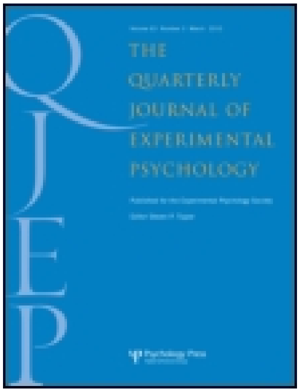

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Subjective time: Cognitive and physical secondary tasks affect timing differently

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Subjective time: Cognitive and physical secondary tasks affect timing differently

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Humans were trained on a temporal discrimination to make one response when the stimulus duration was short (2 s) and a different response when the stimulus duration was long (8 s). They were then tested with stimulus durations in between to determine the bisection point. In Experiment 1, we examined the effect of a secondary cognitive task (counting backwards by threes) on the bisection point when participants were trained without a cognitive load and were tested with a cognitive load or the reverse (relative to appropriate controls). When the cognitive load increased from training, the psychophysical function plotting long responses against the increase in stimulus duration shifted to the right (as if the internal clock slowed down), and when the cognitive load decreased from training the psychophysical function shifted to the left (as if the internal clock speeded up). In Experiment 2, when the secondary task consisted of exerting continuous force on a transducer (a physically effortful task), it had the opposite effect. When the required force increased from training, the psychophysical function shifted to the left (as if the internal clock speeded up), and when the required force decreased from training, the psychophysical function shifted to the right (as if the internal clock slowed down). The results support an attentional view of the subjective passage of time. A cognitive secondary task appears to decrease attention to temporal cues, resulting in the underestimation of the passage of time, whereas a force requirement appears to increase attention to temporal cues, resulting in the overestimation of the passage of time.

Keywords: Timing; Temporal discrimination; Secondary tasks; Attention; Humans.

Various procedures have been used to study human timing ability. In the temporal generalization procedure, a standard duration is presented, and later stimuli are compared to it. The participants respond YES (it is the same or close enough) or NO it is different. In the production procedure, participants are typically given a stimulus that they are requested to reproduce (Wearden, 2003). In the bisection procedure, participants are trained with two standard durations, one short (e.g., 2 s) and the other long (e.g., 10 s). Then a series of test stimuli are presented at various durations in between, and the participant's task is to classify each one in terms of its judged similarity to the short and long standards from a previously acquired temporal discrimination (Wearden,

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1991; Wearden & Ferrara, 1996). The resulting psychophysical function can be used to reveal the nature of the underlying scale of timing (e.g., linear or logarithmic) by determining the bisection point (or point of subjective equality): the stimulus duration at which the participants respond "short" as often as they respond "long". The bisection procedure has also been useful in the assessment of timing by animals (Church & Deluty, 1977; Platt & Davis, 1983) because it does not require verbal instructions. For animals, the bisection point typically occurs near the geometric mean of the reference durations (Gibbon, 1986; Platt & Davis, 1983), whereas for humans, it typically occurs nearer the arithmetic mean (Wearden, 1991; Wearden & Ferrara, 1996).

A number of authors have discussed the role of attention in timing (e.g., Allan, 1992; Brown, 1997; Chaston & Kingstone, 2004; Ferrara, Lejeune, & Wearden, 1997; Grondin & Macar, 1992; Zakay & Block, 1995). In this view, temporal processing requires attentional resources. Specifically, they suggest that the passage of time is judged by the accumulation of pulses from a pacemaker (Church, 2003; Wearden, 1991), and subjective duration is directly related to the attention resources allocated to the passage of time. If one is asked to judge how much time has passed, the fewer attentional resources are allocated to the passage of time, the shorter the time estimate is because directing attention away from time is thought to decrease accumulation of temporal cues. Conversely, the more attention is directed towards the passage of time, the greater the lengthening of subjective time, perhaps because additional resources enhance the accumulation of temporal cues.

Further research on the effects of attention on timing suggests that judgements of the passage of time may be affected by the nature of concurrently occurring activities. The greater the cognitive load of the concurrent activity, the more subjects tend to underestimate the passage of time, whether the intervals being judged are very short (seconds, Brown, 1997, or milliseconds, Chastain & Ferraro, 1997) or much longer (minutes; Hoekstra, 2005). Such results support an attentional view of timing according to which the greater the attention directed to the secondary task, the fewer attentional resources are allocated to the passage of time, and the shorter is the judged duration of time.

