

Time perception, depression and sadness

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A paraître dans / To appear in :

Gil, S., & Droit-Volet, S.. Time perception, depression and sadness. *Behavioural Processes*.

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KEYWORDS: Time ; Timing ; Depression ; Mood ; Sadness

ABSTRACT

This study examined changes in time perception as a function of depressive symptoms, assessed for each participant with the Beck Depression Inventory (BDI). The participants performed a temporal bisection task in which they had to categorize a signal duration of between 400 and 1600 ms as either as short or long. The data showed that the bisection function was shifted toward the right, and that the point of subjective equality was higher in the depressive than in the non-depressive participants. Furthermore, the higher the depression score was, the shorter the signal duration was judged to be. In contrast, the sensitivity to time was similar in these two groups of participants. These results thus indicate that the probe durations were underestimated by the depressive participants. The sadness scores assessed by the Brief Mood Inventory Scale (BMIS) also suggest that the emotional state of sadness in the depressive participants goes some way to explaining their temporal performance. Statistical analyses and modeling of data support the idea according to which these results may be explained by a slowing down of the internal clock in the depressive participants.

INTRODUCTION

One of the most widespread affective disorders is depression. According to the DSM-IV criteria (American Psychiatry Association, 1994), depression is characterized by symptoms of a depressive mood indicated by the feeling of being sad or empty, as well as by a markedly diminished ability to take pleasure in things. Associated with these symptoms, there is also the feeling that time is passing more slowly than normal (Bech, 1975; Blewett, 1992; Hoffer and Osmond, 1962; Kitamura and Kumar, 1982; Lehmann, 1967; Mezey and Cohen, 1961; Straus, 1947; Wyrick and Wyrick, 1977). A patient suffering from depression often says "Every hour seems a year to me" or "Time, it's terribly slow" (Mezey and Cohen, 1961, p. 270). However, as stated by Bech (1975, p. 49) when "the depressed patient tells us that he is very sad and unhappy and when he tells us that time passes by very slowly, he is trying to communicate the same or a similar experience": his sadness, and his dissatisfaction with a period of his life. However this subjective appraisal of the passage of time does not indicate any intrinsic change in time perception, i.e. such individuals experience time in the same way as other people.

In line with Bech (1975) conclusion, some studies have found no evidence that depression affects time perception (Bech, 1975; Hawkins et al., 1988; Kitamura and Kumar, 1984; Mezey and Cohen, 1961; Prabhu et al., 1969). Nevertheless, other studies have suggested that time judgments are modified by depressive affect (Bschor et al., 2004; Grinker et al., 1973; Kuhs et al., 1991; Sévigny et al., 2003; Tysk, 1984). When they asked their participants to count at a rate of one per second or to count quietly up to 10, Tysk (1984) and Kuhs et al. (1991), respectively, showed that their depressive patients counted time more slowly, and consequently underestimated time. In line with these results, Bschor et al. (2004) found that depressive patients underestimated durations by between 7 and 109 s compared with non-depressive patients, both in a temporal production and a verbal estimation task. Using a small number of subjects per group (less than 7), Grinker et al. (1973) obtained a significant correlation between the individual depression scores and time estimates in a discrimination task: the more depressive the subjects were, the shorter the standard durations of 1 and 3s were estimated to be. Furthermore, according to Sévigny et al. (2003), temporal discrimination should be poorer in depressive than in non-depressive subjects. In their study, the former indeed produced fewer correct responses in a discrimination task than the latter for durations of 1.12 and 1.20s, while no depression-related difference was observed for shorter durations from 0.08 to 0.55 s (Experiment 1). The depressive individuals also appeared to be more variable in the timing of a motor response for duration values both shorter and longer than 2s (Experiment 2), although no data was provided relating to the absolute values of the produced durations. Whatever the

case, when time judgments are altered by depression, this modification almost always takes the form of an underestimation of time.

Nonetheless, it is difficult to draw conclusions about the effect of depression on time perception on the basis of the methods used so far. With the exception of two studies which used duration values shorter than 2 s, i.e. Grinker et al. (1973) and Sévigny et al. (2003), all the studies reported above tested durations of several seconds without taking the methodological precaution of preventing the subjects from using a counting strategy. Furthermore, they made use of temporal judgment which required the production and timing of a motor response, i.e. temporal production, tapping, counting. There is now ample evidence that psychomotor alterations are fundamental psychopathological features of depression, which can be seen in a general decrease in movement speed, i.e. retardation (Lemke et al., 1999, 2000). Consequently, in these studies, it is difficult to dissociate the role of the motor component from that of the timing component in temporal performance, even though these two components may be related (Wearden, 2003; Wing and Kristofferson, 1973). For instance, on the basis of results which indicated a slowing down of counting in depressive patients, Tysk (1984, p. 461) concluded that "their sense of time is altered so that the internal second standard is slow, resulting in slow counting". However, without further analysis it is impossible to draw such a conclusion, since the motor component of counting could be the main cause of this deceleration of counting in depressive individuals. Most studies of time and depression are relatively old and a-theoretical. These studies can thus be regarded as exploratory in nature, providing no clear explanation of the mechanisms by which depression might affect time perception. As stated by Sévigny et al. (2003), experimental evidence for the disturbance of time judgments is sparse and somewhat contradictory. The aim of the present study was thus to further investigate the difference between depressive and non-depressive participants in time perception with short durations (<2 s), using a temporal discrimination task that did not require the timing of a motor response, i.e. the temporal bisection task. In addition, in order to test our results, we decided to subject our data to a form of modeling which has been used successfully to explain time perception in animals and humans adults (Allan, 1998; Droit-Volet et al., 2007; Droit-Volet and Wearden, 2001; Penney et al., 2000; Wearden, 1991).

