2008

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Scott W. Brown
University of Southern Maine, swbrown@usm.maine.edu

Recommended Citation
Brown, S. W. (2008). The attenuation effect in timing: Counteracting dual-task interference with time-judgment skill training. Perception, 37(5), 712-724. doi:10.1068/p5698

Perception, 2008, volume 37, pages 712 – 724

doi:10.1068/p5698

The attenuation effect in timing: Counteracting dual-task interference with time-judgment skill training

Scott W Brown
Department of Psychology, University of Southern Maine, Portland, ME 04104-9300, USA;
e-mail: swbrown@usm.maine.edu
Received 22 August 2006, in revised form 21 August 2007; published online 9 May 2008

Abstract. A basic finding in the time-perception literature is an interference effect in dual-task conditions involving concurrent timing and distractor tasks. Dual-task conditions typically cause time judgments to become less accurate than single-task conditions in which subjects judge time alone. Previous research (Brown, 1998 *Psychological Research* **61** 71 – 81; Brown and Bennett, 2002 *Psychological Research* **66** 80 – 89) has shown that practice on the distractor task reduces interference, a phenomenon called the attenuation effect. The present research was designed to determine whether practice on the time-judgment task would produce a similar result. In experiment 1, subjects reproduced 6 – 14 s intervals in a series of practice trials. Some subjects received feedback regarding the accuracy of each response and others received no feedback. Subsequent testing under dual-task (timing + digit memory) conditions showed that feedback training reduced interference. In experiment 2, the practice trials included both single-task and dual-task conditions. Later tests showed that feedback training eliminated the interference effect. The results highlight the role of attentional resources, the transfer of skills, and compensatory decision processes in time-judgment skill training.

1 Introduction

Attention is one of the most important factors influencing time perception. Much of the work in this area revolves around the issues of capacity, resource allocation, and attentiveness to time (eg Brown and West 1990; Casini and Macar 1997; Fortin and Rousseau 1998; Fortin et al 1993; Macar et al 1994; Zakay 1998). A great deal of research has focused on the *interference effect*—a disruption in time-judgment performance produced by a concurrent distractor task (see Brown 1997 for a review). Here, I describe research designed to counteract interference and to promote greater accuracy in timing.

In a typical study on the interference effect, subjects are tested under dual-task conditions in which they attend to the passage of time for an upcoming time judgment (ie prospective timing), and also perform a concurrent distractor task. Virtually any type of distractor task—be it perceptual, motor, or cognitive—interferes with time judgments (Brown 1997). The standard finding is that time judgments under dual-task interference conditions are shorter, more variable, and/or more inaccurate compared with timing-only control conditions.

These findings usually are interpreted in terms of an attentional-resource model (eg Brown 1997; Hicks et al 1977; Thomas and Cantor 1975; Thomas and Waver 1975; Zakay 1989, 1993; Zakay and Block 1996). The central idea is that there is a limited pool (or pools) of attentional capacity, or resources (Gopher 1986; Navon and Gopher 1979; Tsang et al 1995; Wickens 1984, 1991, 1992). These limited resources support all cognitive processing. In dual-task conditions, resources must be shared between the multiple tasks. If the supply of resources is insufficient to meet processing demands, then task performance suffers. Timing research on the interference effect fits easily into this framework. Subjects who attend to time while also performing a concurrent distractor task are placed in a dual-task situation in which they must allocate resources between temporal and nontemporal processing. In this view, the interference effect occurs because resources are diverted away from timekeeping. Fewer resources devoted to time lead to greater error in time judgments.

It follows that, if the resource demand for the distractor task is reduced, then resources would be freed up for the timing task. As a result, one would expect timing performance to improve. One way to reduce the resource demand of a task is practice. The benefits of practice are well-established. The person acquires task-relevant skills, performance improves, and, most critically, there is the development of *automaticity.* Automaticity refers to performing a skilled task with fewer resources than normal (LaBerge 1981; Logan 1988, 1989; Pashler 1994). It is a direct result of practice. A familiar example of automaticity is driving, in which novice drivers experience the task as very effortful and demanding, whereas experienced drivers find it to be relatively effortless and automatic. Several studies have shown that automaticity can improve dual-task performance. The procedure is to pair a well-practiced task with an unpracticed task. Because the practiced task has acquired some degree of automaticity, it requires fewer resources than usual. The result is a reduction in dual-task interference (Ahissar et al 2001; Posner and Snyder 1975; Schneider 1985; Schneider and Fisk 1982).