The effect that a secondary task may have on subjective timing can be confusing because it depends on one's perspective, which in turn depends on whether the task requires participants to *estimate* the duration of a presented stimulus or *produce* a specified duration. If a secondary task requires the participants' attention, and they are asked to estimate the duration of a stimulus, they tend to underestimate how much time has passed. However, if they are asked to produce a duration, they also tend to underestimate how much time has passed, but as a result they tend to produce a duration that is too long.

Although cognitive secondary tasks tend to result in the underestimation of the passage of time, physically effortful secondary tasks may have the opposite effect. Research that has studied subjects when performing physically effortful tasks suggests that their attention tends to be directed to internal physiological cues rather than to external cues (Hutchinson & Tenenbaum, 2006; Schomer, 1986; Tammen, 1996; Vercruyssen, Hancock, & Mihaly, 1989). This research suggests that in contrast to cognitive tasks, physical tasks that direct attention to internal cues may make subjects more aware than usual of the passage to time and thus may cause judgements of the passage of time to appear to be subjectively longer. In the cited research, the judgements of the passage of time were all made retrospectively (after completion of the task) whereas in most timing tasks (especially time discrimination tasks) subjects are tested on many trials, and they can expect that they will be asked about the duration of the stimulus.

The purpose of the present experiments was to examine the effect on subjective timing of the presence of a cognitive secondary task (tested in Experiment 1) and a secondary task involving physical effort (tested in Experiment 2). In Experiment 1, the secondary cognitive task consisted of counting backwards by threes, which should direct attention away from the accumulation of temporal cues (Brown, 1997). In Experiment 2, the secondary task consisted of maintaining strong pressure on a transducer while timing.

In our experiments, participants were trained to discriminate between two stimulus durations, 2 and 8 s, while either performing or not performing the secondary task. On test trials, they were given those durations, as well as various durations in between. For half of the participants in each group, the secondary task conditions were the same as those in training. For the remaining participants in each group, the secondary task conditions were changed to the other condition.

It was assumed that during training, each participant would learn to set his or her criterion for short and long, such that if tested under the same conditions as those in training, the bisection point would fall at about the linear mean of the training values. That is, regardless of the effect of the secondary task on the subjective timing, the bisection point should appear at the same relative location because any change in the passage of subjective time should affect all durations equally.

On the other hand, if participants are trained without a secondary task and are tested with a secondary task, if the effect of the secondary task is to cause less attention to the timing task, the effect of the secondary task on timing should be to cause the psychophysical function (and thus the bisection point) plotting choice of "long" against stimulus duration to shift to the right. That is, participants should judge that less time has gone by than actually has. Conversely, if participants are trained with a secondary task and are tested without a secondary task, the effect of the removal of the secondary task on timing should be to cause the psychophysical function (and thus the bisection point) plotting choice of "long" against stimulus duration to shift to the left. That is, now participants should judge that more time has gone by than actually has.

Thus, in Experiment 1, relative to conditions in which training and testing are experienced under the same conditions (either both with or both without a cognitive load), it is expected that if participants are trained without the secondary task but they are tested with the secondary task, time should appear to go by faster, whereas if participants are trained with the secondary task but they are tested without the secondary task, time should appear to go by slower.

EXPERIMENT 1

Method

Participants

The participants were 48 undergraduate students (approximately 65% were women) at the University of Lille 3, France, all of whom were volunteers.

Apparatus

The study was conducted in a quiet room. Each participant was seated on a chair at a table on which was a monitor connected to a computer. All participants were trained and tested with a program created with Labview 8.0 (National Instruments Corporation, Austin, TX), presented on a computer monitor.

Procedure

The bisection task used was a variant of that used by Wearden, Rogers, and Thomas (1997).

Verbal instructions given by the experimenter were supplemented by an on-screen display.

