THE QUARTERLY JOURNAL OF EXPERIMENTAL PSYCHOLOGY
0000, 00 (0), 1–14

Psychology Press
Taylor & Francis Group

The effect of mild depression on time discrimination

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Depressed mood states affect subjective perceptions of time but it is not clear whether this is due to changes in the underlying timing mechanisms, such as the speed of the internal clock. In order to study depression effects on time perception, two experiments using time discrimination methods with short (<300 ms) and long (>1,000 ms) durations were conducted. Student participants who were categorized as mildly depressed by their scores on the Beck Depression Inventory were less able than controls to discriminate between two longer durations but were equally able to discriminate shorter intervals. The results suggest that mildly depressed or dysphoric moods do not affect pacemaker speed. It is more likely that depression affects the ability to maintain attention to elapsing duration.

Keywords: Time perception; Depression; Dysphoria; Discrimination; Timing; Internal clock.

"Time is a necessary representation, lying at the foundation of all our intuitions" (Kant, 1787/ Q3 1982). In other words, there is a basic temporal component to all human experience. For example, timing processes are intimately linked to the perception that events are simultaneous or occur in succession, with implications for learning and perceived causality (e.g., Eagleman & Holcombe, 2002; Michotte, 1963; Vallee Tourangeau, Murphy, & Baker, 2005). Indeed, functions as simple as crossing a busy road, driving, or waiting for a reply all depend upon judging time in one form or another (Zakay & Block, 1997). In spite of its centrality, time perception is affected by individual differences (e.g., Hancock & Rausch, 2010) and psychopathology (Lehmann, 1967; A. Lewis, 1932). For example, mood states have been shown to influence time perception (e.g., Bschor et al., 2004; Sévigny, Everett, & Grondin, 2003). Exploring how changes in mood affect timing processes may be useful in terms of understanding the underlying timing processes themselves (Meck, 2005) but also in terms of understanding how moods and cognitions interact and how mood states are exacerbated by these changes.

Clinical levels of depressed mood have long been associated with disturbances in time experience (e.g., A. Lewis, 1932), which are usually experienced as a feeling of time passing more slowly than usual (e.g., Hoffer & Osmond, 1962; Mezey & Cohen, 1961). Evidence suggests that such subjective changes in time experience may be linked to changes in objective time judgements (e.g., Bschor et al., 2004; and see Meck, 2005, for a

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http://www.psypress.com/qjep DOI:10.1080/17470218.2011.608908

discussion). There is considerable confusion within the time perception and depression literature in relation to terminology (Bschor et al., 2004), and it is therefore important to define these terms clearly. Here, the term *objective* time judgement refers to “The objectively measurable capacity of a subject to judge the length of a given time span” (Bschor et al., 2004, p. 223). For example, participants might be asked to make a verbal estimate (VE) of the duration of a signalled time interval or to produce a time interval of a given duration (production estimate: PE), using a key press for instance. Many studies examining the effects of depression on objective time judgement have used versions of these methods. Usefully, a comparison of VE and PE performance can be used to make theoretical inferences about the state of the underlying timing processes.

In particular, some theories of time perception postulate the existence of an internal clock process. This is composed of a pacemaker that produces pulses in an analogous manner to ticks on a chronometric clock (e.g., Gibbon, 1981; Treisman, 1963; see Allan, 1998, and Grondin, 2010, for a discussion). Pulses are thought to be gated to an accumulator via an attentional switch. When an elapsed duration has finished, the switch opens, preventing more pulses from entering the accumulator, the contents of which represent perceived duration of an interval (see Figure 1,

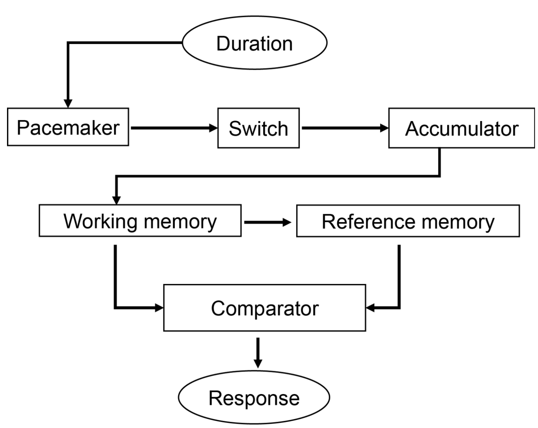

Figure 1. *Schematic diagram of scalar timing model with clock, memory, and decision stages (adapted from Allan, 1998).*

adapted from Allan, 1998). That representation is copied to a short-term memory store and can be compared to previously stored durations via a comparison process; then a judgement or decision about the interval can be made.

One idea is that a pacemaker running at a different pace, relative to that in a nondepressed mood, could produce a slowed perception of time. This would also result in a specific pattern of findings on VE and PE tasks. For example, with a faster clock, more pulses would be accumulated in a given VE interval, resulting in higher estimates of the presented duration. Conversely, in the PE task, more pulses would be produced in a shorter time period, meaning that the produced duration would be shorter (e.g., Bindra & Waksberg, 1956) than that for nondepressed people. Therefore, a distinct pattern of overestimates on the VE task and underestimates on the PE task could be suggestive of a rapidly pulsing internal clock, resulting in the subjective experience of time elapsing slower than usual in depression (Kitamura & Kumar, 1983).

A brief review of published studies examining depression and time perception using VE and PE methods, shown in the Appendix, is suggestive of Q4 this pattern, though there are inconsistencies in the findings. Note that the Appendix does not include (a) studies where people’s performance were compared during a depressive episode and in recovery (e.g., Mezey & Cohen, 1961); or (b) studies including people with depression and some other health issue, such as migraine (e.g., Anagnostou & Mitsikostas, 2004). The review includes sample sizes, details of the specific tasks used, and the durations tested.