These findings formed the basis for several studies on the interference effect in which subjects were given practice on a distractor task (Brown 1998; Brown and Bennett 2002; see also Sawyer 1999). This research describes a series of timing/distractor dual-task experiments involving a pretest – practice – posttest paradigm. The pretest and posttest involved single-task conditions (timing only) and dual-task conditions (in which subjects performed concurrent timing and distractor tasks). Between the pretest and posttest was the practice phase, which was devoted to several sessions of performing the distractor task alone. The distractor task was either manual tracking (Brown 1998, experiment 1; Brown and Bennett 2002, experiment 1) or mirror-reversed reading (Brown and Bennett 2002, experiment 2). Despite the fact that these tasks are very different, the studies produced similar results, namely that practice reduced dual-task interference in timing on the posttest. This reduction in interference is termed the *attenuation effect* (Brown and Bennett 2002). According to an attentional-resource model, practice on the distractor task reduced its attentional demand, thereby increasing the availability of resources for the timing task. More resources devoted to timing improved time-judgment performance.

The present research was designed to extend these findings and to enhance their generality. This research essentially approached the issue from the opposite direction compared with the previous studies. In this instance, subjects were given practice on the timing task rather than the distractor task. In addition to having subjects practice the timing task as opposed to the distractor task, this research was also designed to extend the generality of the previous findings. Compared with earlier work, the present research involved longer durations to be judged (6 – 14 s as opposed to 5 s), a different time-judgment method (reproduction as opposed to production), a different nontemporal distractor task (digit memory as opposed to tracking and reading), and a different experimental design (between-subjects as opposed to within-subjects).

2 Experiment 1

The goal of experiment 1 was to reduce the interference effect as a consequence of time-judgment skill training. It was anticipated that practice on a time-judgment task would lead to greater accuracy (one's performance improves) and greater efficiency (the task becomes automatized, at least to some degree). If timing requires fewer resources, then it may not be affected as much by a concurrent distractor task.

This approach is based on the assumption that practice on a time-judgment task yields the same performance improvements as practice on various nontemporal tasks such as reading, tracking, shadowing, classification, and visual search (eg Ammons 1951; Boronat and Logan 1997; LaBerge 1981; LaBerge and Samuels 1974; Schneider and Fisk 1982). However, it is important to recognize a fundamental difference between temporal

and nontemporal tasks. When practicing many nontemporal tasks, particularly tracking or reading as in the previous research, subjects are well aware that their performance is improving. That is, the nature of these tasks is such that subjects receive continuous implicit feedback about their performance. For example, it is self-evident that one can more easily keep up with the moving target on the tracking task, or that one is able to read faster and with less effort on the reading task. With time judgments, however, there is often no inherent feedback regarding one's performance (see Block and Zakay 2006). Therefore, practice at judging time without any knowledge of the results may not be an effective method for establishing time-judgment skills. Moreover, this procedure would not be comparable to the intrinsic feedback associated with practice on the distractor tasks in the previous research. This issue was resolved by providing subjects with feedback concerning the accuracy of their time judgments during the practice phase.

Many studies have demonstrated that time-judgment feedback reduces variability and improves accuracy (Brown et al 1995; Crowder and Hohle 1970; Franssen and Vandierendonck 2002; Hicks and Miller 1976; Macar and Vitton 1989; Montare 1985; Robinson 1963; Schoeffler and Poole 1967). Informational feedback is a crucial element for developing reliable time-judgment skills. Montare (1988) found no improvement in performance on time-judgment trials without feedback; with feedback, however, the same subjects showed greater accuracy and less variability in their time-judgment responses. Ishikura (2005) tested subjects on a motor-timing task in which they received informational feedback based on every response, the average of every 3 responses, or the average of every 5 responses. The first two conditions resulted in less timing error both during training and on retention tests, whereas the last condition was ineffective. Cognitive theorists have proposed that feedback improves timing performance by developing a more accurate internal temporal representation of the interval or intervals being judged (Franssen and Vandierendonck 2002; Macar and Vitton 1989).

2.1 *Method*

2.1.1 *Subjects.* Fifty-nine students (fifteen males) enrolled in General Psychology classes at the University of Southern Maine participated as subjects in exchange for extra course credit. The mean age of the students was 24.2 years.

2.1.2 *Design and procedure.* Subjects were tested individually. They were asked to remove their watches at the start of the experiment. An Apple II-GS computer equipped with a Timemaster II H. O. clock card (Applied Engineering) set at an interrupt rate of 1024 Hz was programmed to present stimuli and record responses. The experimental design comprised six blocks of time-judgment trials, divided evenly between two sessions. The sessions were scheduled within one week of each other. Blocks 1–5 constituted the practice trials, and block 6 involved the test trials. Each block included 15 trials. Each trial consisted of a stimulus display presented for 6, 8, 10, 12, or 14 s. There were 3 trials for each of these five durations. The trials were presented in a completely randomized order for each subject.

