Improving time discrimination in children and adults in a temporal bisection task: The effects of feedback and no forced choice on decision and memory processes

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In children aged 5 and 8 years old as well as in adults, Experiment 1 tested the effect of feedback on temporal performance using a bisection task. Experiment 2 added a no-forced-choice condition by giving the participants the possibility of responding “I don’t know”. The results of Experiment 1 showed that providing feedback increased the bisection point value (point of subjective equality) in all age groups and increased sensitivity to time in the youngest children. The results of Experiment 2 showed that the proportion of “I don’t know” responses peaked at the probe duration close to the arithmetic mean of the two anchor durations and decreased as the distance from this central value increased in both the adults and the 8-year-olds. In the 5-year-olds, the proportion of “I don’t know” responses was lower and remained constant whatever the probe duration values. Unlike in the youngest children, giving the adults and the 8-year-olds the opportunity to respond “I don’t know” increased their sensitivity to time. The modelling of our data suggests that providing feedback in a temporal bisection task affects both the memory and the decision processes. However, whereas the feedback-related effect had a similar effect on decision processes across the age groups, it had an opposite effect on memory processes in the 5-year-olds and the older participants, decreasing the variability of the memory representation of the anchor durations in the former while increasing it in the latter. Finally, in bisection, feedback only improved temporal performance when the memory for duration was imprecise as in the case of the children.

Keywords: Time; Bisection; Decision; Feedback; Memory; Children.

In order to understand similarities and differences in time judgements between animals and humans, studies of both human adults and children have made use of a temporal categorization task that is currently used with animals—namely, the temporal bisection task. In this task, participants are forced to categorize probe durations (t) as more similar to a short (S) or to a long (L) anchor duration, although some of the durations are of an intermediate value. However, only a few studies have investigated the

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sensitivity of temporal judgement to decision strategies used by humans that may change with the experimental conditions. The purpose of the present study was to investigate the effect of feedback (Experiment 1) and no forced choice between S and L (Experiment 2) and to model the data thus obtained in order to identify their effect on decisional and memory processes.

The temporal bisection task has revealed orderly psychophysical functions, with a proportion of long responses (i.e., t judged as more similar to L than to S) that increases with the probe duration values, both in animals (e.g., Cheng, Etchegaray, & Meck, 2007; Church & Deluty, 1977; Maricq, Roberts, & Church, 1981; Santi, Keough, Gagne, & Van Rooyen, 2007; Santi, Miki, Hornyak, & Eidse, 2006) and in human adults (e.g., Allan, 2002; Allan & Gibbon, 1991; Brown, McCormack, Smith, & Stewart, 2005; Melgire et al., 2005; Penney, Gibbon, & Meck, 2000; Smith, Harper, Gittings, & Abernethy, 2007; Wearden, 1991; Wearden, Todd, & Jones, 2006). However, different experimental conditions have been used to obtain such orderly bisection functions depending on whether the studies involved animals or human adults. Several preliminary sessions of training with the two anchor durations are required for animals, whereas only a short period of familiarization with these two durations (of 2 or 5 presentations) is necessary in the case of human adults. Furthermore, recent studies of human adults, which have compared the bisection performance obtained with (similarity task) and without (partition task) the presentation of the anchor durations (Droit-Volet & Rattat, 2007; Wearden & Bray, 2001; Wearden & Ferrara, 1995), have found similar data in these two bisection tasks, with the same bisection point—BP; point of subjective equality, the probe duration giving rise to p(long) = .50—and the same Weber ratio (WR).

As described below, the WR acts as an index of the steepness of the bisection function and thus as an index of time sensitivity. Consequently, a direct comparison of the probe duration and the standard duration is not necessary for temporal bisection to occur (Allan, 2002; Allan & Gerhard, 2001; Rodriguez-Girones & Kacelnik, 1995; Wearden & Bray, 2001). Thus, in human adults, the initial presentation of the anchor durations in a bisection task does not result in any improvement in temporal sensitivity.