Overall, participants in these studies made time estimates of durations ranging from 1 second to 60 minutes. Verbal estimates involving longer durations in the minutes range were obtained retrospectively, such that participants were not warned in advance that an estimate would be required. Shorter durations in the seconds range were estimated prospectively and participants were informed about the task in advance (see Grondin, 2010). Five of the 10 studies using the VE procedure reported that depressed individuals *overestimated* durations in the seconds to minutes range (Bschor et al., 2004; Dilling & Rabin, 1967; Kitamura & Kumar, 1983; Munzel, Gendner, Steinberg, & Raith, 1988; Wyrick & Wyrick, 1977), while 2 studies reported that depressed people *underestimated* intervals of similar durations (Lehmann, 1967; Tysk, 1984), and 3 studies reported no mood effects (Bech, 1975; Hawkins, French, Crawford, & Enzle, 1988; Prabhu, Agarwal, & Teja, 1969). Findings from studies using the PE procedure were similarly inconsistent. Three studies reported that depressed participants underestimate durations between 10 and 90 s (Bschor et al., 2004; Kuhs, Hermann, Kammer, & Tolle, 1991; Tysk, 1984), another recorded significant variability in depressed people's estimates (e.g., Sévigny et al., 2003), and 4 studies reported no mood effect at all (Kitamura & Kumar, 1983; Munzel et al., 1988; Prabhu et al., 1969). Thus, while there is some evidence for verbal overestimation and production underestimation, this evidence is inconsistent, and some studies do report contradictory findings.

This inconsistency may, in part, be due to the confounding effects of medication with clinical samples as well as the experimental methods used. For example, the neurotransmitter systems implicated in timing (e.g., Ho, Velazquez-Martinez, Bradshaw, & Szabadi, 2002) are also related to depression itself and pharmacological antidepressant treatment. In addition to this, and perhaps more importantly, VE and PE experimental methods must be treated with caution in terms of pacemaker effects. For appropriate performance, durations experienced within the experimental setting must be attended to and then compared to remembered durations. Any aspect of these processes could easily be a source of between-group differences. It has also been noted that experimental manipulations, which have no logical link to pacemaker speed, can produce pacemaker-like
Q5 effects in VE tasks (Matthews, in press). Moreover, a change in pacemaker speed is thought to produce only transient changes in time perception in relation to real time as the timing system soon recalibrates (Killeen, Fetterman, & Bizo, 1997). The final point to make here is that the inconsistency of the findings summarized in the Appendix certainly do not allow for any strong theoretical conclusions. The review does show, however, that disturbances in time perception are not simply subjective feelings but can be detected through objective time judgements.

In recent years, researchers interested in depression have begun to use experimental methods more frequently used in the classical timing literature (Gil & Droit Volet, 2009; Rammsayer, 1990; Sévigny et al., 2003). Temporal discrimination tasks are one example and go some way to accounting for the interpretational problems with VE and PE methods. Participants are exposed to a series of standard and comparison durations in the milliseconds to seconds range, which differ in duration by several hundred milliseconds. They are then simply asked to decide which of the two durations is the longer. After a number of trials, during which the difference between the two stimuli is either reduced or increased depending on performance accuracy, a time discrimination threshold can be calculated, which indicates the smallest difference that can reliably be perceived, which corresponds to around 75% correct (Wetherill, Chen, & Vasudeva, 1966). The rationale for using this task is that if the internal clock is running at a faster pace, producing more pulses per second, it provides relatively finely tuned temporal discrimination (Rammsayer, Hennig, Haag, & Lange, 2001). A clock running at a slower pace would produce the opposite effect, and the individual would be less able to discriminate between two similar intervals. Importantly, such effects would not be influenced by any recalibration of timing processes in relation to chronometric time.

Two currently published studies have reported depression effects on temporal discrimination performance. For example, Rammsayer (1990) found that patients with major depression with melancholia displayed impaired performance in comparison to controls on a time discrimination task where the standard duration was 1,000 ms. Sévigny et al. (2003) used a nonclinical, analogue sample and a different variant of the discrimination task. Their participants were asked to judge whether each standard stimulus was short or long; duration was not adjusted during the procedure. The percentage of correct responses did not differ between groups when stimuli were in the 80–120-ms or 450–550-ms range. However, Sévigny et al. found that depressed participants made fewer correct responses when stimuli were in the 1,120–1,280-ms range. Taken together these two studies provide some indication that depression is associated with worse time discrimination when durations are greater than 1,000 ms but that performance is unaffected with shorter durations.

This distinction between short and long discrimination is interesting because there are implications for the underlying processes affected by depression. This is because evidence from numerous sources suggests that distinct processes involving sensory memory underpin the processing of millisecond durations in comparison to those in the seconds range that involve attention and short-term memory (see Rammsayer et al., 2001, for a discussion). Therefore any differences between the ability to discriminate between millisecond and seconds durations could indicate attentional (P. A. Lewis & Miall, 2003a, 2003b) or cognitive causes (Sévigny et al., 2003) of the effect of depression on timing (but see also Rammsayer & Ulrich, 2005) rather than an effect related to the speed of a pacemaker.

However, this requires further experimentation. Sévigny et al.'s (2003) study, which provides the only direct short versus long comparison, used a sample of student participants categorized as scoring low or high on the Beck Depression Inventory. Although this procedure involves nonrandom group assignment, they did not control for other potentially confounding between-group differences. For example, temporal discrimination performance has been linked to general intelligence (Rammsayer & Brandler, 2007), suggesting that this is an important variable to control.

In the present study, we used short and long versions of the same temporal discrimination procedure with mildly depressed and nondepressed students as categorized by their scores on the Beck Depression Inventory. We attempted to control for preexisting between-group differences by taking measures of IQ, education, and working memory capacity. The durations and procedural details of the discrimination tasks used in Experiment 1 have been used in other similar experiments (Rammsayer et al., 2001). Durations were either "long" in the seconds range (>1,000 ms in Experiment 1a) or were "short" in the milliseconds range (<300 ms in Experiment 1b). Where possible, methodological details are combined to avoid repetition.