Notably, the participants were instructed to avoid counting or performing rhythmic activities during experiment. Instructions to avoid counting or performing rhythmic activities have been found to be successful in avoiding biases with long durations that may be produced by adopting a chronometric counting strategy (see Grondin, Ouellet, & Roussel, 2004). Reference durations were 2 s and 8 s, and the test durations were 2, 3, 4, 5, 6, 7, and 8 s. The to-be-timed stimulus was a blue rectangle that appeared for the appropriate duration.

Stimulus presentations were arranged in 10 blocks of 11 trials each. At the start of each block, there were 4 training trials involving the reference durations (signalled by the word "Training" presented above the blue rectangle).

After each duration had been presented, participants received the display: "Was the duration of the blue rectangle short or long? Click on SHORT or LONG." A rectangle with the word "short" and one with the word "long" were presented below the question. Each reference duration was presented twice in the order short, long, short, long.

After each of the reference durations had been presented twice, seven test durations (2, 3, 4, 5, 6, 7, and 8 s) were presented in random order without feedback. After each stimulus had been presented, participants received the display: "Was that blue rectangle more similar in duration to the short or long reference stimulus? Click on SHORT or LONG." Each stimulus presentation was followed by a delay of 2 s, during which the screen was blank. The next trial was initiated by the prompt "click on ok for next trial." After all seven test stimuli had been presented, the next block of trials was presented with the four reference stimulus trials followed by the seven test trials. This procedure was repeated for the 10 blocks of the experimental session.

The experimental session lasted about 20 minutes.

The subjects were arbitrarily assigned to one of four conditions. For one experimental condition, the reference durations were judged without a concurrent cognitive load, and test stimuli were judged with a concurrent cognitive load (cognitive load test). For a second experimental condition, the reference durations were judged with a cognitive load, and the test durations were judged without a cognitive load (cognitive load train). The two control conditions differed in terms of whether the reference durations and the test durations were both judged under cognitive load (cognitive load both) or neither was judged under cognitive load (cognitive load neither). The cognitive load consisted of having the participants count backward by threes aloud as quickly as possible for the duration of the stimulus, starting with a random number between 500 and 1,000 that appeared on the blue rectangle. Participants were told to "be careful to be as accurate as possible". The experimenter monitored each participant to ensure that the backward counting instructions were being followed.

Results

Bisection points were estimated from test trials for each subject in each of the four conditions. The bisection point was estimated by finding the longest sample duration (t) for which choice of the long test stimulus was less than 50%, calculating the proportion of the next interval that was below 50%, and adding that proportion to t (see Wearden & Ferrara, 1996).

Relative to the cognitive load in both training and testing (cognitive load both) and the cognitive load in neither training nor testing (cognitive load neither), the bisection point for the cognitive load in testing condition (cognitive load test) was higher, and the bisection point for the cognitive load in training condition (cognitive load train) was lower. Direct comparison of the bisection points appears in Figure 1. A one-way analysis of variance performed on the bisection point data from the four conditions indicated that the

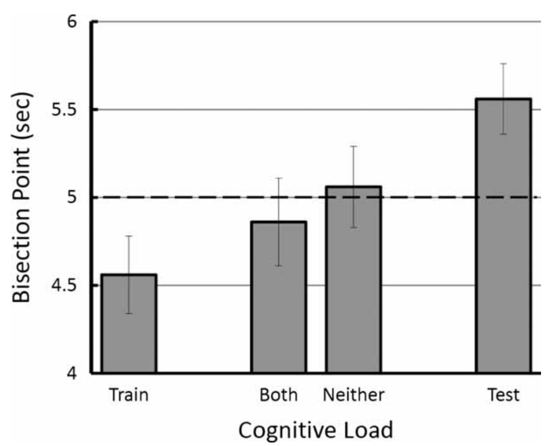

Figure 1. *Experiment 1 test results. Calculated mean temporal discrimination bisection points for participants trained with cognitive load (counting backward by threes) and tested without cognitive load (train), trained with cognitive load and tested with cognitive load (both), trained without cognitive load and tested without cognitive load (neither), and trained without cognitive load and tested with cognitive load (test). Error bars represent the standard error of the mean.*