In developmental studies, temporal bisection tasks similar to those used in human adults have been employed in order to identify age-related differences in temporal performance in similar across-age conditions. As in the bisection procedure used in adults, McCormack, Brown, Maylor, Darby, and Green (1999) and Droit-Volet and Rattat (2007) presented each anchor duration five times before the bisection test. In other studies, Droit-Volet and her colleagues trained young children to discriminate the short from the long anchor durations by giving them feedback on a series of blocks of 8 trials each (4 for the short and 4 for the long anchor duration) and tested the children only when they obtained more than 75% of correct responses on one trial block. Nevertheless, as of the age of 5 years, the number of training trials required to discriminate correctly between S and L appears to be relatively small. In these studies, when the S–L difference was large (e.g., 0.5 vs. 2 s; 1 vs. 4 s; 2 vs. 8 s; 3 vs. 6 s), the majority of the 5-year-olds did not produce any incorrect responses as of the first block of training trials (Droit-Volet, 2003, 2008; Droit-Volet, Clement, & Fayol, 2008; Droit-Volet, Meck, & Penney, 2007; Droit-Volet & Wearden, 2001; Rattat & Droit-Volet, 2001, 2005). When the S–L difference was smaller (i.e., 0.20 vs. 0.80 s; 0.40 vs. 1.5 s), the 5-year-olds required more training blocks than the older children, but the mean number of training blocks remained relatively low (<3 blocks; Droit-Volet, Tourret, & Wearden, 2004; Droit-Volet & Wearden, 2002). Nevertheless, whatever the extent of pretraining with the anchor durations, the psychophysical functions obtained in the bisection test were always flatter in the 5-year-olds than in the older children, with a significantly higher WR indicating a lower sensitivity to time in the younger children.

Recently, Droit-Volet and Rattat (2007) compared children’s temporal performance in the
partition and the similarity bisection tasks. They found that the presentation of anchor durations prior to the bisection test improved temporal performance in the children (although to a lesser extent in the 8-year-olds than in the 5-year-olds), but not in the adults. The authors therefore suggested that, unlike adults, children find it more difficult to set a bisection criterion if they have no representation of the anchor durations in reference memory. However, in the bisection task used until now, no feedback is given to the children during the phase testing for identification of the anchor durations. We may thus suppose that in the absence of feedback, young children tend to forget the anchor durations during the course of the testing phase. Furthermore, as no feedback is given, probe duration values close to the anchor durations that give rise to S or L responses could also be integrated in the memory representation of the anchor durations. This might increase the variability of children's memory representation of the anchor durations, consequently flattening their bisection functions and increasing the WR values. Although they also respond S or L for these durations close to the anchor durations, adults would not integrate these durations in memory because they are more confident about their identification of the short or the long anchor duration. Some studies that have used the bisection task in adults have not provided any feedback (e.g., Allan, 2002; Smith et al., 2007; Wearden, 1991, Wearden et al., 2006) whereas others have provided feedback for the anchor durations (e.g., Allan & Gibbon, 1991, Exp. 1; Melgire et al., 2005; Penney et al., 2000). However, none of them has investigated the effect on temporal bisection performance of providing feedback to participants. The purpose of Experiment 1 was thus first to test the effect of feedback on bisection performance in children and adults and then to model the data obtained using a bisection model (described below) in order to try to identify the mechanisms underlying the feedback-related effects.

The effect of feedback on time judgement has not been investigated per se in a temporal bisection task. However, it has been tested in human adults in a temporal reproduction and a temporal production task (Fransen & Vandierendonck, 2002; Montare, 1985, 1988; Ryan & Fritz, 2007; Ryan & Robey, 2002) and in a temporal estimation task (Wearden & Farrar, 2006). Droit-Volet and Izaute (2005) have also tested the effect of feedback in children and adults in a temporal generalization task in which the participants had to judge whether a probe duration was or was not the same as a standard duration. Wearden and Farrar (2006) found no effect of feedback, either on the mean estimates or on the coefficient of variation of these estimates. The feedback simply reduced the interindividual deviation of the estimates from the mean. In contrast, other studies have shown that feedback improves mean accuracy and reduces the variability of time estimates and does so to a greater extent in children than in adults. Consistently with Fransen and Vandierendonck's (2002) findings, the modelling of Droit-Volet and Izaute's data suggests that providing feedback reduces the variability of the memory representation of the standard duration in the temporal generalization task, and this in all age groups, although this effect is more pronounced in young children. However, the effect of feedback depends on the demands of the task used (Ryan & Fritz, 2007). Unlike in the temporal generalization task or the reproduction task, in the bisection task, adults are able to accurately bisect the stimulus durations even if the standard durations are presented only a few times or not at all (e.g., Allan, 2002; Allan & Gerhard, 2001; Wearden & Bray, 2001). This suggests that, as the standard durations are accurately processed by the adults and represented in reference memory, there is little to correct. Consequently, it is likely that providing feedback does not improve bisection performance in adults. However, as discussed above, young children's processing of durations is "fuzzier", and they consequently experience difficulties in identifying a bisection point (Droit-Volet & Rattat, 2007). We may therefore imagine that, unlike in the case of adults, providing children with feedback will improve their time sensitivity by making their memory representation of the anchor durations more precise.
EXPERIMENT 1