In the temporal bisection task, the subjects were presented with two standard durations, one short and the other long. They were then presented with comparison durations of a duration intermediate between or equivalent to the standards and were simply required to categorize each comparison duration as being more similar to the long (long responses) or to the short (short responses) standard duration. According to the time models based on the scalar timing theory (Gibbon and Church, 1990; Gibbon et al., 1984), the raw material for the representation of duration depends on the functioning of a pacemaker-accumulator clock system. The internal clock system is composed of a pacemaker, an attention-controlled switch, and an accumulator. The pacemaker emits pulses at a certain rate. At the beginning of a stimulus to be timed, the switch closes and the pulses enter into the accumulator. At the end of this stimulus, the switch opens. Thus, the estimated duration depends on the number of pulses accumulated during the to-be-timed stimulus. However, the bisection judgment which consists of responding short or long also depends on memory and decision processes. The duration which has just been presented, t , is stored in working memory and compared with a sample drawn from the distribution of exemplars for the short, s^* , and the long, l^* , standard durations stored in long-term memory. Thus, when $(t - s^*)$ is greater than $(l^* - t)$, the participants respond long, and inversely, when $(l^* - t)$ is greater than $(t - s^*)$ they respond short provided that the difference exceeds a threshold. According to the scalar timing models, the duration is processed accurately and the main sources of noise in time judgments come from the variability in the representation of the standard durations (for review, see, for example, Jones and Wearden, 2004; Droit-Volet and Rattat, 2007). However, recent studies have demonstrated that the variability in the memory representation of standard durations results from noise in the processing of stimulus durations (Delgado and Droit-Volet, 2007; McCormack et al., 2005).

The mechanism in the processing of time that might be affected by depressive mood has been not yet clearly identified, probably because there is not one but several mechanisms involved. Nevertheless, although they did not specify the exact mechanisms involved, Sévigny et al. (2003) suggested that the ability to keep attention focused during the

processing of long durations explains the differences in the temporal judgments made by depressive and non-depressive participants. However, these authors observed poorer temporal performances in the former than in the latter for short durations close to 1 s, i.e. in their Experiment 1 with durations of 1.12 and 1.20 s and Experiment 2 with a duration of 1 s. These durations are considered to require only a low level of attentional resources (Lewis and Miall, 2006). As discussed in more detail below, most researchers believe that the depression-related difference in time perception is also due to the speed of the internal clock which runs more slowly in depressive individuals (Bschor et al., 2004; Grinker et al., 1973; Lehmann, 1967; Lemke et al., 2000; Tysk, 1984). Indeed, if the internal clock runs more slowly than normal in people suffering from depression, fewer pulses are accumulated per unit of time and the duration is judged to be shorter. This slowing down of the internal clock would be associated with the affective aspect of depression – the feeling of sadness – which is one aspect of depressive symptomatology. A number of studies have indeed demonstrated that the mood of sadness is associated with a low arousal level and a slowing down of mental and motor activity (Barr-Zisowitz, 2000; Russel, 1980; Schwartz et al., 1981).

However, the few studies that provide support for the clock-rate hypothesis have investigated the effect of depression on time perception in outpatients and hospitalized patients who were being treated with antidepressant medication. It is thus difficult to dissociate the effect of medication on time judgment from that of the mood *per se*. Consequently, in the present study, we decided to recruit non-hospitalized participants, who were not receiving medication, on the basis of their Body Mass Index (BMI). Indeed, the frequency of depression is greater among the overweight than the normal-weight population (Herva et al., 2006; Roberts et al., 2000; Stunkard et al., 2003). Furthermore, as suggested by Grinker et al. (1973), it is the depressive state and not the fact of being over-weight *per se* that affects temporal judgments. We obtained a depression score for each participant by using the short form of the Beck Depression Inventory (BDI) (Beck and Beamesderfer, 1974) and a sadness score on the basis of the Brief Mood Inventory Scale (BMIS) (Mayer and Gaschke, 1988). Each participant was given a temporal bisection task with signal durations between 400 and 1600 ms. Our hypothesis was that the depressive participants would judge the signal duration as shorter than the non-depressive participants due to the fact that their internal clock runs more slowly. We also tested this clock hypothesis by modeling our data.