bisection points were significantly different, $F(3, 44) = 3.43$, $p = .02$. A planned comparison indicated that the bisection points for the cognitive load train condition were significantly lower than those for the cognitive load test condition, $F(1, 22) = 11.09$, $p = .003$. Additional comparisons were made between the two conditions that had their cognitive load switched between training testing and the appropriate control condition for each (i.e., the control condition for which the cognitive load conditions on test trials were the same). Although the bisection points for the cognitive load test condition were significantly higher than the bisection points for the cognitive load both condition, $F(1, 22) = 4.55$, $p = .02$, the bisection points for the cognitive load train condition were not significantly lower than the bisection points for the cognitive load neither condition, $F(1, 22) = 2.48$, $p = .13$.

A measure of the sensitivity of the various conditions to the two categories of time (2 s and 8 s) is the Weber ratio (see Beckman & Young, 2009). The Weber ratio is the difference limen (or the difference in duration between 25% choice of long and 75% choice of long—the smaller the interval the more sensitive the categorization) divided by the bisection point. The Weber ratios for the four conditions appear in Figure 2. As can be seen in the figure, sensitivity was comparable in the four conditions. A one-way analysis of variance supported that observation, $F < 1$.

Another means of analysing the data is by fitting logistic functions to the number of "long" responses by stimulus duration using nonlinear mixed-effects modelling (see Beckman & Young, 2009). These fits are shown in Figure 3. Because the best fitting values were derived from every data point for each individual, they occasional do not coincide with the means.

The bisection points estimated from the logistic functions were similar to those that appear in Figure 1. For the cognitive load neither and cognitive load both conditions they were 5.09 s and 4.87 s, respectively. Relative to these two no-change conditions, the bisection point for participants who were tested under greater cognitive load than they were trained under was somewhat

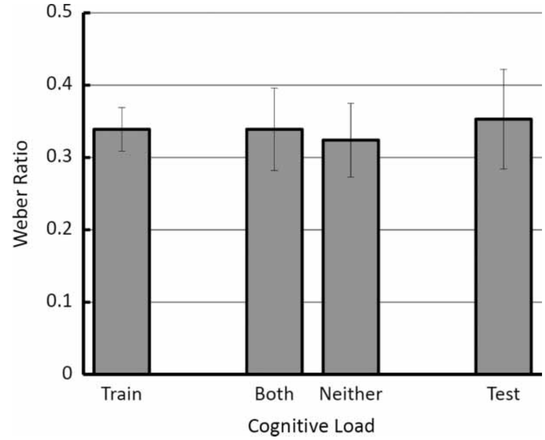

Figure 2. *Experiment 1 test results. The Weber ratio (a measure of the sensitivity to the passage of time) calculated by dividing the difference limen (the estimated test stimulus duration between 25% choice of "long" and 75% choice of "long") by the bisection point for participants trained with cognitive load (counting backward by threes) and tested without cognitive load (train), trained with cognitive load and tested with cognitive load (both), trained without cognitive load and tested without cognitive load (neither), and trained without cognitive load and tested with cognitive load (test). Error bars represent the standard error of the mean.*

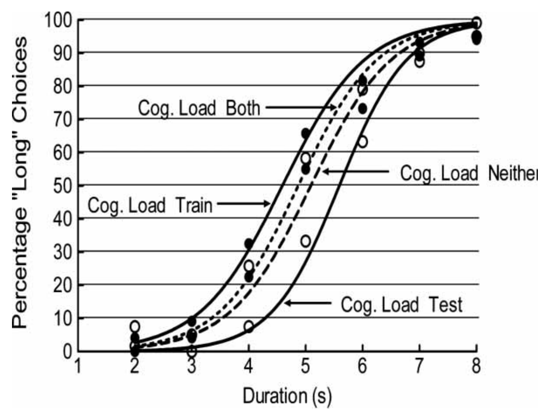

Figure 3. *Logistic functions plotting choice of the "long" response using nonlinear mixed-effects modelling for temporal durations between 2 s and 8 s for participants trained with cognitive load (counting backward by threes) and tested without cognitive load (train), trained with cognitive load and tested with cognitive load (both), trained without cognitive load and tested without cognitive load (neither), and trained without cognitive load and tested with cognitive load (test).*

higher (5.59 s), and for those who were tested under less cognitive load than that they were trained under it was somewhat lower (4.59 s).