Method

Participants
The sample consisted of 120 participants: 40 five-year-olds (21 girls and 19 boys; mean age = 5.09 years, SD = 0.33), 40 eight-year-olds (22 girls and 18 boys; mean age = 8.19 years, SD = 0.27), and 40 adults (28 females and 12 males; mean age = 20 years, SD = 1.95). The children came from nursery and primary schools, and the adults were psychology students, all in Clermont-Ferrand, France.

Materials
The participants were seated in a quiet room in front of a Power Macintosh microcomputer. The experimental program was written using PsyScope. The stimulus to be timed was an auditory signal (500 Hz, 70 dB) generated by the computer’s internal speaker. The participants responded to the stimulus by pressing one of two keys (“d” and “k”) on the computer keyboard. The feedback was the face of a smiling (correct response) or a frowning clown (incorrect response) displayed for 2 s in the centre of the computer screen.

Procedure
In each age group, the participants were randomly assigned either to the feedback or to the no feedback duration group. In each group, each participant completed a bisection task consisting of a training phase with short and long anchor durations (0.15 and 1.05 s) and a testing phase with seven probe durations—namely, the two anchor durations and five intermediate durations (0.3, 0.45, 0.6, 0.75, 0.9 s).

The participants were presented with the short and the long anchor durations and were trained on 8 trials (4 for each anchor duration) to press one button to indicate that the stimulus corresponded to the short anchor duration and the other button to indicate the long anchor duration. The button-to-response assignment was counterbalanced. The participants were then told that they would hear stimulus durations and would have to judge whether the stimulus was more similar to the short or to the long anchor duration. The participants were tested on 10 blocks of 11 trials each—that is, 3 trials for the short anchor duration, 3 trials for the long anchor duration, and a trial for each of the five intermediate durations. The trials were presented in a random order, and the intertrial interval was a randomly selected interval between 1 and 3 s. In addition, in the feedback (FB) group, the response for each anchor duration was followed by feedback. A correct response resulted in the appearance of the smiling clown and an incorrect one in that of the frowning clown.

Results and discussion

Statistical analyses of the data
Figure 1 illustrates the bisection function that plots the mean proportion of long responses, $p(\text{long})$, against the probe durations for the 5- and the 8-year-olds and the adults. Figure 1 clearly suggests that providing feedback in the bisection session shifted the bisection function towards the right for the intermediate probe durations in such a way that the bisection point (BP) was close to the arithmetic mean of the two anchor durations. To investigate the bisection performance, we performed an analysis of variance (ANOVA) on three indexes: (a) the proportion of long responses, (b) the BP, and (c) the Weber ratio (WR). The BP is an index of the location of the bisection criterion—that is, the stimulus duration at which the $S$ and $L$ responses occur with equal frequency, $p(\text{long}) = .5$. The WR is the ratio between the difference limen (half the distance between the stimulus duration that results in .25 and .75 long responses) and the BP. It is a measure of temporal sensitivity. The smaller the Weber ratio, the steeper the slope of the bisection function and the higher the temporal sensitivity. The BP and the WR were calculated on the basis of the slope and intercept of the linear regression for the steepest part of the individual bisection function (for more details, see Droit-Volet & Wearden, 2001). The linear regression was not significant for one 5-year-old in the no-feedback (no-FB) condition. This
child was therefore excluded for the analyses conducted on the BP and the WR (see Table 1). In the other participants, all the regressions produced $r^2$ values of at least .95, or between .85 and .95 in the case of 6 participants (all aged 5 years) in the no-FB condition and 5 in the FB condition (3 aged 5 years and 2 aged 8 years).