EXPERIMENT 1

Method

Participants

University students were asked to complete the Beck Depression Inventory (BDI: Beck, Ward, Mendelson, Mock, & Erbaugh, 1961) as part of a mass screening procedure in order to volunteer for participation. Thirty-six students, who were invited to participate, completed the BDI a second time during participation to ensure a stable BDI score. No participants were excluded at this point on the basis of an inconsistent or too high BDI score. Participants were then assigned to the depressed ($n = 18$) and nondepressed ($n =$ 18) groups on the basis of their scores on the BDI (Beck et al., 1961). Participants with BDI scores of 9 or above were categorized as mildly depressed, while those with scores of 8 or below were assigned to the nondepressed group with the constraint that half the participants in each group were female. We collected data on a range of relevant variables including age, Digit Span scores (Lezak, 1995), premorbid IQ as measured by the National Adult Reading Test (NART; Nelson, 1982), and years of education in order to be aware of any preexisting between-group differences. In Experiment 1a, groups were matched on these variables (all $t < 1.97$) and differed on BDI scores ($M = 17.2$, $SE = 1.8$, and $M = 4.7$, $SE =$ 0.5) for the depressed and nondepressed group, respectively: $t(34) = 6.61$, $p < .001$. BDI scores in the depressed group ranged from 9 to 40, with 7 of those 18 participants scoring in the moderate range. However, in Experiment 1b, although groups were matched on age and education, all $t < 1$, the depressed group produced lower Digit Span ($M = 6.3$, $SE = 0.2$) and NART scores ($M = 25.8$, $SE = 1.9$) than the nondepressed group: digit, $M = 7.3$, $SE = 0.2$, $t(34) = 2.94$, $p < .001$; NART, $M = 31.3$, $SE = 1.9$, $t(34) = 2.05$, $p < .05$. The mood groups in Experiment 1b also differed on BDI scores ($M = 15.2$, $SE = 1.1$, and $M = 4.9$, $SE = 0.7$, for the depressed and nondepressed group, respectively, $t(34) = 7.81$, $p < .001$. BDI scores in the depressed group ranged from 9 to 29, and, of those, 7 participants fell into the moderately depressed range.

Apparatus

The visual stimuli consisted of a 10-cm diameter red circle and a 10-cm blue square presented on the computer screen. The two auditory stimuli were created using RealBasic NotePlayer, Q6 Instruments 57 and 58. Both were played at middle C (pitch 60 in RealBasic) at the same velocity of 127 (this refers to the intensity or loudness of the sound stimulus, which could vary from 0 to a maximum of 127) and were presented through headphones. On 50% of trials, the circle and Instrument 57 signalled the standard duration, and on the other 50% of trials, the square and Instrument 58 signalled the standard duration. Auditory and visual stimuli were presented simultaneously. This simultaneous presentation of auditory and visual stimuli is relatively unusual but identical to that used by Smith and colleagues (Smith, Taylor, Rogers, Newman, & Rubia, 2002) in their work with children with attention-deficit/hyperactivity disorder (ADHD). Their concern, shared here, was to make the task suitable for participants who may have some difficulty in maintaining attention. We also wanted to use a suitable variant of the time discrimination task that has detected differences between controls and relatively high-functioning diagnostic categories.

Procedure

Participants arrived in the lab and completed the BDI. They were then given instructions for the time discrimination task, which involved participants being asked to judge the difference between standard and variable comparison durations presented sequentially. On each of 32 trials, both durations were marked by the simultaneous presentation of both an auditory and a visual stimulus. The visual stimuli were a red square or blue circle presented on the computer screen, accompanied by a sound of the same duration. In order to avoid time order error (the finding that the presentation order of standard and comparison intervals biases discrimination judgements, see Allan, 1977; Eisler, Eisler, & Hellstrom, 2008), presentation order was partially randomized with the constraint that the standard interval should be presented first on 50% of trials. In all conditions, the standard duration remained the same throughout the procedure, and the comparison duration was reduced by a factor of X for each correct answer and increased by $3X$ for each incorrect answer.

Experiment 1a. In the long version of the task, the standard duration was always 1,000 ms, and the variable comparison duration was initially set to 1,400 ms. For Trials 1 to 4, the downward "step" was 100 ms, while the upward step was 300 ms. For Trials 5 to 32, the downward step was 25 ms, and the upward step was 75 ms.

Experiment 1b. In the short version of the task, the standard duration was 50 ms, and the variable comparison duration started at 75 ms. For Trials 1 to 4, the downward step was 3 ms, while the upward step was 9 ms. For Trials 5 to 32, the downward step was 2 ms, and the upward step was 6 ms.

Participants initiated each trial by clicking on the "start button" located at the centre of the computer screen. After a 900-ms delay, the first interval was presented, followed, after a 900-ms interstimulus interval (ISI), by the second interval. After the termination of the second interval, a message appeared on the screen asking participants to indicate which stimulus was on the screen for the longer period. Once the judgement had been made, the start button returned to the screen so that participants could initiate the next trial. The procedure resulted in a series of "runs" of successive correct and incorrect responses. After an incorrect response, the comparison duration was increased by the relevant upward step, and after a correct response, the comparison duration was decreased by the relevant downward step. Once the procedure was complete, participants were thanked, paid a nominal sum for participation, and debriefed.

Data analysis

Discrimination performance was measured by calculating a mean time discrimination threshold, using the midrun estimates of the last 20 trials, for each participant (Rammsayer et al., 2001). Here, the term "run" refers to series of correct responses, where each midrun estimate is equivalent to the average difference between the standard and comparison durations judged correctly. The threshold is then averaged over the "runs" generated by each participant. This measure has been shown to be a reliable estimate of the difference duration at which participants are 75% correct (Wetherill et al., 1966). The midpoint of the last run was only included in each participant's average, if it was an unbiased end to the run, rather than a run artificially terminated by the end of the procedure.