Discussion

The results of Experiment 1 support the attentional view of timing according to which it is hypothesized that a cognitive task such as counting backwards by threes has the effect of directing attention away from temporal cues. When the cognitive load increases between training and testing, attention is directed away from the passage of time, and it results in a tendency to underestimate the passage of time. Furthermore, when the cognitive load decreases between training and testing, attention is focused on the passage of time, and it results in a tendency to overestimate the passage of time. This result using the temporal discrimination procedure is consistent with earlier effects of a cognitive secondary task on subjective judgements of the passage of time using other procedures (e.g., Allan, 1992; Brown, 1997; Chaston & Kingstone, 2004; Ferrara et al., 1997; Grondin & Macar, 1992; Zakay & Block, 1995).

The purpose of Experiment 2 was to determine whether a secondary task involving physical effort would result in the same effect on time judgements as a cognitive task, resulting in the underestimation of the passage of time, or would result in the opposite effect by focusing attention on internal temporal cues, resulting in the overestimation of the passage of time (see Hutchinson & Tenenbaum, 2006; Schomer, 1986; Tammen, 1996; Vercruyssen et al., 1989). For example, in the Vercruyssen et al. study, subjects were asked to press a button and release it 10 s later, while riding on a stationary bicycle exerting moderate effort. It was found that the duration of the button press was systematically less than 10 s and was significantly less than a similar measure taken either prior to the effort or following the effort. As this was a production procedure, the overestimation of the passage of time resulted in an underestimation of the production of a 10-s interval.

EXPERIMENT 2

Method

Participants and apparatus

Forty-eight students from the University of Lille 3, similar to those used in the first experiment, participated in Experiment 2 (approximately 65% were women). The apparatus was the same as that used in Experiment 1, except we added a Novatech Mini40 ATi force cell (Tatem Industrial Automation Ltd., Derby, UK), which served to measure force.

Procedure

The procedure was the same as the one described in Experiment 1, except where noted. Instead of the cognitive load requirement, participants were required to press on the force cell with either high force or no force. Before starting the experiment, we asked each participant to press the force cell with the maximum force possible with his or her dominant hand. For each participant, we defined the high force used in this experiment as at least 50% of this maximum force. Participants indicated that this amount of force was relatively effortful when exerted repeatedly throughout the session. The actual high force produced by the participants varied considerably from a low of 20 N to a high of 100 N. On experimental trials involving high force, participants were prompted to "press with high force during the stimulus presentation as long as the stimulus is present" and to "be careful, if you do not respond with sufficiently high force the trial will start again". If they did not meet the force criterion, a message appeared, "You have not pressed with enough force, try again", and the trial started again. Participants in the force test condition were told to press only during test trials, whereas those in the force train condition were told to press only during training trials. As in Experiment 1, there were 10 blocks of 11 trials each, with 4 training trials at the start of each block followed by 7 test trials.

Results

Again, bisection points were estimated from test trials for each subject in the four conditions using the procedure described earlier. Relative to the force required in both training and testing (force both) and the force required in neither training nor testing (force neither), the bisection point for the force required in the testing condition (force test) was lower, and the bisection point for the force required in the training condition (force train) was higher. Direct comparison of the bisection points appears in Figure 4.

A one-way analysis of variance performed on the bisection point data from the four conditions indicated that the bisection points were significantly different, $F(3, 44) = 4.69$, $p = .006$. A planned comparison indicated that the bisection points for the force train condition were significantly higher than those for the force test, $F(1, 22) = 17.75$, $p = .0004$. In addition, the bisection points for the force test condition were significantly lower than the bisection points for the force both condition, $F(1, 22) = 4.69$, $p = .04$, and the bisection points for the force train condition were significantly higher than the bisection points for the force neither condition, $F(1, 22) = 6.83$, $p = .02$.

Again, Weber ratios were calculated for the different conditions. The Weber ratios for the four conditions appear in Figure 5. As can be seen in the figure, once again, sensitivity was comparable in the four conditions. A one-way analysis of variance supported that observation, $F < 1$.