METHOD

PARTICIPANTS

The final sample consisted of 92 healthy French adult volunteers, paid 10 euros for their participation (50 females and 44 males, mean age=25.8, S.D.=3.9). Since depressive symptoms increase with Body Mass Index (BMI), kg/m², we ran local newspaper advertisements in order to recruit a larger number of depressive patients on the basis of their BMI. There were 34 normalweight (BMI = 18.5–24.9 kg/m²; mean = 21.4, S.D. = 2.1; 16 males and 18 females), 30 overweight (BMI = 25.0–29.9 kg/m²; mean = 27.0, S.D.=1.6; 15 males and 15 females), and 28 obese participants (BMI >30.0 kg/m²; mean = 34.2, S.D. = 3.2; 11 males and 17 females). Subjects with medical or psychiatric disorders and/or who were receiving medication were excluded (*N*= 2).

MATERIALS

The participants were tested individually in a quiet room in Blaise Pascal University, Clermont-Ferrand, France. They were seated in front of a computer that controlled the stimuli and recorded the data using PsyScope software for Macintosh. The responses were made using the “K” and “D” keys on the computer keyboard. The signal to be timed was a pink oval (12cm × 16cm) presented in the center of the computer screen.

For each subject, a depressive symptom score was calculated using the short form of the BDI (Beck and Beamesderfer, 1974) translated into French by Collet and Cottraux (1986). In this self-report questionnaire, the participants’ answers are scored on a scale from 0 to 39, with a score ≥16 indicating major depressive symptoms. More precisely, four categories of depressive symptoms can be distinguished: (1) from 0 to 3, no depression, (2) from 4 to 7, light

depression, (3) from 8 to 15, moderate depression, and (4) greater than 16, severe depression (Beck and Beamesderfer, 1974). The BMIS (Mayer and Gaschke, 1988), in a French translation as used by Niedenthal and Dalle (2001), was also used to assess the current mood state. In this self-report questionnaire, our participants were presented with 16 affect-related adjectives (e.g. happy, sad, ugly), and had to indicate the extent to which they felt each affective state using a 4-point scale from 1 “definitely do not feel” to 4 “definitely do feel”. In line with Niedenthal and Setterlund (1994) simplified use of this test, a happiness score and a sadness score were calculated for each participant.

PROCEDURE

After giving their informed consent, the participants first performed the bisection task followed by the BDI and the BMIS, with the order in which the questionnaires were administered being counterbalanced across the participants. The bisection task consisted of two phases. In the first, i.e. the training phase, the participants were presented with the short (400 ms) and the long (1600ms) standard signal durations five times each at random, and were trained to press one button to indicate that the signal duration corresponded to the short standard (“K”) and the other button to indicate that it corresponded to the long standard (“D”). The response keys were counterbalanced across participants. In the second phase, i.e. the testing phase, the participants were then presented with seven signal durations, namely two signal durations equal to the standard duration (400 and 1600 ms) and five of intermediate value (600, 800, 1000, 1200, 1400ms). The participants were asked to judge if each probe duration was more similar to the long or to the short standard duration. Each participant completed 63 trials, i.e. 9 trials for each probe duration (9 × 7). The trials were presented in a random order and the intertrial interval was a random interval between 1 and 2s.

RESULTS

As expected, the Body Mass Index and the depression scores assessed by the BDI were positively correlated ($r = 0.31$, $p = 0.003$), thus indicating that depression scores increased with BMI. Initial analyses of variance (ANOVA) on the three performance indexes used in the subsequent analyses (proportion of long responses, point of subjective equality, Weber ratio) exhibited neither a main effect of BMI nor any interaction involving this factor. As the BMI *per se* did not affect time perception, this factor was excluded from the following statistical analyses (see also Grinker et al., 1973).

To investigate the putative depression-related effects on temporal bisection performance, the subjects were distributed to three depression groups as a function of their BDI score: (1) no depression (2) mild depression and (3) moderate depression. Moderately and severely depressive participants were combined within the same moderate depression group as there were only three participants rated as having a high BDI with scores of 16, 16, and 19, respectively. Table 1 provides information about each depressive symptom group. The pairwise group comparisons revealed no differences between the groups in terms of age or sex (Mann–Whitney U , all $p > 0.05$).

Table 1 - Number of participants, mean age (*standard deviation*) and mean (*standard deviation*) Beck Depression Inventory (BDI) score for the men and the women in the non-depressive, mild and moderate depressive symptom groups.

	Non			Mild			Moderate		
	N	Age	BDI	N	Age	BDI	N	Age	BDI
Men	24	26(3)	2(1)	12	25(3)	5(1)	6	29(5)	10(1)
Women	19	26(3)	2(1)	18	26(4)	5(1)	13	25(4)	11(4)

Fig. 1 shows the proportion of long responses for each depressive symptom group plotted against stimulus duration. An examination of this Figure suggests that the bisection function shifted toward the right as the depressive symptoms increased, indicating a shortening effect on time judgments. The ANOVA conducted on the proportion of long responses, with probe duration as within-subjects factor, and sex and depression as between-subjects factors, revealed

a main effect of signal duration, $F(6, 516) = 676.2, p < 0.05$, and this effect did not interact with any other factor. Thus, the proportion of long responses increased with the probe duration value, and this whatever the depression group. However, there was a significant depression effect, $F(2, 86) = 3.11, p < 0.05$, with no other effect being significant. The Sheffe post hoc tests on the proportion of long responses (collapsed across probe durations) revealed that the proportion of long responses was significantly lower for the moderate depression group than for the no depression group (0.55 vs. 0.62, $p < 0.05$), whereas the mild depression group (0.59) produced an intermediate value that did not significantly differ from that of the other two groups ($p > 0.05$). These results are further supported by the significant negative correlation between the mean proportion of long responses and the individual depression scores ($r = -0.23, p < 0.05$) which indicates that the higher the depression scores were, the shorter the signal duration was judged to be.