Results and discussion

Experiment 1A

The mean discrimination thresholds calculated for each mood group were lower for the nondepressed ($M = 105.7$, $SE = 8.5$) than for the depressed participants ($M = 161.4$, $SE = 20.4$). As these data were not normally distributed, $W(36) = .83$, $p < .001$, thresholds were converted to natural logarithms, after which the distribution approximated normality, $W(36) = .984$, $p = .866$. The transformed data were then analysed using an independent-samples *t* test with mood group (depressed, nondepressed) as the between-subjects factor.[1] Consistent with observations, the depressed group produced a significantly higher discrimination threshold than the nondepressed group, $t(34) = 2.51$, $p = .017$.

Experiment 1B

The mean discrimination thresholds calculated for each mood group were very similar. Nondepressed participants were able to discriminate reliably between durations that differed by 30.1 ms ($SE = 2.5$), whereas depressed participants were able to discriminate between differences of 27.0 ms ($SE = 2.8$). Raw threshold data were normally distributed, $W(36) = .957$, $p = .175$, and were analysed using an independent-samples *t* test with mood group (depressed, nondepressed) as the between-subjects factor. The small difference between the depressed and nondepressed groups was not reliable, $t(34) = 0.82$, *ns*.

The findings of Experiment 1 suggest that discrimination performance is impaired in depression with durations of over 1,000 ms but unaffected with shorter durations of less than 300 ms. In this experiment, we used relatively unusual simultaneous presentations of visual and auditory stimuli in order to define the durations. In spite of this, our findings are consistent with Sévigny et al. (2003) who also noted a distinction between short and long discrimination performance. However, in Experiment 1, short and long time discriminations were studied in different samples, and the possibility is that uncontrolled between-sample differences are responsible for the distinction. Depressed participants who participated in the "short" task had marginally lower BDI scores ($M = 15.2$, $SE = 1.1$) than those who completed the long task ($M = 17.2$, $SE = 1.8$). This difference, though small, does span the published cut-off scores for mild (BDI = 9 to 15) and moderate depression (BDI = 16+) using this version of the BDI and could have influenced the difference between the two sets of findings. A stronger test of the short versus long discrimination distinction requires a within-participants comparison of short and long discrimination performance with a larger

[1] All analyses in Experiments 1 and 2 were carried out including sex as a variable. Sex on its own did not have a reliable effect on discrimination threshold or in interaction with mood, all $p > .25$. This variable was not of interest in the present study and was not included in any of the analyses reported here.

sample. Moreover it is important to include a dependent measure, such as the Weber fraction, which allows direct comparisons of timing sensitivity across short and long durations.

EXPERIMENT 2

Method

Participants

Eighty-eight university students were recruited for this experiment and were assigned to the depressed ($n = 40$) and nondepressed ($n = 48$) groups using the same criteria as those in previous experiments. No participants were excluded on the basis of an inconsistent or too high BDI score. In this experiment, we also collected handedness data through participant self-report and found that 3 of the depressed and 6 of the nondepressed participants were left-handed; all other participants were right-handed. In our initial analyses, we found that left-handedness, albeit with only 9 participants, seemed to have a significant influence on the effect of duration on discrimination performance, $F(1,\ 72) = 4.13$, $p = .04$, $\eta^2 = .05$, with those who were left-handers producing higher long thresholds ($M = 203.5$ ms, $SE = 28.4$) than right-handers ($M = 140.8$ ms, $SE = 9.9$) but not short thresholds. Given that there is some evidence that laterality has an influence on time perception with the right hemisphere being related to visual information processing and left hemisphere to specialized timing processes (see Grondin & Girard, 2005; Grondin, Voyer, & Bisson, in Q7 press; Polzella, DaPolito, & Hinsman, 1977), we decided to exclude data provided by left-handed participants from further analysis in order to reduce this noise in the data rather than attempt to account for the added variability statistically.

Therefore, the final sample was 79 participants, 42 of whom were assigned to the depressed group (male, $n = 22$; female, $n = 20$) and 37 participants who were categorized as nondepressed (male, $n = 20$; female, $n = 17$). The depressed and nondepressed groups were matched on age and education (all $t < 1.16$) but not NART and Digit Span scores. Depressed participants scored lower on the Digit Span task ($M = 6.7$, $SE = 0.2$) and NART ($M = 25.6$, $SE = 1.0$) than did their nondepressed counterparts: digit, $M = 7.4$, $SE = 0.3$, $t(77) = 1.93$, $p < .05$; NART, $M = 31.8$, $SE = 1.0$, $t(77) = 4.47$, $p < .05$. Depressed participants also scored reliably higher on the BDI ($M = 17.43$, $SE = 0.45$) than did their nondepressed counterparts ($M = 3.86$, $SE = 1.04$), $t(49.14) = 11.94$, $p < .001$, equal variances not assumed. BDI scores in the depressed group ranged from 9 to 31, with 20 of the participants scoring in the moderately depressed range.

Apparatus and procedure

Apparatus, stimuli, and procedures were the same as those in Experiment 1. As participants would be completing both the short and long versions of the time discrimination task, the order of presentation was counterbalanced, with approximately half of the participants in each mood group completing the short discrimination first and the others completing the long discrimination first. One further difference in procedures was that three experimenters were involved in running the experiment, with H.S. running 38 participants, G.B. 17, and R.M. running 24 participants.

Data analysis

The aim of this experiment was to replicate the findings of Experiment 1 and make direct comparisons between short and long duration discrimination performance. Although short and long discrimination thresholds are both calculated using the same millisecond scale, they are not directly comparable, as the "step width" and parameters used in the procedure and the available variability are quite different. Therefore, Weber fractions, which are a classical psychophysical measure of timing sensitivity, were calculated by taking the ratio of the threshold on the standard duration for each condition (see Grondin, Ouellet, & Roussel, 2001, for a discussion). Standard natural log transformations were required (see Table 1), as the raw data did not approximate normality. Following successful transformations, the data were analysed using mixed analysis of

Table 1. *Mean thresholds, Weber fractions, and normality tests for short and long time discriminations*

		Discrimination threshold		*Weber fraction*		*Shapiro–Wilks* p	
Mood	*Duration*	M	SE	M	SE	*Raw*	*Ln*
ND	Short	32.60	2.45	.66	.05	.001	.338
D	Short	30.56	2.10	.61	.04		
ND	Long	129.23	15.04	.13	.02	<.001	.294
D	Long	159.21	12.88	.16	.01		

Note: ND = nondepressed. D = depressed. Raw = raw data distributions. Ln = natural log-transformed distributions. Shapiro–Wilks tests the normality of the distributions.

variance, with mood (depressed, nondepressed) as a between-subjects factor and duration (short, long) as the within-subjects factor. "Experimenter" and "counterbalancing order" variables, as well as age and education covariates, were included in the analyses.