For the practice blocks, subjects judged time without any distractions or other task requirements. In this case, the stimulus displays consisted of a set of three 8 mm × 5 mm rectangles positioned in a horizontal arrangement across the center of the screen. Subjects reproduced the duration of these displays by pressing the spacebar to mark the beginning of their time estimate, and then when they judged that an amount of time equal to the display interval had passed by, they pressed the spacebar once again to mark the endpoint of their estimate. The subjects were assigned randomly to two groups: control ($n = 30$) and training ($n = 29$). The control group was instructed to be as accurate as possible when making their time judgments. The training group received

immediate feedback regarding the accuracy of their judgments. After completing each reproduction response, a feedback display appeared informing the subjects about the distance and direction of their judgment error (eg "Your estimate was 3.6 seconds too long", or "Your estimate was 2.2 seconds too short"). If the judgment error was less than 1 s, then the feedback message read "Accurate estimate".

For the test block, all subjects made time judgments without feedback. There were three different types of stimulus displays, which represented three memory-load conditions. The 0-item memory-load corresponded to the rectangle displays used in the practice blocks. This type of display represents a timing-only, single-task condition. The 3-item memory-load involved stimulus displays that consisted of three unique 3-digit numbers presented in a row across the center of the screen. These numbers ranged from 100 to 999 inclusive. The subjects were instructed to keep track of time and to silently rehearse the digits while they were displayed on the screen. This represents a dual-task condition involving time + digit memory. After reproducing the display interval, subjects received a digit-recognition memory test. In this test, a single 3-digit number appeared, and subjects judged whether or not it matched one of the numbers from the stimulus display. Subjects responded by pressing either 1 (a match) or 2 (no match). In half the cases the recognition test number matched a number from the stimulus display, and in half the cases the numbers did not match. In the 6-item memory-load condition, the stimulus displays consisted of six unique 3-digit numbers arranged in two columns in the center of the screen. This display represents another dual-task, time + digit memory condition. The 6-item condition was included in the design as a check on whether any potential attenuation effects due to practice on the timing task are moderated by a more difficult distractor task. Time-judgment and digit-recognition memory responses were obtained as before. For both the 3-item and 6-item memory-load conditions, subjects were instructed to regard the time judgments and memory judgments as being equally important.

2.2 *Results and discussion*

2.2.1 *Data scoring.* The main issue is the accuracy of time judgments under the different experimental conditions. Performance was assessed in terms of the absolute error in time judgments (ie how much the temporal reproductions deviated from accuracy). There were two reasons for selecting absolute error as the dependent measure. First, most feedback studies involving time judgments focus on measures of absolute error or variability (eg Franssen and Vandierendonck 2002; Hicks and Miller 1976; Montare 1985). These measures are considered to be the most appropriate in this context because the feedback procedure is designed to reduce any deviations from accuracy, regardless of the direction of error. Second, numerous studies have shown that absolute error is an especially sensitive measure of timing performance (eg Boltz 1995; Brown 1985; Brown and West 1990; Goldstone 1975; Schwartz 1978). Some authors have argued that measures of absolute error are more reliable than measures of directional error (eg Brown and Boltz 2002; Franssen and Vandierendonck 2002).

Percentage absolute-error scores were computed for each subject by submitting each temporal reproduction to the formula $[(|\text{duration} - \text{reproduction}|)/\text{duration}] \times 100$. This procedure computes the absolute difference between the actual display duration and the subjects' reproduction response, divides the result by the display duration so that all differences are expressed in proportion to the interval being judged, and then multiplies this value by 100 to express the result as a percentage by which the time judgment deviates from the actual duration. Thus, judgments of different durations are on the same relative scale and judgment errors are directly comparable. For purposes of analysis, composite percentage absolute-error scores were calculated for each subject.

The composite scores for the practice blocks were calculated by averaging the 15 scores in each block.(1) For the test block, composite scores were computed by averaging the 5 individual scores associated with each of the three memory-load conditions.

2.2.2 *Practice trials.* Figure 1 shows the mean percentage absolute-error scores for the two groups of subjects across the five blocks of practice trials. These scores were submitted to a 2×5 (group $\times$ block) mixed analysis of variance (ANOVA). The analysis uncovered a significant effect for group ($F_{1,57} = 16.71$, $p < 0.001$, $\eta_p^2 = 0.22$). As expected, the training group exhibited less time-judgment error ($M = 6.5\%$) than the control group ($M = 9.4\%$). This result replicates other studies showing that feedback improves time-judgment accuracy (eg Franssen and Vandierendonck 2002; Hicks and Miller 1976; Montare 1985). None of the other effects in the ANOVA achieved significance.

