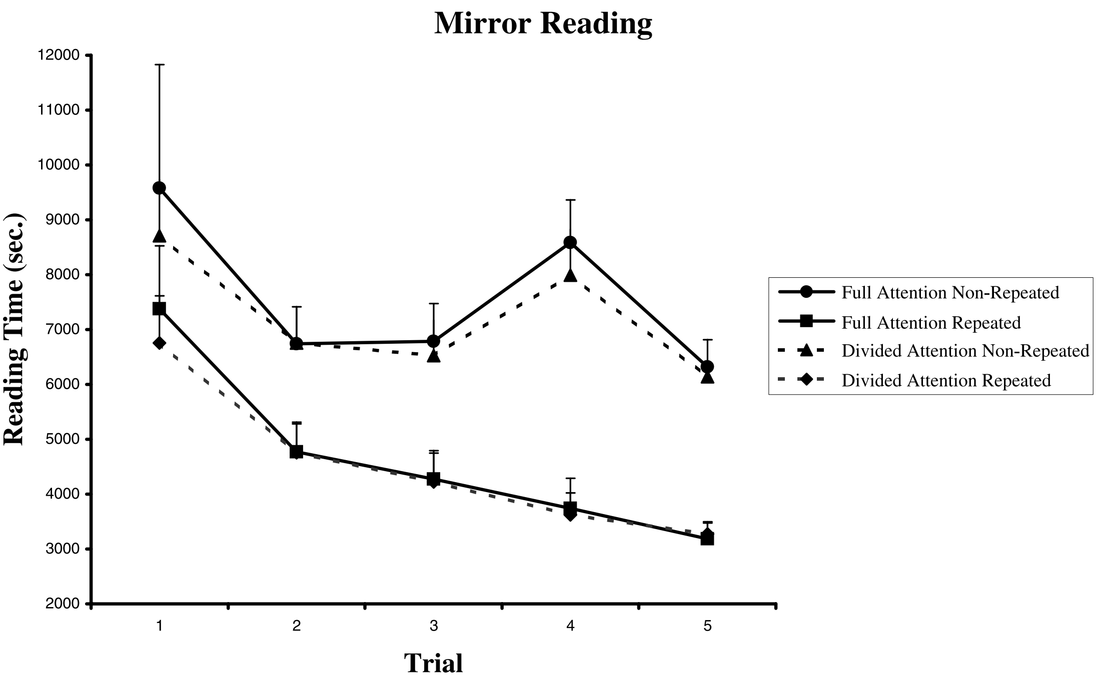

Fig. 2. Mean (and standard errors) reading time of repeated and non-repeated words for the FA and DA groups across learning trials.

$\eta^2 = .36$, observed power $= 1.00$, and the non-repeated words, $F(1, 78) = 8.03$, $p < .01$, $\eta^2 = .09$, observed power $= .80$. Attentional load did not affect learning rate, $F(4, 312) = .20$, $p > .05$, $\eta^2 = .003$, observed power $= .09$. The non-significant triple interaction, Attentional load × Learning trials × Repetition, $F(4, 312) = .08$, $p > .05$, $\eta^2 = .001$, observed power $= .07$, indicates that the reading time of repeated and non-repeated words was affected by attentional load to the same extent over the learning trials.

Tower of Hanoi Puzzle

A mixed-design ANOVA for repeated measures was conducted to analyze the effects of group (FA and DA) and learning trials (trials 1–5). The former is a between-subjects factor and the latter is a within-subjects factor. The mean number of moves required for solving the Tower of Hanoi puzzle for the FA and DA groups across learning trials is presented in Figure 3. Both main effects, but not the interaction, reached significance, group, $F(1, 78) = 21.44$, $p < .001$, $\eta^2 = .22$, observed power $= 1.00$, and learning trials, $F(4, 312) = 13.80$, $p < .001$, $\eta^2 = .15$, observed power $= 1.00$. Results indicate that the group performing the task under DA was impaired (i.e., required more moves overall to solve the Tower of Hanoi puzzle) as compared to the group under FA. The non-significant interaction, $F(4, 312) = .70$, $p > .05$, $\eta^2 = .01$, observed power $= .23$, indicates that there is no evidence that the groups' task-learning rate differs.