Results and discussion

Discrimination thresholds and Weber fractions for short and long discriminations are shown in Table 1. Nondepressed participants produced lower thresholds than depressed participants for long durations but not short. In fact, for short discriminative stimuli, depressed participants performed marginally better than nondepressed. Weber fractions mirrored this pattern, although timing sensitivity was better for all participants with longer durations.

The analyses of variance carried out on the threshold and Weber fraction data supported these observations. Here we report only the analysis of Weber fractions but note where there were differences between the two analyses. The duration by mood interaction was significant, $F(1, 68) = 5.18$, $p = .026$, $\eta^2 = .07$. The main effect of duration failed to reach the significance level for Weber faction data, $F(1, 68) = 3.64$, $p = .06$, $\eta^2 = .05$, but as expected, long thresholds were reliably longer than short thresholds, $F(1, 68) = 17.58$, $p < .001$, $\eta^2 = .21$. The duration by counterbalancing order interaction was also reliable, $F(1, 68) = 6.88$, $p = .011$, $\eta^2 = .09$, although as the interaction involving the counterbalancing variable did not involve mood, it is not discussed further. Planned comparisons showed that the effect of mood on the long discrimination thresholds was relatively small and of borderline significance, $F(1, 68) = 3.89$, $p = .053$, $\eta^2 = .054$, whereas there was clearly no difference attributable to mood with short durations, $F < 1$. In addition, for both nondepressed and depressed participants, the Weber fractions derived from long discriminations were significantly smaller than those from short discriminations (both Fs > 171, both ps $< .001$). However, the size of these effects was greater for depressed ($\eta^2 = .83$) than for nondepressed ($\eta^2 = .72$) participants.

These data replicate the effects of mood on discrimination performance identified in Experiment 1. All participants performed similarly on the short time discrimination task. However, people categorized as depressed were less able than the nondepressed to discriminate between durations in the region of 1,000 ms. The distinction between short and long discrimination performance noted in Experiment 1 is replicated in Experiment 2, in which all participants completed both short and long conditions.

GENERAL DISCUSSION

The data from the two experiments reported here provide evidence for differences in objective time judgement related to depression but little evidence for changes in clock speed. In the present study, where mood differences emerged, the depressed groups were less able to discriminate durations than the nondepressed group. At first glance, this might be thought of as consistent with a slower pacemaker, except that between-group differences were restricted to longer durations of over 1,000 ms. This finding is consistent with Sévigny et al. (2003) who reported that their depressed participants were less likely to answer correctly when durations were long but not short. A change in pacemaker speed should affect both short and long time discrimination performance. If other aspects of timing, such as the accumulator, comparator, and decision processes, were affected by depression, then those effects should also be evident in short and long conditions. This suggests that depression affects the remaining components of the model, either attention or memory, and that these effects come into play with longer durations.

For example, an attentionally mediated "flicker" in the switch, which provides the pacemaker accumulator connection (also see Lejeune, 1998; Meck, 2005, for a discussion), would probably be more evident with longer durations. This would reduce the number of pulses accrued in a given interval, giving the appearance of a slowed clock with longer durations and making it more difficult for participants to discriminate between those durations. Interestingly, this explanation is also consistent with more recent findings from an interval bisection task.

Interval bisection tasks involve the presentation of what are termed "short" and "long" reference durations. Participants are then presented with a series of intermediate probe durations and are asked to categorize them as short or long. Gil and Droit-Volet (2009) found that their moderately depressed participants were less likely than controls to judge probe stimuli that varied between 600 and 1,400 ms as long. In other words, there was a tendency, correlated with BDI scores, to underestimate these durations. This effect was interpreted as indicating a reduction in clock speed whilst also acknowledging that the findings did not exclude an attentional explanation. It seems then that there is converging evidence that points to attention as a source of depression-related differences in time perception.

However, memory should also be considered in relation to these effects. During time discrimination and temporal bisection tasks, current durations must be maintained in working memory (see Figure 1) in order to be compared to the previous duration stored in reference memory. As the role of reference memory has been called into question in temporal bisection due to preserved performance in roving or partition conditions (Allan, 2002; Droit Volet & Rattat, 2007), working memory is the focus here. If working memory capacity or duration were compromised in depression, this could potentially explain the short versus long distinction we have observed.

This does not seem likely for several reasons, although there is some evidence of working memory impairment in depression (Channon, 1993; Rose & Ebmeier, 2006; and see Gotlib & Hammen, 2009, for a discussion). First, the interstimulus interval between standard and comparison durations was the same (900 ms) in both short and long discrimination conditions. Therefore, the working memory requirements for maintaining the first stimulus until the second stimulus was presented were the same across short and long conditions. Moreover, in terms of maintaining information over time to ensure appropriate performance, a previous study showed that analogue depressed participants showed no disadvantage when ISIs were 1,000 ms long (Msetfi, Murphy, Kornbrot, & Simpson, 2009).

Working memory capacity requirements did differ across the long and short conditions, however, because longer durations would require more pulses to be maintained until the comparison and decision process. This is unlikely to be the source of the mood differences at longer durations because the performance of depressed participants started with the longest durations being discriminated correctly (1,000 to 1,400 ms comparison) and only deteriorated as durations and differences decreased (1,000 vs. around 1,160 ms). Impaired working memory capacity would presumably mean that shorter durations in this range were more likely to be maintained and therefore discriminated correctly over longer durations. This was not the case in this study, and it therefore seems that attentional, rather than working memory, processes are more likely to underlie the effects of depression on time discrimination performance.