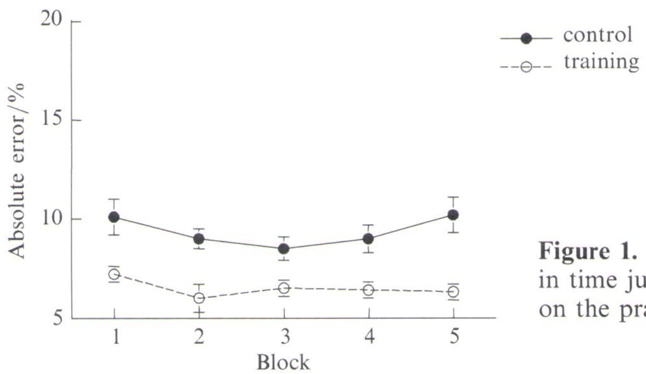

Figure 1. Mean percentage absolute-error scores in time judgments for control and training groups on the practice blocks in experiment 1.

2.2.3 *Test trials: Timing performance.* Mean absolute-error scores for the two groups of subjects in the three memory-load conditions on the test trials are depicted in figure 2. These scores were submitted to a 2×3 mixed ANOVA, and both main effects were significant. The memory-load effect ($F_{2,114} = 11.58$, $p < 0.001$, $\eta_p^2 = 0.16$) showed that timing error increased from the timing-only (0-item) condition to the two dual-task (the 3-item and 6-item memory-load) conditions. Orthogonal contrasts were applied to these data to test for differences between means. Contrast 1 confirmed a significant increase in error from the single-task condition ($M = 9.3\%$) to the combined dual-task conditions ($M = 12.9\%$; $F_{1,57} = 25.79$, $p < 0.001$, $\eta_p^2 = 0.29$). Contrast 2, comparing the two dual-task conditions, was not significant ($F < 1$).

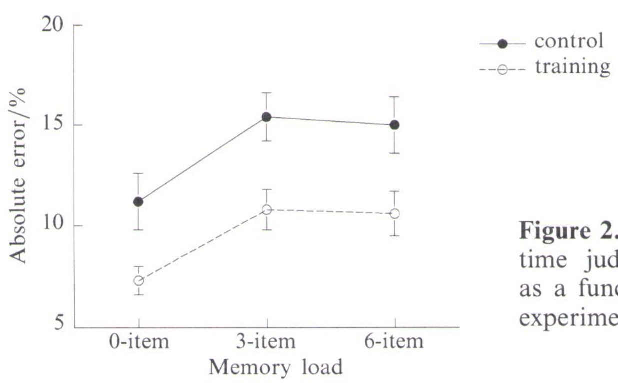

Figure 2. Mean percentage absolute-error scores in time judgments for control and training groups as a function of memory load on the test block in experiment 1.

(1) The composite scores in the practice blocks mask trial-to-trial changes in performance. These changes are revealed by trend analyses conducted on the absolute-error scores associated with the 15 practice trials in block I. There were no significant trends in timing performance for the control group. However, the training group exhibited a significant linear decrease in error ($F_{1,28} = 12.04$, $p < 0.002$) from trial 1 ($M = 8.4\%$) to trial 15 ($M = 6.1\%$). These results are consistent with other studies that have shown a decrease in timing error after the first few trials with feedback (eg Franssen and Vandierendonck 2002; Montare 1985; Robinson 1963).

The main result is the group effect ($F_{1,57} = 11.10$, $p < 0.002$, $\eta_p^2 = 0.16$), which showed that there was less timing error for the training group ($M = 9.6\%$) than for the control group ($M = 13.9\%$). Note that prior training attenuated, but did not eliminate, the interference effect. Subjects in the training group were still adversely affected by the distractor task, but the impact was less than that on the control group. Compared with the control group, the training group maintained a nearly constant reduction in error across the 0-item, 3-item, and 6-item memory-load conditions of approximately 4% (range 3.9% to 4.4%). Thus, although the two groups showed a similar *proportional* increase in timing error from the single-task to dual-task conditions, in *absolute* terms, the training group showed less dual-task interference than the control group. Despite the fact that feedback training was restricted to the single-task condition, the benefits of the training transferred to dual-task conditions as well. Indeed, the training group averaged less timing error under dual-task (3-item and 6-item memory-load) conditions (for the combined dual-task conditions $M = 10.7\%$) than the control group produced under single-task (0-item) conditions ($M = 11.2\%$). Prior training under noninterference conditions minimized the amount of error imposed by the distractor task on timing responses.