Divided Attention Task

Accuracy on the DA task was analyzed in order to test whether performance was comparable across all tasks. This information is critical for the interpretation of the results. Comparable performance on the DA task would indicate absence of a differential trade-off between the memory task and the DA task. As described above, for each participant two of the tasks were administered under FA and two under DA. Thus, in analyses of the DA task performance, on different memory tasks, for half of the participants it is a

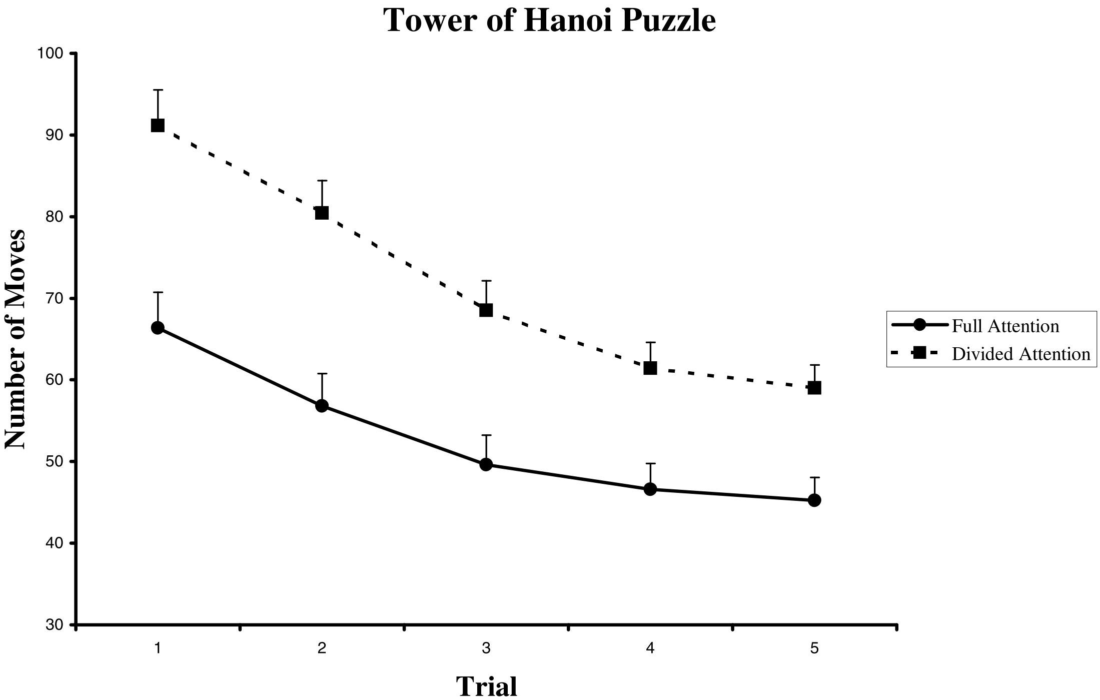

Fig. 3. Mean (and standard errors) number of moves required for solving the Tower of Hanoi puzzle for the FA and DA groups across learning trials.