Proportion of long responses. The overall ANOVA\(^1\) on the proportion of long responses with probe duration as a within-subject factor and age and feedback (no-FB vs. FB) as between-subject factors revealed a significant main effect of probe duration, $F(6, 684) = 627.27, p < .0001$, as well as a significant Probe Duration $\times$ Age interaction, $F(12, 684) = 7.32, p < .0001$, while the main effect of age was not significant, $F(2, 114) = 2.29, p = .11$. This is consistent with the results of studies in children showing that the slope of the bisection function increases with age, thus indicating an age-related improvement in sensitivity to time. Indeed, when we compared each age group, the ANOVAs revealed a significant Stimulus $\times$ Age interaction—5 versus 8, $F(6, 468) = 4.8$; 8 versus adults, $F(6, 468) = 3.45$; 5 versus adults, $F(6, 468) = 10.67$ (all $p$s < .002)—with a systematic effect of probe duration—$F(6, 468) = 340.45, 418.09, 345.07$, respectively (all $p$s < .0001)—and no effect of age (all $p$s > .05).

In addition, there was a significant main effect of feedback, $F(1, 114) = 22.85, p < .0001$, and a significant Feedback $\times$ Probe Duration interaction, $F(6, 684) = 11.30, p < .0001$. There were no other significant interactions involving the feedback factor: Age $\times$ Feedback, $F(2, 114) = 0.40, p = .67$; Age $\times$ Stimulus $\times$ Feedback, $F(12, 684) = 1.07, p = .43$. The Feedback $\times$ Probe Duration interaction was due to the FB/no-FB difference that was significant for the intermediate probe durations close to the bisection point—0.3 s, $t(118) = 2.12, p < .04$; 0.45 s, $t(118) = 4.35, p < .0001$; 0.6 s, $t(118) = 4.84, p < .0001$; 0.75 s, $t(118) = 3.49, p < .0001$—but not for the two shorter stimulus durations—0.15 s, $t(118) = 1.50, p = .14$; 1.05 s, $t(118) = 0.08, p = .94$—or the long anchor duration—0.9 s, $t(118) = 1.87, p = .06$—although in the latter case it just failed to reach significance. Therefore, providing the participants with feedback in a bisection test decreased the proportion of long

\(^{1}\) The ANOVAs showed neither an effect of sex nor an effect of button-press order, nor any interaction involving these factors.
responses for the intermediate probe duration values, and this to the same extent in all the age groups.

**Bisection point.** The results of the statistical analyses on the BP are consistent with the data showing that the proportion of long responses decreased for the intermediate duration values when feedback was provided. Indeed, the ANOVA on the BP indicated neither a main effect of age, \( F(2, 113) = 1.08, p = .34 \), nor an interaction between age and feedback, \( F(2, 113) = 0.23, p = .79 \), but a significant main effect of feedback, \( F(1, 113) = 19.64, p < .0001 \). Therefore, in each age group, the provision of feedback to the participants during the bisection test increased the BP value (no-FB: 469; FB: 586) in such a way that it shifted from a value closer to the geometric mean (397) to a value closer to the arithmetic mean of the two anchor durations (600).

**Weber ratio.** The ANOVA on the WR also showed a main effect of feedback, \( F(1, 113) = 10.41, p < .002 \). Therefore, providing FB to children did not eliminate the difference between children’s and adults’ sensitivity to time in a bisection task. However, our study demonstrates that FB decreases this age-related difference in time sensitivity. Indeed, in the no-FB condition, the WR was higher in the 5-year-olds than in either the 8-year-olds or the adults (Tukey tests, both \( ps < .01 \)), while the WR value was the same for the 8-year-olds and for the adults (\( p = .35 \)). In contrast, in the FB condition, the WR value was similar both for the 5-year-olds and the 8-year-olds and for the 8-year-olds and the adults (all \( ps > .05 \)). It was only between the two extreme age groups (5-year-olds and adults) that the WR values differed significantly, being higher for the youngest age group (\( p < .04 \)). For each age group taken separately, the one-way ANOVA conducted on the WR revealed no effect of feedback in either the 8-year-olds or the adults, \( F(1, 38) = 1.01, F(1, 38) = 1.11 \), respectively (both \( ps > .30 \)). It was only in the youngest age group that FB improved sensitivity to time, with the WR being lower in the FB (0.26) than in the no-FB (0.46) condition, \( F(1, 37) = 8.31, p < .007 \). Furthermore, as indicated the standard deviation of the WR, Table 1, the FB reduced the interindividual variability that was particularly high in the no-FB condition for the 5-year-olds.