2.2.4 *Test trials: Recognition performance.* Mean recognition scores for the two memory-load conditions were formed by calculating the percentage of correct-recognition responses across the five trials of each memory-load condition. These scores were analyzed in a 2×2 (group $\times$ memory-load) mixed ANOVA. As expected, the memory-load main effect ($F_{1,57} = 11.43$, $p < 0.001$, $\eta_p^2 = 0.17$) indicated that recognition performance was more accurate in the 3-item load condition ($M = 82.7\%$) than in the 6-item load condition ($M = 70.5\%$). However, neither the group nor the group $\times$ memory-load effects was significant.

In summary, experiment 1 showed that time-judgment skill training effectively attenuated the interference effect. The time-judgment skill, although acquired under single-task, timing-only conditions, had generalized to dual-task interference conditions.

3 Experiment 2

The purpose of experiment 2 was to assess a different method for counteracting distractor-task interference on timing performance. Researchers have explored the effectiveness of different procedures for improving dual-task performance. The two main procedures are single-task practice and dual-task practice (see Brown 1998 for a discussion). In contrast to single-task practice (employed in experiment 1), which is designed to improve performance by promoting automaticity and thus reducing resource demands, dual-task practice is designed to help develop *timesharing* skills (T L Brown and Carr 1989; Detweiler and Lundy 1995; Schneider and Detweiler 1988; Wickens 1992, pages 383–385). Timesharing refers to rapidly switching attention between concurrent tasks. Timesharing skills may include learning to integrate the two tasks, learning to coordinate the flow of information, determining how long to dwell on one task before switching attention to the other, etc. In terms of time judgments and the interference effect, timesharing skills may involve learning to make adequate corrections or adjustments to temporal judgments. These adjustments would serve to compensate for any loss of attentiveness to time (see Doob 1971, pages 33–37; Frankenhaeuser 1959, page 18 for discussions of this issue). Thus, incorporating all the memory-load conditions in the training phase may allow subjects to better counteract distractor-task interference and produce a stronger attenuation effect. Therefore, the training trials were modified to include both single-task (timing-only) conditions as in experiment 1, and dual-task (timing + digit memory) interference conditions.

3.1 *Method*

3.1.1 *Subjects.* Forty-three students (fifteen males) enrolled in General Psychology classes volunteered for the experiment in exchange for extra credit. The average age of the students was 26.0 years.

3.1.2 *Design and procedure.* Subjects were tested individually and watches were removed prior to the experiment. The computer hardware was the same as used in experiment 1. The software was altered to include the 0-item, 3-item, and 6-item memory-load conditions in the practice blocks as well as in the test block. Otherwise, the experimental design was similar to that of the first experiment. There were six blocks of trials spread over two sessions separated by less than a week. As in experiment 1, blocks 1 – 5 comprised the practice trials and block 6 corresponded to the test trials. There were 15 trials per block, which consisted of stimulus displays presented for 6, 8, 10, 12, or 14 s. Time judgments were in the form of temporal reproductions.

The subjects were assigned randomly to control ($n = 21$) and training ($n = 22$) groups. The control group was encouraged to be as accurate as possible when judging time; the training group received feedback regarding the magnitude and direction of time-judgment error immediately after each reproduction response. The only difference from experiment 1 was in the practice trials, which included all the memory-load conditions (0-item, 3-item, and 6-item memory loads). The test trials were the same as the practice trials, with the exception that the training group no longer received feedback for their time-judgment responses. In both practice and test trials, the 3-item and 6-item memory-load displays were accompanied by a recognition memory test. As before, a single 3-digit number appeared on the screen, and subjects judged whether or not this number matched any of the numbers from the stimulus display. All subjects were instructed to regard the time judgments and recognition judgments as being equally important.

3.2 *Results and discussion*

3.2.1 *Data scoring.* The time-judgment data were converted into percentage absolute-error scores. For each block of trials, composite scores for each subject were created by averaging individual scores across the 5 trials associated with each memory-load condition. As for the recognition-memory scores, the percentage of correct responses was calculated separately for the 3-item and 6-item memory-load conditions for each block of trials.

3.2.2 *Practice trials: Timing performance.* Mean absolute-error scores for the practice trials are shown in figure 3. Examination of the figure suggests that (a) the training group produced less time-judgment error than the control group, (b) there appears to be less timing error for the single-task conditions and more error for the dual-task conditions, and (c) the scores for the control group tend to be more variable than those for the training group. These observations were corroborated by the statistical analysis of the data. The scores were submitted to a group (control and training) × memory-load (0-item, 3-item, and 6-item loads) × block (blocks 1 – 5) mixed ANOVA. The main effect for group ($F_{1,41} = 26.02$, $p < 0.001$, $\eta_p^2 = 0.39$) confirmed that the training group produced less time-judgment error ($M = 9.2\%$) than the control group ($M = 14.8\%$). The main effect for memory load ($F_{2,82} = 12.29$, $p < 0.001$, $\eta_p^2 = 0.22$) showed a significant difference in error between 0-item memory-load ($M = 8.7\%$) versus the 3-item ($M = 13.3\%$) and 6-item ($M = 13.9\%$) memory-load conditions.