within-subjects comparison and for the other half it is a between-subjects comparison. Accordingly, using *t*-test for independent samples for half of the group indicated that the percent of correct responses on the DA tasks for the perceptual (i.e., partial word-identification) ($M = 76.85$, $SD = 20.09$) and conceptual (i.e., category production) ($M = 74.06$, $SD = 19.01$) priming tasks was not significantly different, $t(38) = .45$, $p > .05$. Similar results were found for the other half of the group using *t*-test for paired samples, $t(19) = .50$, $p > .05$, comparing performance on the DA task with the perceptual ($M = 79.31$, $SD = 15.29$) and conceptual ($M = 81.11$, $SD = 17.15$) priming tasks. Comparison of the performance on the DA task with the mirror reading ($M = 69.56$, $SD = 17.34$) and the Tower of Hanoi ($M = 59.13$, $SD = 28.04$) skill-learning tasks using *t*-test for independent samples indicated that performance was not reliably different, $t(38) = 1.42$, $p > .05$. For the other half of the group, when *t*-test for paired samples was used, performance on the DA task with the skill-learning tasks, mirror reading ($M = 77.47$, $SD = 22.89$), and the Tower of Hanoi ($M = 65.95$, $SD = 21.22$) was significantly different, $t(19) = 11.52$, $p < .05$. Unlike the other comparison in which we found a comparable performance on the DA task, in this comparison performance on the DA task with the Tower of Hanoi puzzle was less accurate than with the mirror reading task. This finding suggests that there was no trade-off between performance on the DA task and the Tower of Hanoi puzzle, since the impaired performance on the latter was not due to investment of resources on the DA task, as indicated by impaired performance on this task as well. In other words, if the difference in DA performance had been in the opposite direction, it could have been interpreted as the result of a trade-off between the task of interest and the DA task. If the DA performance with the Tower of Hanoi had been better than that with mirror reading, it might have suggested that the poor performance on the Tower of Hanoi task is due to the priority given to the DA task and vice versa with the mirror reading task.

DISCUSSION

Consistent with previous reports (Russo & Parkin, 1993), the DA task used in the present study (i.e., tone-monitoring) interfered with the explicit task (i.e., cued recall), but not with the perceptual priming task (i.e., partial word-identification). Furthermore, the results of the category production task are consistent with earlier findings (Mulligan, 1997; Mulligan & Hartman, 1996) in showing that DA not only reduced, but actually eliminated the conceptual priming effect.

DA did not interfere with the learning rate on either skill-learning task. However, although it did interfere with baseline performance on the Tower of Hanoi puzzle, it did not affect baseline performance on the mirror reading task. These findings suggest that even though different cognitive processes were needed to perform the tasks, skill learning per se was not impacted by DA. In previous studies we have pointed out the dissociation between two components of the Tower of Hanoi puzzle, "baseline performance" and "learning rate." It was found that aging (Vakil & Agmon-Ashkenazi, 1997) and mental retardation (Vakil, Shelef-Reshef, & Levy-Shiff, 1997) affected baseline performance but not the learning rate. Similarly, participants in the present study performing the task under DA needed more moves overall to solve the Tower of Hanoi puzzle (i.e., different baseline), but their learning rate was not impaired by the DA. Therefore, the effect of DA on baseline performance is more interpretable due to its consistency with previous studies than if it had affected learning rate. However, in such a case (i.e., effect of DA on learning rate), we would also have viewed it as an indication of sensitivity of the Tower of Hanoi puzzle to attentional demand, and as such would have considered it as a conceptual skill-learning task. By contrast, DA affected neither the baseline nor the learning rate of the mirror reading task. These results indicate that these two tasks differ in their demands on attention and/or working memory. Hence, the Tower of Hanoi puzzle, just like explicit memory (i.e., cued recall task) and conceptual priming (i.e., category production task) was affected by DA. However, like perceptual priming, the mirror reading task was not affected by DA (i.e., partial word-identification task). Based on these findings, we would like to propose a dissociation between perceptual and conceptual skill-learning tasks that mirrors the dissociation between perceptual and conceptual priming tasks.