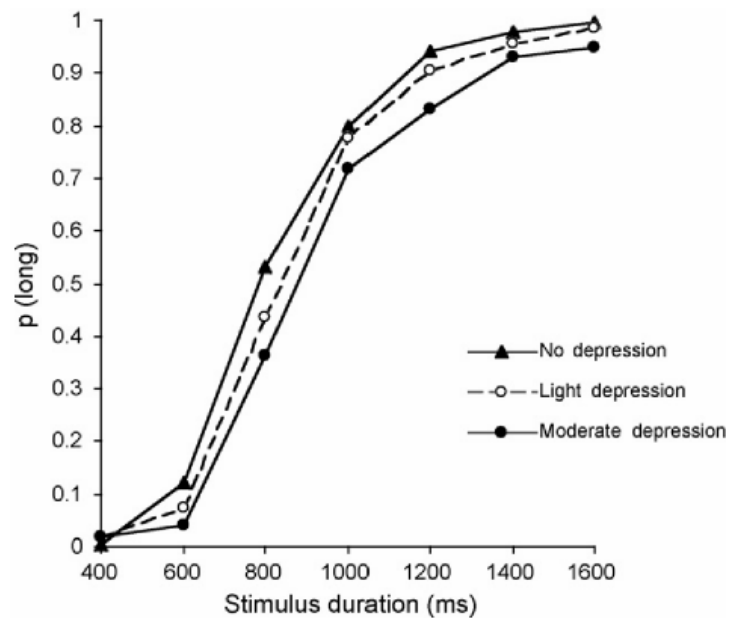


Figure 1. Proportion of long responses ($p(\text{long})$) plotted against stimulus duration for each depressive symptom group defined on the basis of the individual Beck Depression Inventory scores.

In addition, our results suggest that this temporal shortening effect was, in part, linked to the mood of sadness exhibited by the depressive participants. Indeed, the depression scores were positively correlated with the sadness scores ($r = 0.39, p < 0.05$), and negatively correlated with the happiness scores ($r = -0.24, p < 0.05$). Consequently, the higher the sadness scores were, the shorter the duration was judged to be ($r = -0.26, p < 0.05$) (see Fig. 2). Conversely, the higher the happiness scores were, the longer the duration was considered to be ($r = 0.31, p < 0.05$). Hierarchical regression analyses were conducted on the mean proportion of long responses on the basis of the depression and the sadness scores. The results of these analyses suggest that the sadness scores were one of the factors predicting the proportion of long responses in the present study ($p < 0.01$), although the total amount of variance explained by sadness was relatively low, i.e. 0.08 ($p < 0.01$). Indeed, when sadness was entered in the equation, the depression score was no longer a significant predictor ($p > 0.05$). This indicates that, in the present study, sadness mediated a part of the depression-related differences in the proportion of long responses.

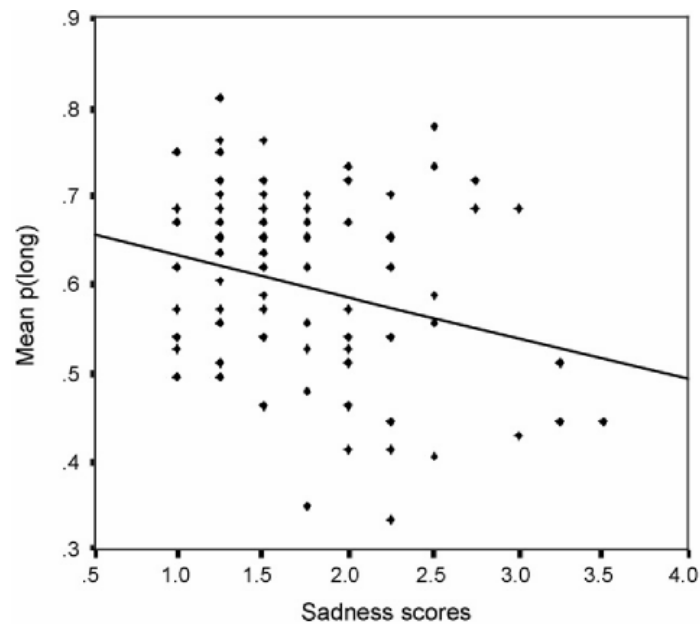


Figure 2. Correlation between mean $p(\text{long})$ responses and the sadness scores assessed by the Brief Mood Inventory Scale.