The main effect for block ($F_{4,164} = 23.56$, $p < 0.001$, $\eta_p^2 = 0.36$) is compounded by the group × block ($F_{4,164} = 8.68$, $p < 0.001$, $\eta_p^2 = 0.17$) interaction. Simple main-effects tests applied to the interaction showed that the mean scores varied across blocks only for the control group ($F_{4,164} = 29.41$, $p < 0.001$, $\eta_p^2 = 0.41$). In contrast, the scores for

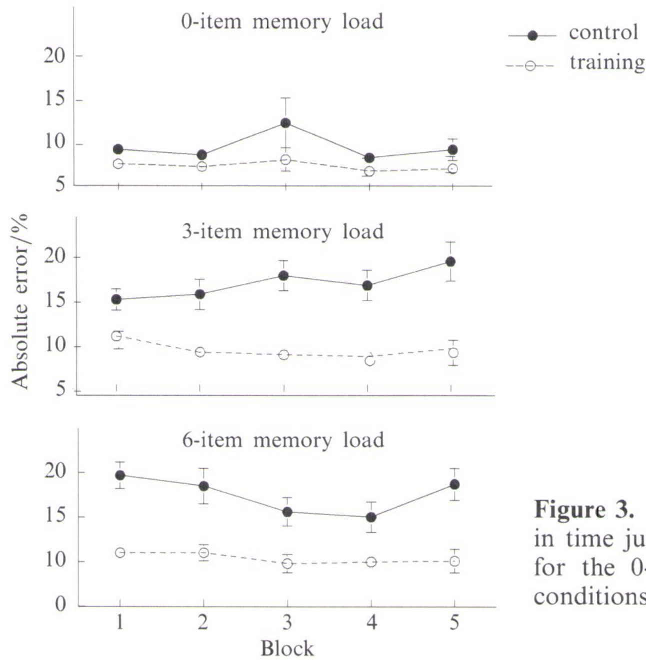

Figure 3. Mean percentage absolute-error scores in time judgments for control and training groups for the 0-item, 3-item, and 6-item memory-load conditions on the practice blocks in experiment 2.

the training group were relatively stable across blocks ($F < 1$). Finally, the memory-load × block ($F_{8,328} = 3.11$, $p < 0.002$, $\eta_p^2 = 0.07$) interaction, although of weak magnitude, was also significant. Tests of simple main effects showed that differences between memory-load conditions tended to be reliable only in block 2 ($F_{2,82} = 25.45$, $p < 0.001$, $\eta_p^2 = 0.40$), where the mean scores for the 0-item, 3-item, and 6-item load conditions were 8.2%, 12.6%, and 14.7%, respectively. None of the other effects in the ANOVA were significant.

3.2.3 *Practice trials: Recognition performance.* Percentage correct-recognition scores for the practice trials were entered into a group (control and training) × memory-load (3-item and 6-item) × block (blocks 1–5) 2 × 2 × 5 mixed ANOVA. The primary result was a main effect for group ($F_{1,41} = 11.47$, $p < 0.002$, $\eta_p^2 = 0.22$), which showed that recognition performance was lower for the training group ($M = 74.0\%$) than for the control group ($M = 82.5\%$). This result suggests that the training group invested more attentional resources to the timing task in the course of developing time-judgment skills, thereby leaving fewer resources available for memory processing. The main effect for memory-load ($F_{1,41} = 13.44$, $p < 0.001$, $\eta_p^2 = 0.25$) revealed the expected result, that recognition scores were higher for the 3-item condition ($M = 85.0\%$). than for the 6-item condition ($M = 71.2\%$). The block main effect ($F_{4,164} = 14.57$, $p < 0.001$, $\eta_p^2 = 0.26$) is compounded by a weak memory-load × block interaction ($F_{4,164} = 2.75$, $p < 0.03$, $\eta_p^2 = 0.06$). Simple main-effects tests comparing the memory-load conditions within each block showed that source of the interaction is restricted to block 3 ($F_{1,41} = 21.37$, $p < 0.001$, $\eta_p^2 = 0.34$). The mean recognition score for the 3-item condition was 84.2%, whereas the corresponding score for the 6-item condition was 66.5%. None of the other effects in the ANOVA was significant.