It is important to stress again that DA, although it affected level of performance on the Tower of Hanoi puzzle, did not affect the learning rate per se. This suggests that the interference only affects the availability of stimuli to be linked with procedural responses. Similarly, with the conceptual priming task, DA interfered with the encoding of the words. Consistent with this line of thinking, the lack of effect of DA on the partial word-identification and mirror reading tasks suggests that it did not interfere with availability of stimuli for processing, whether or not priming or skill learning was applied to those stimuli. The selective effect of DA on baseline performance, but not on learning rate of the Tower of Hanoi puzzle, reaffirms the importance of the distinction between these two components of skill learning. The implications of this dissociation are two-fold: first, that different cognitive processes mediate these two components, as one (i.e., baseline performance) is dependent on attentional demands and the other (i.e., learning rate) is not. Second, consistent with previous findings regarding aging (Vakil & Agmon-Ashkenazi, 1997) and mental retardation (Vakil et al., 1997), it could be concluded that these two components are subserved by different brain structures. The frontal lobe is probably involved with the baseline performance, because of its role in working memory (Courtney, Petit, Maisog, Ungerleider, & Haxby, 1998) and its vulnerability to age (Raz et al., 1997). In our opinion, it is speculative at this stage to point to a particular brain structure involved with learning rate. Further studies are required in order to demonstrate a double dissociation between the two components of skill learning and different brain structures.

An alternative interpretation of the results could be that the differential effect of DA on mirror reading and the Tower of Hanoi tasks is related to the difficulty level of the tasks rather than to the different underlying cognitive processes (i.e., perceptual vs. conceptual). This possibility should be empirically examined by varying difficulty within the same task; for example, testing the performance on the Tower of Hanoi puzzle with 3, 4, and 5 disks under FA compared to DA. Our prediction is that even with an easier version of the task, performance will be impaired under DA compared to FA, since solution of the Tower of Hanoi puzzle on all levels of difficulty is dependent on implementation of the same recursive law.

Russo and Parkin (1993) have shown that DA reduces the explicit recollection of young adults to the level of the elderly. The similarity of the effect of DA on the performance of young adults with that of an elderly group on the Tower of Hanoi puzzle task suggests that DA simulates the effect of age not only on explicit recollection, as previously demonstrated by Russo and Parkin, but also on the baseline performance of the Tower of Hanoi puzzle.

The two skill-learning tasks (i.e., mirror reading and the Tower of Hanoi puzzle) were categorized on a priori grounds as either perceptual or conceptual, based on the tasks' requirements. The contribution of the present study is that it offers an additional objective criterion (i.e., DA) for classifying a skill-learning task as perceptual or conceptual. This additional criterion is particularly important when the mental processes involved in a task are not as clear as in the tasks used in the present study. At this point it is important to stress that we do not think that DA should be used as the sole criterion for distinguishing between perceptual and conceptual processes (neither priming nor skill learning). When DA interferes with a task, this indicates (by definition) that the task is mediated by effortful processes (Shiffrin & Schneider, 1977) and that it requires working memory capacity. Thus, a task requiring substantial cognitive resources will thereby need more working memory, and as such will be more vulnerable to DA. Such a task is likely to be mediated by conceptual processes. However, not every task that requires more working memory is necessarily mediated by conceptual processes. Yet in the case of the Tower of Hanoi puzzle, vulnerability to DA is consistent with other indicators that would suggest its being mediated by conceptual processes.

A related issue is the question about the association between controlled versus automatic processes and explicit versus implicit tests of memory, respectively. Shiffrin and Schneider (1977), among many other researchers, have used DA as a criterion for the development of automatic processes. That is, when a task is unaffected by DA, it is assumed to be processed automatically. Accordingly, implicit tasks (category production and the Tower of Hanoi puzzle), that were shown in this study to be affected by DA, do not meet the criterion for automaticity. Jacoby (1991) has pointed out the difficulty in equating explicit tasks with controlled processes and implicit tasks with automatic processes because the tests are not process pure. Hence, based on the present results, it could be concluded that perceptual but not conceptual implicit tasks involve automatic processing. Jacoby offered the process-dissociation procedure as a way to dissociate between automatic and controlled processes within a single task. Jacoby's procedure could be applied in future research in an attempt to differentiate between the automatic and controlled components of different skill-learning tasks.