The key conclusion of the present study is that depression effects on time discrimination are not related to changes in clock speed. Depression effects may be linked to attention because the attentional switch linking pacemaker and accumulator flickers open and closed during elapsing duration (Lejeune, 1998). Or, it might be that an attentional gate that channels pulses through to the switch is not optimally wide open, allowing fewer pulses to pass through (Zakay & Block, 1997). Reduced arousal in depressive states or attention lapses due to intrusive ruminative thoughts could produce such effects. In other words, depression effects are probably not specific to timing mechanisms but are secondary effects of more general processes.

However, as many other cognitive processes rely on and interact with the perception of time, any, albeit general, impairment that impacts on time perception is likely to have consequences reaching further than the discrimination of short durations in an experimental task. Consider the potential effect of fewer time pulses entering the accumulator during short intervals. For example, events separated in time could appear closer together, resulting in an erroneous perception of causality. Waiting times in between actions, behaviours, and subsequent outcomes might appear to be shorter than usual, inducing passivity rather than activity. Even simple situations like those we have just described, which occur repeatedly, could potentially result in feelings of self-blame and helplessness, respectively, eventually exacerbating depressed mood.

People who took part in this study were students scoring low or high on the BDI, and this could be thought of as a limitation. However, our findings of mood effects on discrimination at intervals of >1,000 ms are consistent with findings with clinically depressed participants. It is also the case that the low levels of depression have an extremely high prevalence (e.g., Barrett, Oxman, & Gerber, 1987; Salokangas, Poutanen, Stenggard, & Jahi, 1996). Understanding the cognitive and experiential changes that happen with low levels of depression will elucidate our understanding of how those changes can escalate to clinical levels of depression. Furthermore, the current study implicates the importance of attention in mood differences observed in normal samples of participants. That is, mood effects on time perception, as measured by the discrimination of time intervals as short as 50 ms, are a generic cognitive effect rather than effects related to changes in pacemaker or clock speed.

Original manuscript received 1 December 2010
Accepted revision received 18 July 2011
First published online day month year

REFERENCES

Allan, L. G. (1977). The time-order error in judgments of duration. *Canadian Journal of Psychology*, *31*(1), 24–31.

Allan, L. G. (1998). The influence of the scalar timing model on human timing research. *Behavioural Processes*, *44*(2), 101–117.

Allan, L. G. (2002). Are the referents remembered in temporal bisection? *Learning and Motivation*, *33*, 10–31.

Anagnostou, E., & Mitsikostas, D. D. (2004). Time perception in migraine sufferers: An experimental matched pairs study. *Cephalalgia*, *25*, 60–67.

Barrett, J., Oxman, T. E., & Gerber, P. (1987). Prevalence of depression and its correlates in a general medical practice. *Journal of Affective Disorders*, *12*(2), 167–174.

Bech, P. (1975). Depression: Influence on time estimation and time experience. Acta *Psychiatrica Scandinavica*, *51*(1), 42–50.

Beck, A. T., Ward, C. H., Mendelson, M., Mock, J., & Erbaugh, J. (1961). An inventory for measuring depression. *Archives of General Psychiatry*, *4*, 561–571.

Bindra, D., & Waksberg, H. (1956). Methods and terminology in studies of time estimation. *Psychological Bulletin*. Q8

Bschor, T., Ising, M., Bauer, M., Lewitzka, U., Skerstupeit, M., Maller Oerlinghausen, B., et al. (2004). Time experience and time judgment in major depression, mania and healthy subjects. A controlled study of 93 subjects. *Acta Psychiatrica Scandinavica*, *109*(3), 222–229.

Channon, S. (1993). Working memory in clinical depression: An experimental study. *Psychological Medicine*, *23,* 87–91.

Dilling, C. A., & Rabin, A. I. (1967). Temporal experience in depressive states and schizophrenia. *Journal of* Q9 *Consulting Psychology*.

Droit Volet, S., & Rattat, A.-C. (2007). A further analysis of time bisection behavior in children with and without reference memory: The similarity and partition task. *Acta Psychologica*, *125,* 240–256.

Eagleman, D. M., & Holcombe, A. O. (2002). Causality and the perception of time. *Trends in Cognitive Sciences*, *6*(8), 323–325.

Eisler, H., Eisler, A. D., & Hellstrom, A. (2008). Psychophysical issues in the study of time perception. S. Grondin (Ed.), *Psychology of time*. Bingley, UK: Emerald Group Publishing Limited.

Gibbon, J. (1981). On the form and location of the bisection function for time. *Journal of Mathematical Psychology*, *24,* 58–87.

Gil, S., & Droit Volet, S. (2009). Time perception, depression and sadness. *Behavioural Processes*, *80*(2), 169–176.

Gotlib, I., & Hammen, C. L. (2009). *Handbook of depression* (2nd ed.). New York, NY: The Guilford Press.

Grondin, S. (2010). Timing and time perception: A review of recent behavioral and neuroscience findings and theoretical directions. *Attention, Perception, & Psychophysics*, *72*(3), 561–582.

Grondin, S., & Girard, C. (2005). About hemisperic differences in the processing of temporal intervals. *Brain and Cognition*, *58*(1), 125–132.

Grondin, S., Ouellet, B., & Roussel, M. (2001). About optimal timing and stability of Weber fraction for duration discrimination. *Acoustical Science and* Q7 *Technology*, *22*(5), 370–372.

Grondin, S., Voyer, D., & Bisson, N. (in press). Perceptual asymmetries in the discrimination of brief auditory time intervals. *Laterality: Asymmetries of Body, Brain and Cognition*, Advance online publication. doi: http://www.informaworld.com/10.1080/1357650X.2010.485353.

Hancock, P. A., & Rausch, R. (2010). The effects of sex, age, and interval duration on the perception of time. *Acta Psychologica*, *133*(2), 170–179.