Again, “long” responses by stimulus duration were analysed by fitting logistic functions to the data using nonlinear mixed-effects modelling. These fits are shown in Figure 6. The bisection points estimated from the logistic functions were similar for the force neither and force both conditions (4.90 s and 5.09 s, respectively). Relative to these two no-change conditions, the bisection point for participants who were tested under the force that they were trained under was somewhat lower (4.57 s), and for those who were tested without the force that they were trained under it was somewhat higher (5.58 s).

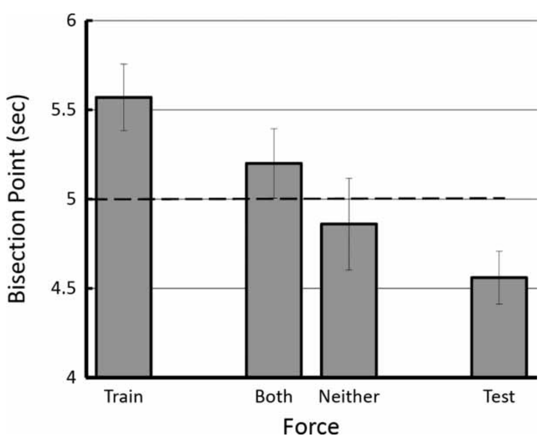

Figure 4. *Experiment 2 test results. Calculated mean temporal discrimination bisection points for participants trained with force required and tested without force required (train), trained with force required and tested with force required (both), trained without force required and tested without force required (neither), and trained without force required and tested with force required (test). Error bars represent the standard error of the mean.*

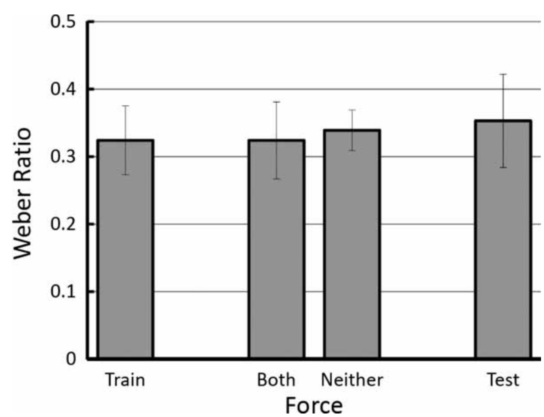

Figure 5. *Experiment 2 test results. The Weber Ratio (a measure of the sensitivity to the passage of time) calculated by dividing the difference limen (the estimated test stimulus duration between 25% choice of “long” and 75% choice of “long”) by the bisection point for participants trained with force required and tested without force required (train), trained with force required and tested with force required (both), trained without force required and tested without force required (neither), and trained without force required and tested with force required (test). Error bars represent the standard error of the mean.*

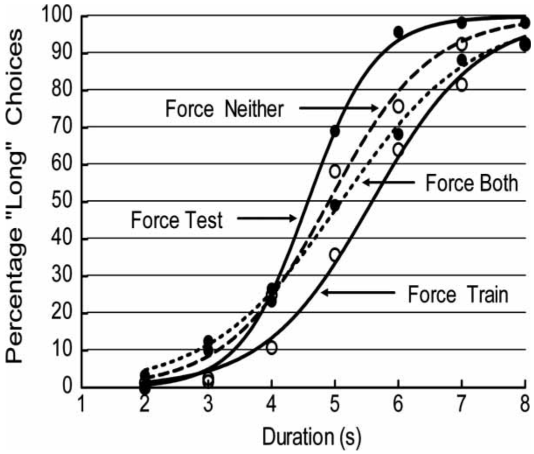

Figure 6. *Logistic functions plotting choice of the "long" response using nonlinear mixed-effects modelling for temporal durations between 2 s and 8 s for participants trained with force required and tested without force required (train), trained with force required and tested with force required (both), trained without force required and tested without force required (neither), and trained without force required and tested with force required (test). Error bars represent the standard error of the mean.*