3.2.4 *Test trials: Timing performance.* Figure 4 shows mean absolute-error scores for the control and training groups across the three memory-load conditions in the test block. These scores were submitted to a 2 × 3 (group × memory-load) mixed ANOVA, and the group ($F_{1,41} = 15.61$, $p < 0.001$, $\eta_p^2 = 0.28$), memory-load ($F_{2,82} = 12.43$, $p < 0.001$, $\eta_p^2 = 0.23$), and group × memory-load ($F_{2,82} = 8.69$, $p < 0.001$, $\eta_p^2 = 0.17$) effects were all significant. Simple main-effects tests comparing the memory-load conditions within

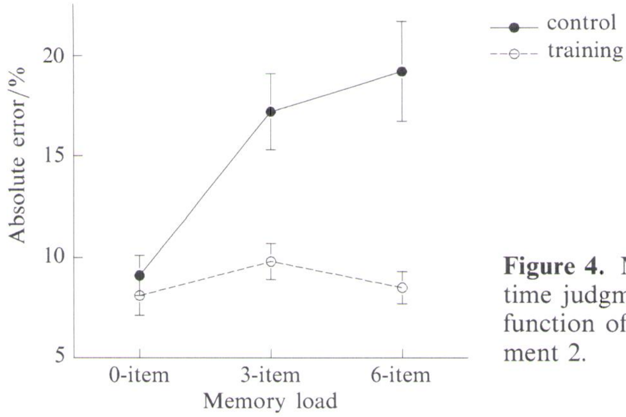

Figure 4. Mean percentage absolute-error scores in time judgments for control and training groups as a function of memory load on the test block in experiment 2.

each group were applied to the interaction. The different memory loads had no effect on timing error for the training group ($F < 1$). As shown in figure 4, the timing error for this group remained essentially constant across the different memory-load conditions. In contrast, the memory-load conditions exerted a strong effect on the control group ($F_{2,82} = 20.11$, $p < 0.001$, $\eta_p^2 = 0.33$). Orthogonal contrasts were used to test for differences between means. Contrast 1, comparing the 0-item load ($M = 9.1\%$) versus the combined 3-item and 6-item loads ($M = 18.2\%$), was significant ($F_{1,20} = 14.45$, $p < 0.001$, $\eta_p^2 = 0.43$). Contrast 2, the 3-item ($M = 17.2\%$) versus 6-item ($M = 19.2\%$) comparison, was not significant.

3.2.5 *Test trials: Recognition performance.* Percentage correct-recognition scores were calculated for the 3-item and 6-item memory-load conditions for the test trials and submitted to a 2 × 2 (group × memory-load) mixed ANOVA. The only significant result was a main effect for memory-load ($F_{1,41} = 12.49$, $p < 0.001$, $\eta_p^2 = 0.23$). The 3-item condition ($M = 84.7\%$) was associated with higher memory scores than the 6-item condition ($M = 71.6\%$). Neither the group nor the group × memory-load effects achieved significance.

Summarizing the main results of experiment 2, time-judgment skill training under dual-task conditions effectively eliminated the interference effect in timing on the test trials. Indeed, time-judgment error for the training group was low (averaging less than 10%) and remained at virtually the same level under the 0-item, 3-item, and 6-item memory-load conditions. In contrast, the control group exhibited a strong interference effect in time judgments, with error literally doubling from the single-task (0-item) to dual-task (3-item and 6-item) conditions.

4 General discussion

This research offers some interesting insights into the role of cognitive processes in time perception. There are two main points of discussion. The first point concerns the attenuation effect, a reduction in dual-task interference in timing performance as a result of practice. The second point involves a comparison of experiment 1 with experiment 2. These and other issues are considered more fully below.

4.1 *Attenuation effect*

The main finding is that time-judgment skill training was effective at attenuating the classic interference effect in timing. This finding complements the previous research showing a similar attenuation effect as a result of practice on a distractor task (Brown 1998; Brown and Bennett 2002). The results are in line with an attentional model that emphasizes the role of practice in reducing the amount of resources required for task performance. In the previous research, practice on a distractor task automatized the task sufficiently so as to produce less interference with a simultaneous timing task.

In the present case, practice on the timing task reduced its attentional demand to the point where it was less affected by a concurrent distractor task. The results also show an underlying commonality between temporal and nontemporal tasks, and support the view that time estimation is comparable to other perceptual tasks. According to Michon's (1972, 1985) 'equivalence postulate', processing temporal information is in essence no different from processing nontemporal information. Both types of task are subject to the same principles governing practice, automaticity, and resource allocation.