Hawkins, W. L., French, L. C., Crawford, B. D., & Enzle, M. E. (1988). Depressed affect and time perception. *Journal of Abnormal Psychology*, *97*(3), 275–280.

Ho, M. Y., Velazquez-Martinez, D. N., Bradshaw, C. M., & Szabadi, E. (2002). 5-hydroxytryptamine and interval timing behaviour. *Pharmacology Biochemistry, and Behavior*, *71*(4), 773–785.

Hoffer, A., & Osmond, H. (1962). The relationship between mood and time perception. *Psychiatric Quarterly Supplement*. Q10

Kant (1982). *The critique of pure reason* (J. M. D. Meiklejohn, Trans.). London, UK: Henry, G. Bohn (Original work published 1787). Q3

Killeen, P. R., Fetterman, J. G., & Bizo, L. A. (1997). Time's causes. C.M. Bradshaw (Ed.), *Advances in psychology: Vol. 120. Time and behaviour: Psychological and neurobehavioural analyses* (pp. 79–131). Amsterdam, The Netherlands: North-Holland/Elsevier Science Publishers.

Kitamura, T., & Kumar, R. (1983). Time estimation and time production in depressive patients. *Acta Psychiatrica Scandinavica*, *68,* 15–21.

Kuhs, H., Hermann, W., Kammer, K., & Tolle, R. (1991). Time estimation and the experience of time in endogenous depression (melancholia): An experimental investigation. *Psychopathology*, *24,* 7–11.

Lehmann, H. E. (1967). Time and psychopathology. *Annals of the New York Academy of Sciences*, *138,* 798–821.

Lejeune, H. (1998). Switching or gating? The attentional challenge in cognitive models of psychological time. *Behavioural Processes*, *44*(2), 127–145.

Lewis, A. (1932). The experience of time in mental disorder. *Proceedings of the Royal Society of Medicine*, *25,* 611–620.

Lewis, P. A., & Miall, R. C. (2003a). Brain activation patterns during measurement of sub- and supra-second intervals. *Neuropsychologia*, *41,* 1583–1592.

Lewis, P. A., & Miall, R. C. (2003b). Distinct systems for automatic and cognitively controlled time measurement: Evidence from neuroimaging. *Current Opinion in Neurobiology*, *13,* 250–255.

Lezak, M. D. (1995). *Neuropsychological assessment* (3rd ed.). New York, NY: Oxford University Press.

Matthews, W. J. (in press). Can we use verbal estimation to dissect the internal clock? Differentiating the effects of pacemaker rate, switch latencies, and judgement processes. *Behavioural Processes*. Q5

Meck, W. H. (2005). Neuropsychology of timing and time perception. *Brain and Cognition*, *58*(1), 1–8.

Mezey, A. G., & Cohen, S. I. (1961). The effect of depressive illness on time judgment and time experience. *Journal of Neurology, Neurosurgery, and Psychiatry*, *24,* 269–270.

Michotte, A. (1963). *The perception of causality*. Oxford, UK: Basic Books.

Msetfi, R. M., Murphy, R. A., Kornbrot, D. E., & Simpson, J. (2009). Impaired context maintenance in mild to moderately depressed students. *Quarterly Journal of Experimental Psychology*, *62*(4), 653–662.

Munzel, K., Gendner, G., Steinberg, R., & Raith, L. (1988). Time estimation of depressive patients: The influence of interval content. *European Archives of Psychiatry and Neurological Sciences*, *237,* 171–178.

Nelson, H. (1982). *National adult reading test (NART): Test manual*. Windsor, UK: NFER-Nelson.

Q11 Newman & Gaudiano (1984)

Polzella, D. J., DaPolito, F., & Hinsman, M. C. (1977). Cerebral asymmetry in time perception. *Perception and Psychophysics*, *21*(2), 187–192.

Prabhu, G. G., Agarwal, A. K., & Teja, J. S. (1969). Effect of anxiety and depression on time estimation and judgement. *Indian Psychological Review*, *6*(1), 16–21.

Rammsayer, T. H. (1990). Temporal discrimination in schizophrenic and affective disorders: Evidence for a dopamine-dependent internal clock. *International Journal of Neuroscience*, *53*(2–4), 111–120.

Rammsayer, T. H., & Brandler, S. (2007). Performance on temporal information processing as an index of general intelligence. *Intelligence*, *35,* 123–139.

Rammsayer, T. H., Hennig, J., Haag, A., & Lange, N. (2001). Effects of noradrenergic activity on temporal information processing in humans. *The Quarterly Journal of Experimental Psychology*, *54B*(3), 247–258.

Rammsayer, T. H., & Ulrich, R. (2005). No evidence for qualitative differences in the processing of short and long temporal intervals. *Acta Psychologica*, *120,* 141–171.

Rose, E. J., & Ebmeier, K. P. (2006). Pattern of impaired working memory during major depression. *Journal of Affective Disorders*, *90*(2), 149–161.

Salokangas, R.K.? R., Poutanen, O., Stenggard, E., & Jahi, R. (1996). Prevalence of depression among patients seen in community health centres and community mental health centres. *Acta Psychiatrica Scandinavica*, *93*(6), 427–433.

Sévigny, M., Everett, J., & Grondin, S. (2003). Depression, attention and time estimation. *Brain and Cognition*, *53,* 351–353.

Smith, A., Taylor, E., Rogers, J. W., Newman, S., & Rubia, K. (2002). Evidence for a pure time perception deficit in children with ADHD. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, *43* (4), 529–542.

Treisman, M. (1963). Temporal discrimination and the indifference interval: Implications for a model of the “internal clock”. *Psychological Monographs*, *77,* 1–31.

Tysk, L. (1984). Time perception and affective disorders. *Perceptual and Motor Skills*, *58*(2), 455–464.

Vallee Tourangeau, F., Murphy, R. A., & Baker, A. G. (2005). Contiguity and the outcome density bias in action–outcome contingency judgements. *Quarterly Journal of Experimental Psychology: Comparative and Physiological Psychology*, *58B,* 177–192.