To further analyze the effect of depression on the bisection function, we calculated two indices which are commonly used in time perception studies: the bisection point (BP) and the Weber ratio (WR). The BP is the point of subjective equality, i.e. the probe duration at which “short” and “long” responses occur with equal frequency ($p(\text{long}) = 0.5$). The WR is the ratio between the Difference Limen, i.e. half the difference between the probe duration that gives rise to $p(\text{long}) = 0.75$ and that which gives rise to $p(\text{long}) = 0.25$, divided by the BP. It is an index of temporal sensitivity, i.e. the lower the WR is, the greater the sensitivity to time. These two indices were calculated on the basis of the slope and intercept resulting from a linear regression performed on the steepest part of each individual bisection function (for a more detailed explanation, see Wearden and Ferrara, 1996; Droit-Volet and Rattat, 2007; Santi et al., 2006). The mean BP and WR values for each depression group are shown in Table 2.

Table 2 - Bisection (BP) and Weber ratio (WR) for each depressive symptom group: nondepressive, mild and moderate depressive symptoms.

Group of depression	BP		WR	
	M	S.D.	M	S.D.
Non	833	120	0.23	0.06
Mild	901	131	0.24	0.07
Moderate	929	147	0.22	0.06

An ANOVA was run on both the BP and the WR with the depression group and the sex of the participants as between-subjects factors. In line with the results found for the proportion of long responses, there was a significant main effect of depression, $F(2,86) = 3.95$, $p < 0.05$, but neither a main effect of sex nor a depression by sex interaction. The pairwise depression group comparisons showed that the BP value was significantly greater for the moderate depression group than for the no depression group (Sheffe tests, $p < 0.05$), whereas the difference in the BP between the mild depression group and the other two depression groups did not reach significance. These results are consistent with those showing a significant correlation between the depression scores and the BP values ($r = 0.25$, $p < 0.05$). Thus, when the depression scores increased, the BP shifted toward the right, indicating that the subjective mid-point between the two anchor

durations was located at a longer signal duration value. The BP value was also significantly positively correlated with the sadness scores ($r = 0.25, p < 0.05$) and negatively correlated with the happiness scores ($r = -0.26, p < 0.05$), respectively. The hierarchical regression analyses on the BP, when the depression and the sadness scores were entered in the equation, revealed that the sadness scores were a significant predictor of the BP (variance in BP = 0.06, $p < 0.01$), with the depression score no longer being a significant predictor ($p > 0.05$). Consequently, in the present study, the sadness score was also a factor that mediated the depression-related difference in the rightward shifting of the BP.

As far as the WR is concerned, the ANOVA revealed neither a significant effect of depression, $F(2, 86) = 0.44, p > 0.05$, nor of any other factor (all $p > 0.05$). Similarly, there was no significant correlation between the individual depression scores and the WR values ($r = 0.03, p > 0.05$). Thus, the depression scores did not affect sensitivity to time. In line with these findings, the WR was not correlated with the sadness scores ($r = 0.009, p > 0.05$). However, the results revealed a significant positive correlation between the WR and the individual happiness scores ($r = 0.28, p < 0.05$). The happier the subjects felt, the lower their sensitivity to time appeared to be.

Our results indicate that there was a shortening effect as the intensity of the depressive symptoms increased and this would seem to be related to sadness-induced slowing down of the internal clock. However, this temporal shortening effect may be due to the fact that the internal clock runs more slowly in the depressive than in non-depressive participants (clock-rate hypothesis), as well as to an attention-related effect, with more attention being distracted away from the processing of time in the former than in the latter participants (attentional hypothesis). In both cases, fewer pulses are accumulated per unit of time and the duration is judged shorter. However, scalar timing theory (Gibbon, 1977; Gibbon et al., 1984) provides a mathematical model that allows us to distinguish between these two hypotheses (Buhusi and Meck, 2006; Burle and Casini, 2001; Droit-Volet and Wearden, 2002; Wearden et al., 2007). The clock rate effect should be manifested in the slope of the bisection function, with the clock effect being relatively larger for the long than for the shorter duration values. In contrast, the attentional effect should be manifested in the intercept of the bisection function and remain constant irrespective of the tested durations. As a first step in analyzing the hypothesis that the internal clock was slowed in the depressive group, we tested the effect of the depression factor on the proportion of long responses for the shorter stimulus durations (averaged values for the 400, 600 and 800 ms stimulus durations) and the longer stimulus durations (averaged values for the 1200, 1400 and 1600 ms stimulus durations). According to the attentional hypothesis, the depression effect should be significant for both the shorter and the longer stimulus durations. However, in line with the internal clock hypothesis, the results revealed a significant depression effect only for the longer stimulus durations (shorter stimulus durations, $F(2, 89) = 2.75, p = 0.07$; longer stimulus durations, $F(2, 89) = 7.13, p = 0.001$). As a second step, we used the individual slope and intercept values from the linear regression performed on the individual bisection functions and used t -tests to compare the no depression with the depression group (collapsed across the two depression groups). There were no differences in the intercept values between the two groups (138 vs. 127, $t(89) = 0.38, p = 0.71$), and the value of the slope tended to be significantly higher in the no depression (0.64) than in the depression group (0.62), $t(89) = 1.90, p = 0.059$. This result therefore also tends to support the clock-rate hypothesis.