One bit of evidence supporting an attentional-resource account concerns recognition performance on the distractor task. Experiment 2 provides the most information, because subjects performed recognition tests on the practice trials as well as on the test trials. On the practice trials, subjects in the training group produced significantly lower recognition scores than subjects in the control group. This pattern may reflect a greater commitment of resources to the timing task as subjects were in the process of developing time-judgment skills. On the test trials, however, the training group maintained virtually the same level of recognition performance as the control group. Yet at the same time, the training group also made accurate temporal reproductions, even under these dual-task conditions. This same basic result also occurred on the test trials in experiment 1, in which the training group produced a comparable level of recognition performance to the control group, and yet simultaneously made more accurate temporal reproductions. These data suggest that the improved accuracy in timing on the test trials did not come at the expense of the memory task.

4.2 *Experiment 1 versus experiment 2*

Although both experiments were successful in counteracting the interference effect, experiment 2 was more effective than experiment 1. There are at least two factors that may account for this differential effectiveness: the transferability of skills and compensatory processes. One important finding to emerge from the literature on practice involves the transferability of skills across different conditions. The benefits of practice are generally restricted to those specific conditions that prevail under training, and the transfer of skills across different domains or conditions may be limited (Bahrick and Shelly 1958; T L Brown and Carr 1989; Logan 1979; Schneider 1985; Schneider and Detweiler 1988). In experiment 1, practice was confined to the timing-only (0-item memory-load) condition and performance on later test trials revealed that dual-task interference in the 3-item and 6-item load conditions was *reduced* but not eliminated. This partial attenuation of the interference effect may represent an incomplete transfer of timing skills to a different set of conditions. In contrast, the practice trials in experiment 2 included all the memory-load conditions, and therefore perfectly matched the makeup of the test trials. In this case, dual-task interference on the test trials was eliminated. This more complete attenuation of the interference effect may correspond to a more complete transfer of skills to a set of already-familiar conditions.

The second factor that may play a role in the greater effectiveness of experiment 2 involves compensatory processes in the dual-task conditions. The essential feature of the interference effect is that it is difficult to keep track of time while simultaneously performing another task. Time slips by unnoticed, temporal cues lose their salience, counting processes may be disrupted, etc. Subjects therefore make their time judgments on the basis of a flawed temporal representation of the interval and their judgments are correspondingly inaccurate and variable. However, practice at judging time under dual-task conditions (as in experiment 2) may promote skills at compensating for the incomplete temporal record. These subjects may have learned to make more adequate adjustments to their time judgments. Very few writers have addressed this issue. One notable exception is Doob (1971), who draws a distinction between primary and secondary levels of temporal judgments. The primary judgment is the initial, spontaneous impression of the length of

an interval. This initial impression may then be moderated by the secondary judgment, which corresponds to a revision or re-evaluation of the primary judgment. The secondary judgment represents a refinement or fine tuning based on intuition, experience, and reinforcement. These factors lead one to correct (or overcorrect) the primary judgment (see also Gilliland et al 1946). The dual-task practice trials in experiment 2 may have provided subjects with these compensatory skills, prompting them to make more accurate adjustments to their primary judgments. In contrast, the subjects in experiment 1 practiced judging time only under single-task, noninterference conditions, and thus did not have the opportunity to develop these compensatory skills.

It is instructive to compare experiment 1 and experiment 2 in the context of the previous research on the attenuation effect. In Brown (1998, experiment 1), subjects received single-task practice by performing the distractor task (tracking) alone. Correspondingly, in the present experiment 1, subjects received single-task practice by performing the timing task alone. Both studies showed an attenuation of the interference effect under dual-task conditions. In Brown (1998, experiment 2), subjects received dual-task (concurrent timing + distractor) practice, which was not effective in attenuating the interference effect. However, in the present experiment 2, dual-task practice was very effective at eliminating interference. The discrepancy in outcomes may be attributed to a critical methodological difference between the two experiments. This critical difference concerns the presence or absence of time-judgment feedback. In the previous research there was no feedback for timing. This lack of feedback means that it was not possible for subjects to develop adequate compensatory time-judgment skills under dual-task conditions. In the present research, subjects did receive feedback for their time judgments in the practice trials. It is reasonable to assume that feedback is a necessary component for the establishment of compensatory skills.

The main finding from this research is that practice can minimize the interference effect in timing. Moreover, practice on either the timing task (as in the present case) or the distractor task (Brown 1998; Brown and Bennett 2002) is effective. This pattern suggests that attentional processes are an important aspect of the results. Finally, the results also indicate that the interference effect is not a structural (ie built-in) limitation of temporal information processing. Rather, the effect is modifiable, and can be counteracted with an appropriate training regime.

Acknowledgments. I thank Chad J Desrochers for his assistance in recruiting and testing subjects. An earlier version of this paper was presented at the New England Sequencing and Timing (NEST) 16th Annual Meeting, Haskins Laboratories, New Haven, CT in March 2006.

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