Wetherill, G. B., Chen, H., & Vasudeva, R. B. (1966). Sequential estimation of quantal response curves: A new method of estimation. *Biometrika*, *53*(3/4), 439–454.

Wyrick, R. A., & Wyrick, L. C. (1977). Time experience during depression. *Archives of General Psychiatry*, *34* (12), 1441–1443.

Zakay, D., & Block, R. A. (1997). Temporal cognition. *Current Directions in Psychological Science*, *6*(1), 12–16.

Q4 APPENDIX

Sample and methodology information of studies testing the effects of depression on verbal and production estimation of time

Study	*Sample*	*Task*	*Temporal orientation*	*Interval content*	*Duration*	*Findings*
Prabhu et al. (1969)	Clinical psychotic D ($n = 32$), anxiety ($n = 32$), controls ($n = 18$)	VE	Probably retrospective but unclear	Other time tasks	15 min	No differences
Bech (1975)	Clinical D (S1: $n = 17$,[a] E2: $n = 24$[a]), psychiatric controls (S1: $n = 6$), normal controls (S1: $n = 8$),	VE	Probably retrospective but unclear	Driving task Questionnaire	3 min 5 min	No differences
Hawkins et al. (1988)	Mood induction: elated ($n = 28$), neutral ($n = 28$), depressed ($n = 28$)	VE	Retrospective	Sorting task	4 & 13 min	No differences
Lehmann (1967)	Clinical D ($n = 14$), controls ($n = 20$), other diagnostic groups	VE	Probably retrospective but unclear	Interview and other experimental tasks	Variable, 20–60 min	Over 90% of Ds categorized as underestimators
Dilling & Rabin (1967)	Clinical D ($n = 20$), schizophrenics ($n = 20$), controls ($n = 20$)	VE	Probably retrospective but unclear	Other time tasks	14 & 31 min	More Ds categorized as overestimators
Wyrick & Wyrick (1977)	Clinical D ($n = 30$), controls ($n = 30$)	VE	Prospective for the durations in s	Other time tasks	5, 10, 20, 80, 160, 240 s 15 & 30 min	Ds overestimated durations between 160 s and 30 min
Kitamura & Kumar (1983)	Clinical D ($n = 23$), controls ($n = 23$)	VE	Prospective	Empty	5, 10, 20, 80, 160, 240s	Ds overestimated 10, 20, & 80 s
Tysk (1984)	Clinical D with & without melancholia ($n = 56$), controls ($n = 60$)	VE	Prospective	Empty (but counting encouraged)	7.5, 17.5, 27.5 s	Ds with melancholia underestimated
Munzel et al. (1988)	Clinical D ($n = 47$), controls ($n = 16$)	VE	Retrospective	Empty, picture comparison vs. concentration task	240 s	Ds overestimated only empty & picture comparison intervals
Bschor et al. (2004)	D ($n = 32$) and manic patients ($n = 30$), controls ($n = 31$)	VE	Prospective	Empty	8, 43, & 109 s	D and manic patients overestimated 109 s
Lehman (1967)	Clinical D ($n = 14$), controls ($n = 20$), other diagnostic groups	PE		Tapping	15 s	No differences
Prabhu et al. (1969)	Clinical psychotic D ($n = 32$), anxiety ($n = 32$), controls ($n = 18$)	PE PE		Counting Tapping	30 s 30 s	No differences No differences
Munzel et al. (1988)	Clinical D ($n = 47$), controls ($n = 16$)	PE		Empty	1, 5 & 10 s	No differences
Kitamura & Kumar (1983)	Clinical D ($n = 23$), controls ($n = 23$)	PE		Empty	30 s	No differences.

(*Continued overleaf*)

Appendix Continued.

Study	*Sample*	*Task*	*Temporal orientation*	*Interval content*	*Duration*	*Findings*
Newman & Gaudiano (1984) Q11	Elderly participants ($N = 68$)	PE		Empty	40 s	Positive correlation with BDI scores
Tysk (1984)	Clinical D with & without melancholia ($n = 56$), controls ($n = 60$)	PE		Empty (but counting encouraged)	10, 20, & 30 s	Ds with melancholia underestimated
Kuhs et al. (1991)	Clinical D ($n = 25$), controls ($n = 12$)	PE		Counting	30 s	Ds underestimated
Sévigny et al. (2003)	Analogue D ($n = 15$), controls ($n = 20$)	PE		Tapping	1 & 10 s	Ds more variability
Bschor et al. (2004)	D ($n = 32$) and manic patients ($n = 30$), controls ($n = 31$)	PE		Empty (but counting not prevented)	7, 35 & 90 s	Ds & manic patients underestimated 35 & 90 s

Note: VE = verbal estimation, PE = production estimation, D = depressed. In this table, the terms *underestimate* and *overestimate* refer to estimates that are less than or greater than the target value (see Tysk, 1984) relative to estimates made by the control group. For VE tasks, the temporal orientation of the time judgement is noted as retrospective (participants are unaware that a time judgement will be required during the elapsing duration) or prospective (participants are informed about the time task before it commences), see Grondin (2010, p. 563).

[a]In the Bech (1975) study, the depressed groups were split into three diagnostic groups of around 6 participants each. Significance tests were based on these smaller *n*s.

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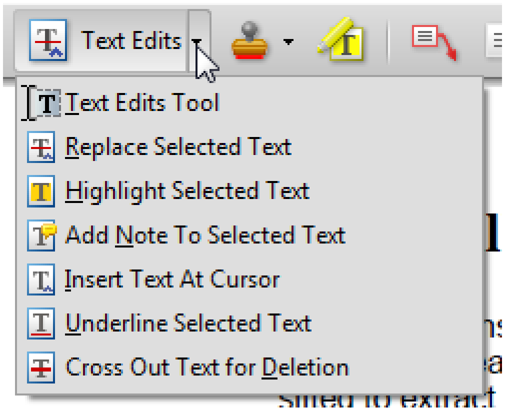

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