The third step in our analysis of the clock hypothesis consisted of simulating our data using the modified difference model which was developed and adapted for human bisection performance by Wearden (1991) and has been employed by other authors since (Delgado and Droit-Volet, 2007; Droit-Volet and Izaute, 2008; Droit-Volet and Wearden, 2001; Droit-Volet et al., 2004b; McCormack et al., 1999). This model is described in full elsewhere (e.g. Wearden, 1991; Droit-Volet and Wearden, 2001; McCormack et al., 1999). In the present version of the model, there are four parameters, c , b , k and h . To simulate bisection performance, this model calculates two absolute (*abs*) differences: $abs D(s^*, t)$ and $abs D(l^*, t)$, where t is the probe duration, s the short and l the long standard duration. s^* and l^* are samples taken from the long-term memory of the short and the long standard durations. s^* and l^* differ from trial to trial and are taken from Gaussian distributions with means equal to the value of the short and the long standard duration and a coefficient of variation termed the c parameter. c is thus the coefficient of variation of the standard duration in memory. If the value of c decreases while the other parameter values are held constant, the

steepness of the bisection function increases as illustrated in Fig. 3, thus indicating a lower time sensitivity associated with a greater WR value.

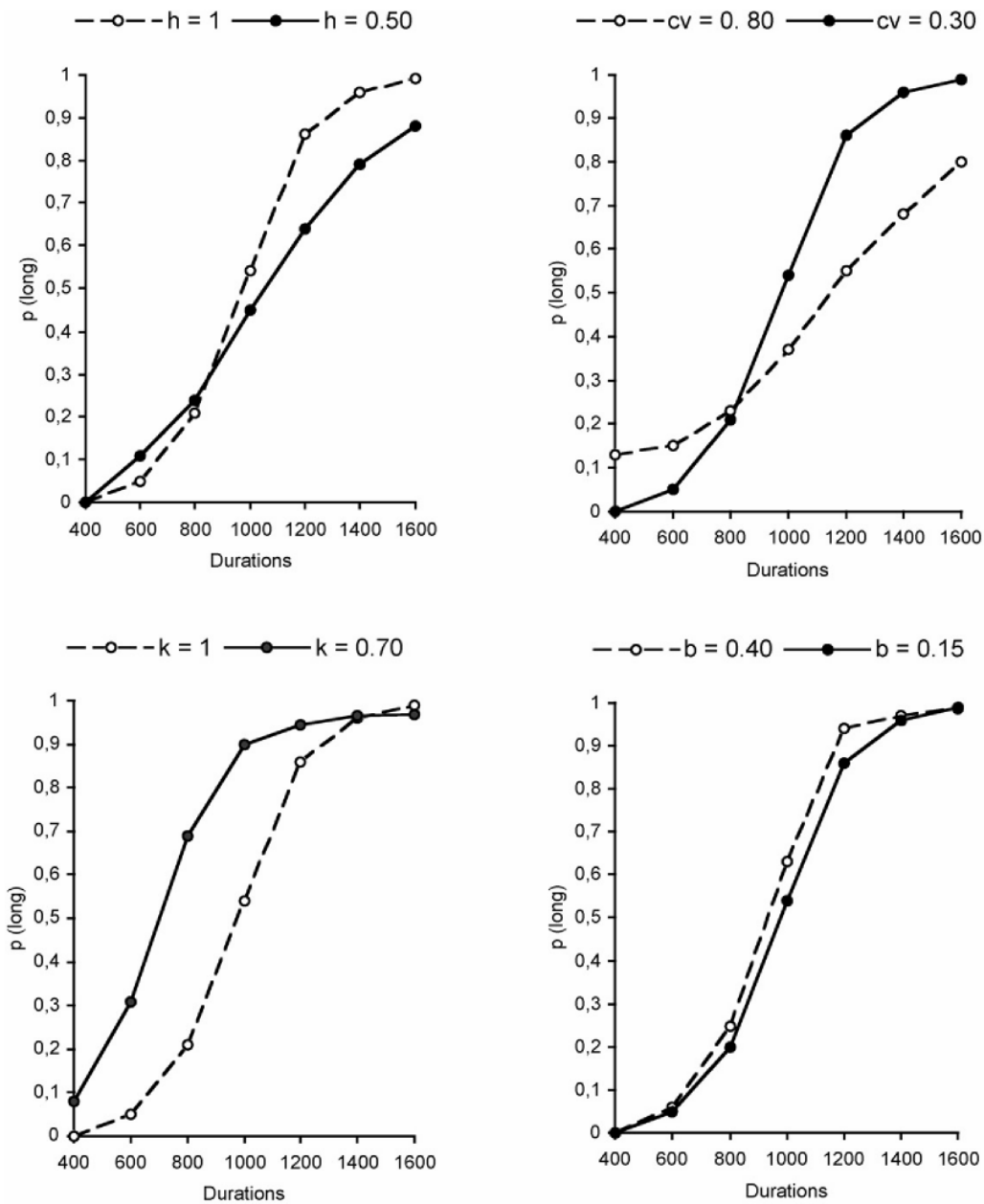


Figure 3. Data derived from simulations using the bisection model discussed in the text, with one parameter value varying while the other parameter values are held constant. Panel a, varying h (clock-rate parameter), panel b varying c (the coefficient of variation of the memory representation of the standard duration), panel c varying k (memory distortion of the standard duration) and panel d varying b (the decisional threshold).