In addition, at least with regard to the Tower of Hanoi puzzle, it is possible that five learning trials are insufficient training in order to reach automaticity. This possibility is consistent with the claim made by several researchers that skilled performance is acquired in stages. The initial and later stages are *declarative* and *proceduralization* (Anderson, 1982) or *cognitive* and *autonomous* (Fitts, 1964). Accordingly, it is predicted that DA will affect performance in the early stage (as in the current study), but not in the later stage of skill acquisition. In other words, with more practice performance on the Tower of Hanoi puzzle will become automated, and then by definition we would not expect interference by DA.

Prior research on attention and priming has focused on the role of attention during encoding on later priming. However, because there is no natural break between the study and test phases in the two skill-learning tasks, the tone-monitoring distracter was used throughout the entire task. This fact prevents us from determining whether DA affects encoding, retrieval, or both. Recent studies with explicit memory tasks have demonstrated that DA affects memory when presented during encoding, but not during retrieval (Naveh-Benjamin, Craik, Guez, & Dori, 1998). Nevertheless, it is suggested that in future studies, the skill-learning task should be designed in a way that would allow for independent manipulations of encoding and retrieval processes. It is important to stress that, regardless of the fact that both skill-learning tasks were performed under DA throughout the task, performance selectively affected the Tower of Hanoi puzzle but not the mirror reading task.

Nissen and Bullemer (1987) reported that DA interfered with sequence learning in the serial reaction time task. Hence, according to the criterion used in the present study, this task would be classified as a conceptual task. However, Stadler (1995) argues that Nissen and Bullemer's results are due to their specific DA task (tone-counting), which interfered with sequence organization. Stadler demonstrated that attentional load alone did not interfere with sequence learning, whereas disruption of organization did interfere. This distinction is important because it emphasizes not only the strength of the DA task, as noted by Mulligan (1998), but that the specific nature of the DA task is crucial as well.

In spite of the fact that partial word-identification and mirror reading tasks require verbal responses, they were not interfered by the tone-monitoring task that also requires verbal responses. Future studies should proceed cautiously in this regard, since when performance is interfered under DA condition, the interference could be attributed to peripheral response interference rather than or in addition to central processing resources interference.

The dissociation between the two skill-learning tasks (i.e., mirror reading and the Tower of Hanoi puzzle) could help to resolve conflicting findings in studies that used these two tasks with different patient groups. Performance on the mirror reading task was intact for patients with Parkinson's disease (Harrington et al., 1990), Huntington's disease (Martone et al., 1984), and Korsakoff's disease (Martone et al., 1984). However, most studies found these three patient groups to be impaired on the Tower of Hanoi puzzle or an easier version of it, the Tower of Toronto. Patients with Parkinson's disease were impaired on the Tower of Toronto (Saint-Cyr, Taylor, & Lang, 1988; but see Morris et al., 1988), patients with Huntington's disease were impaired on the Tower of Hanoi puzzle (Butters, Wolfe, Martone, Granholm, & Cermak, 1985) as well as on the Tower of Toronto (Saint Cyr et al., 1988), and patients suffering from Korsakoff's disease were impaired on the Tower of Hanoi puzzle (Butters et al., 1985). Based on the dissociation offered in the present study, the findings with these three patient groups could be interpreted as indicating preserved perceptual, but impaired conceptual, skill-learning ability. This claim is consistent with the fact that the basal ganglia (which are impaired in patients affected by Parkinson's and Huntington's disease) have massive connections with the prefrontal cortex (Alexander, DeLong, & Strick, 1986).

Finally, the dissociation between perceptual and conceptual skill-learning tasks needs to be investigated further by methods (in addition to DA) used to distinguish between perceptual priming and conceptual priming (e.g., effect of depth of processing). Classification of the other skill-learning tasks might help resolve conflicting findings concerning these tasks.

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