Discussion

The results of Experiment 2 were quite different from those of Experiment 1. Whereas in Experiment 1, the effect of the secondary cognitive load task during testing was to extend the bisection point beyond that of the condition in which the secondary task was involved in both training and testing, in Experiment 2, the effect of the secondary force task during testing was to shorten the bisection point relative to its appropriate control condition. Furthermore, in Experiment 1, when the secondary cognitive task was experienced during training but was removed during testing, it tended to have the opposite effect. That is, it shortened the bisection point relative to the control condition, in which the cognitive load task was not experienced in either training or testing. In Experiment 2, however, when the secondary force task that was experienced during training was not required during testing, it extended the bisection point beyond that of the control condition, in which the force task was not experienced in either training or testing. Thus, an increase in physical force requirement between training and testing caused time to appear to pass faster, whereas a decrease in physical force requirement between training and testing caused time to appear to pass slower. Results using the temporal discrimination procedure are consistent with earlier effects of physical exercise on subjective judgements of the passage of time using retrospective measures (asking subjects to estimate how much time had passed after having experienced a physical task; Padgett & Hill, 1989). They are also consistent with the results of experiments that have used the production method (asking subjects to produce a particular duration; Vercruyssen et al., 1989).

GENERAL DISCUSSION

The results of both experiments provide strong evidence that subjective duration is directly related to the amount of attentional resource that is allocated to the accumulation of temporal cues. Chaston and Kingstone (2004) attributed the subjects' underestimation of the passage of time when one is engaged in a demanding task to the relative inattention given to temporal cues. Specifically, they suggested that the passage of time is judged by the accumulation of pulses coming from the pacemaker. If, because of the cognitive demands of a task, attention is not directed sufficiently at the timing of the interval, Chaston and Kingstone proposed that either the pulse output is slowed or some of the pulses may be lost (see also Zakay, 1993). In either case, the sum of the accumulator will be less than the actual time that has elapsed, resulting in an underestimation of the passage of time. If directing attention away from time can affect subjective timing, then one would expect that directing attention towards time might affect the estimation of the duration of an interval in the opposite direction. The more attention devoted to time, the greater the subjects would overestimate the passage of time, perhaps because devoting greater additional resources to timing would enhance the accumulation of temporal cues. The results of our experiments suggested that cognitive activity detracted from the accumulation of temporal cues, which biased participants to underestimate the passage of time (Experiment 1). Interestingly, when pigeons were required to engage in a secondary task that required them to focus attention away from timing, they too tended to underestimate the passage of time (as indicated by a shift in the bisection point in the direction of a longer duration; Zentall, Friedrich, & Clement, 2006; Zentall & Singer, 2008). Furthermore, in the present research, directing attention to cues associated with the passage of time (by engaging in physical activity) increased the accumulation of temporal cues, which biased participants to overestimate the passage of time (Experiment 2).

How a pacemaker-based clock model of timing would account for the results of Experiment 2 is not clear. One would have to assume that under typical timing conditions without a secondary cognitive task some of the pulses from the pacemaker are lost. If one becomes more sensitive to the output of the pacemaker by having to engage in a task requiring physical effort, more pulses would accumulate than would normally given the passage of the same amount of time.

A neural model of this kind has been proposed by Migliore, Messineo, and Cardaci (2000). According to their model, neural background noise contributes to pulse production by the pacemaker. When neural background noise is inhibited it reduces the pacemaker output, making it send out fewer pulses. The effect of a secondary cognitive task would be to draw attention away from the timing task and to inhibit the neural background noise, thus resulting in fewer pulses from the pacemaker. Fewer pulses from the pacemaker would make time appear to pass slower. Conversely, the effect of a physical task would be to draw attention to the timing process and to increase the neural background noise, thus increasing the number of pulses from the pacemaker. Increasing the number of pulses from the pacemaker would make time appear to pass faster.

It is also possible that the mild aversiveness of the physical effort required in Experiment 2 had the effect of increasing the rate of output of the pacemaker. Such a change in the output of the pacemaker would also have the effect of overestimating the passage of time.

Whatever the mechanism, the present results support the hypothesis that judgements of the passage of time may reflect the nature of the additional activities occurring concurrently (Brown, 1997; see also Droit-Volet & Meck, 2007), and the results of the present experiments indicate that those activities can make time appear to pass either faster or slower than it would otherwise, depending on the nature of those activities.

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