If the difference between $D(s^*, t)$ and $D(l^*, t)$ is greater than a threshold value b , the model responds short or long depending on which of the differences between the standard duration and t is the smaller. If $D(s^*, t) < D(l^*, t)$, it responds “short”, and if $D(s^*, t) > D(l^*, t)$, it responds “long”. However, when the difference between the intervals separating t from the anchor durations is smaller than the threshold value, that is to say when the model cannot tell whether t is closer to the short or the long standard duration, it responds “long”. The b parameter thus acts as a kind

of decisional bias in favor of “long” responses, i.e. the default response in ambiguous cases. To account for the psychophysical functions obtained, we added two other parameters: k and h . k has been already used by McCormack et al. (1999). This parameter acts as a multiplier of the standard duration. If k is less than 1.0, the standard durations are remembered as shorter than they really are. This shifts the bisection point toward the left. h , the clock parameter, acts also as a multiplier, but in this case for both the standard and the comparison durations. An h value smaller than 1.0 indicates that the clock is running more slowly, thus shifting the bisection function toward the right and is thus consistent with the slope effect described above but not with the intercept effect.

Table 3 - Parameter values derived from fits of the model with the bisection functions.

	c	b	k	h	MAD
No depression	0.25	0.20	0.95	1.00	0.024
Moderate depression	0.25	0.20	0.90	0.68	0.027

Note: c is the coefficient of variation of the standard duration in memory, b the decisional bias, k the memory distortion of the standard duration, and h the multiplier factor (clock parameter) for all the durations. MAD is the mean absolute deviation, i.e. the sum of the absolute differences between the data point and the fitted function divided by 7, the number of data points.

The model described above was implemented in a program written in Visual Basic 4, and the experimental conditions were simulated using 10,000 trials. Table 3 shows the parameter values obtained from the model fits in the form of their respective mean absolute deviations (MAD), i.e. the sum of the absolute deviation between the data and the modeling data, divided by the seven probe durations. Fig. 4 shows the fits of the model with the data for the no depression and the moderate depression group. The model fitted our data very well, with the mean absolute deviations being smaller than 0.03. The model found approximately the same c and b parameters values as those obtained in the other bisection studies (Delgado and Droit-Volet, 2007; Droit-Volet et al., 2004b; Droit-Volet and Wearden, 2001; Rattat and Droit-Volet, 2001). However, as in McCormack et al.’s (1999) study, the k value appeared to be smaller than 1.0, thus indicating a shortening effect for the standard duration stored in memory. This shortening effect on the memory representation of standard durations did not appear to be any greater in the depression group than in the no depression group. In addition, and more interestingly here, the h parameter value was smaller for the depression than for the no depression group. To summarize, our model suggests that the clock rate was slower for the individuals suffering from depression, thus explaining their temporal underestimation in a bisection task.

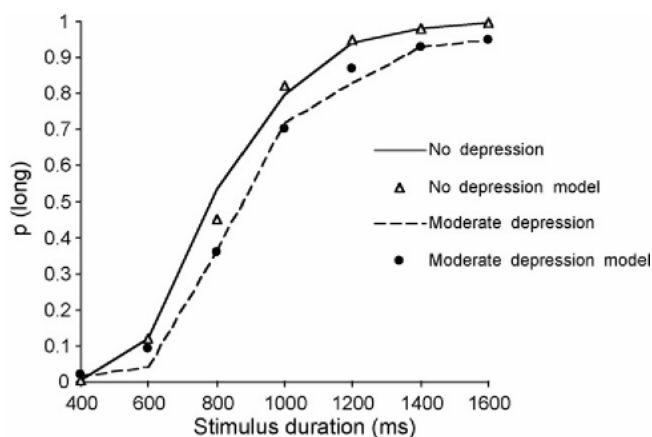


Figure 4. Lines without symbols indicate bisection functions from the moderate depression and the non-depression group (plotted as in Fig. 1). Unconnected symbols indicate the best fitting functions derived from the bisection model.

DISCUSSION

Our experiment using a bisection task with short durations (<2 s) showed that sensitivity to time was similar in the depressive and non-depressive participants, as indicated by the fact that these two groups of participants exhibited the same Weber ratio value. The depressive participants were thus able to discriminate time as well as the non-depressive participants. Despite having the same sensitivity to time, the former were characterized by a rightward shift of bisection function and a high bisection point value when compared to the latter, thus indicating that the depressive participants judged time to be relatively shorter. Furthermore, the correlation analyses revealed that the more the depression scores increased, the shorter the signal duration was judged to be. These results are consistent with those obtained in studies which have revealed an underestimation of time in participants with a depressive pathology (Bschor et al., 2004; Kuhs et al., 1991; Tysk, 1984).

As reported in Section 2, the use of not one but several sets of time anchors might perhaps have allowed us to better dissociate the mechanisms (attention vs. clock speed) underlying time bisection performance. However, (1) the fact that the durations used in the present study (<2 s) did not favor attentional processing, (2) our model with a clock-related multiplier factor (h parameter) assigned to each perceived comparison duration, and (3) our analyses of both the shorter–longer stimulus duration differences and the slope of the bisection function, all suggest that this temporal shortening effect in depression would be due to the speed of the internal clock which ran more slowly in our depressive participants. As stated in the introduction, depressed individuals feel that time passes more slowly than normal. Finally, our results suggest that this awareness of the slowing down of the passage of time might be based on a physiological reality, namely a slowing down of the internal clock. In line with this idea, Blewett (1992) revealed a positive correlation between the subjective impression of the slow passage of time and psychomotor retardation scores. Thus, the feeling that time is passing slowly may be based on an awareness of the slowing down of the internal clock and/or an awareness of changes in the rhythm of executive functions in comparison with time in the outside world. Finally, performance in time perception tasks might be a good indicator of a slowing down of mental functions. Recently, Rammsayer and Brandler (2007) reintroduced the notion of a master clock responsible for the coordination of various neural activities. Thus, the internal clock speed would be an index of information processing speed (Eagleman et al., 2005; Rammsayer and Brandler, 2007). However, a clock-based hypothesis does not allow us to exclude the possibility that attention might play a critical role in temporal differences between the time judgments made by depressive and non-depressive individuals since the clock and the attention hypotheses are not mutually exclusive. Moreover, the speed of the clock may also affect attentional capacities. Future investigation, and in particular studies using long anchor durations, will be required to test the role of attention in temporal differences between depressive and non-depressive people.

Given that the internal clock might run more slowly than normal in depression and the durations were judged to be shorter, the question that now needs to be addressed is: Why does the internal clock slow down in depressive individuals? Some researchers have related the slow speed of the internal clock in depression to a general retardation in motor behavior, in terms of the planning, preparation and execution of movement (Lemke et al., 2000). According to Alexander et al. (1986) study, depression is associated with an alteration of the structures in the basal ganglia involved in motor functioning. Brain imagining studies have suggested that the basal ganglia also play a primary role in time perception (Buhusi and Meck, 2005; Matell and Meck, 2004). For example, patients with Parkinson's disease suffering from damage in the substantia nigra which reduces levels of the neurotransmitter dopamine in the striatum (Cools et al., 2002; Jovoy-Agid and Agid, 1980; Tessitore et al., 2002) have problems in time perception (Harrington et al., 1998; Riesen and Schnider, 2001). Moreover, Parkinson's disease patient and depressive patients both exhibit the same depressive symptoms and retardation of motor activity (Bermanzohn and Siris, 1992; Merschedorf et al., 2003). In addition, antidepressant drugs act on dopamine receptors in the brain which have been identified as playing a critical role in depression (Dailly et al., 2004; Willner et al., 2005).

Closely linked to psychomotor retardation, the slowing down of the internal clock in depression may be also due to a decrease in levels of arousal. According to the DSM-IV criteria, one major symptom of depression is fatigue, or a low level of energy every day, coupled with a depressive mood dominated by sadness. Our data is consistent with this

description in revealing a correlation between the time estimates and the sadness scores as assessed by the BMIS: the higher the sadness scores were, the shorter the time was judged to be. Our regression analyses suggested that sadness is one of the factors that helps account for the effect of depression scores on time judgments. However, the amount of variance in time bisection that was explained by sadness was relatively low, thus suggesting that other factors were also involved in the difference in time perception between our depressive and non-depressive participants. Indeed, depression cannot be reduced to the feeling of sadness (Izard, 1991). Furthermore, as Izard (1991) and Lazarus (1991) explain, the relationships between sadness and levels of arousal are complex and depend on the motivational states elicited in a specific context. For example, the level of arousal may increase rather than decrease when an individual perceives sadness in another individual. Indeed, the perception of another person's sadness increases the observer's motivation to understand and solve this distress, while in the latter, one makes a great effort to struggle against this discomfort. This is consistent with results obtained concerning the effect of the perception of emotional faces on time perception. Droit-Volet et al. (2004a) and Gil and Droit-Volet (submitted for publication) showed that the brief (between 400 and 1600 ms) presentation of faces expressing sadness produced an overestimation of the presentation duration of these faces compared to neutral faces, due to an increase in the level of arousal (Droit-Volet and Meck, 2007). However, a prolonged and intense state of sadness, such as in depression, may result in resignation rather than a desire to fight. Depressed individuals feel helplessness and hopelessness and become disengaged from life. This explains why depression induces a slowing down in psychomotor functioning. Thus, the affective state of sadness in depressive individuals affects their time perception in such a way that they experience time as passing slowly.

To summarize, in line with the literature on depression and on the basis of the present results, we are entitled to suggest that a slowing down of the internal clock explains the differences in the perception of short durations between depressive and nondepressive individuals. However, future studies will need to identify whether other related cognitive mechanisms may also contribute to time distortions in depression, and this for different range of durations, i.e. shorter or longer than 2s. A new question that needs to be addressed concerns the relationship between the rhythm of our internal clock and our cognitive capacities.

ACKNOWLEDGEMENT

This research was supported by Grant ANR07-NEURO-048 from the Minister of Research in France.

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