**Modelling of the data**

Experiment 1 showed that providing feedback resulted in a shift of the BP toward the right for

### Table 1. The mean and standard deviation of individual bisection points and of individual Weber ratios in the no-feedback and the feedback group for the 5-year-olds, the 8-year-olds, and the adults

<table>
<thead>
<tr>
<th>Age</th>
<th>BP (M)</th>
<th>BP (SD)</th>
<th>WR (M)</th>
<th>WR (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No-FB</td>
<td>FB</td>
<td>No-FB</td>
<td>FB</td>
</tr>
<tr>
<td>5 years</td>
<td>473</td>
<td>151</td>
<td>0.46</td>
<td>0.27</td>
</tr>
<tr>
<td>8 years</td>
<td>495</td>
<td>128</td>
<td>0.27</td>
<td>0.09</td>
</tr>
<tr>
<td>Adults</td>
<td>439</td>
<td>107</td>
<td>0.19</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Note: BP = bisection point. WR = Weber ratio. No-FB = no feedback group. FB = feedback group.

Geometric mean = 397. Arithmetic mean = 600.

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all the age groups, but that it only significantly improved sensitivity to time in the youngest children. As suggested by both Fransen and Vandierendonck (2002) and Ryan and Fritz (2007), the feedback may affect the reference memory of duration and the decision-making processes. To attempt to identify the role of feedback on these mechanisms in time bisection, we used the developmental version of Wearden’s (1991) modified difference model (MDM; Droit-Volet & Wearden, 2001). 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 anchor duration, and $l$ the long anchor duration; $s^*$ and $l^*$ are samples drawn from the long-term memory of the short and the long anchor durations; $s^*$ and $l^*$ differ from trial to trial and are taken from Gaussian distributions with means equal to the values of the short and the long anchor duration and a coefficient of variation, $c$. $c$ is the “reference memory” parameter of the model. The greater the $c$ parameter value, the “fuzzier” the memory of the anchor durations is. As shown in Droit-Volet and Wearden’s study (2001), increasing the value of $c$ flattens the slope of the bisection function, thus indicating a lower sensitivity to time.

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 anchor 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 anchor duration—it responds “long”. The value $b$ thus acts as a kind of decisional bias in favour of “long” responses—that is, the default response in ambiguous cases. When the value of $b$ is close to zero, the bisection point is located at the arithmetic mean of the short and long anchor durations. When the value of $b$ is larger, the bisection point shifts leftwards and closer to the geometric mean of the two anchor durations; $b$ is the “decision” parameter of the model. In the developmental version of the MDM, there is a third parameter—namely, the $p$ parameter. The $p$ parameter is the probability of producing a response at random without regard to probe duration—that is, the proportion of short and long responses are equal for each probe duration.

The model was implemented in a program written in Visual Basic 6, and the experimental conditions were simulated with 1,000 trials that made use of each probe duration. The three parameters were varied over a wide range of values until the smallest mean absolute deviation between the simulated data and mean data, those shown in Figure 1. The parameter values derived from the optimal fits of the model are shown in Table 2. The models found developmental trends consistent with those identified in other bisection studies (Droit-Volet & Clément, 2005; Droit-Volet et al., 2007; Droit-Volet et al., 2004; Droit-Volet & Wearden, 2001). Indeed, the value of the $c$ parameter decreased with age, although this value appeared to be very similar in the 8-year-olds and the adults. This suggests that the memory representation of the anchor durations is probably fuzzier in the young children, thus explaining their lower sensitivity to time (for a more detailed interpretation, see the General Discussion). The $p$ parameter value also appeared to be greater in the 5-year-olds than in the older participants. The probability of random responses was approximately .10 in the 5-year-olds, whereas it was close to zero in both the 8-year-olds and the adults. Furthermore, and more interestingly here, we found that the differences in both the $c$ and the $p$ parameters between the 5-year-olds and the older participants persisted irrespectively of the experimental conditions. Thus, in spite of the feedback that improved the young children’s sensitivity to time, the age-related difference in temporal sensitivity persisted.

Our model is also able to account for the effect of feedback on our data. It suggests that providing FB reduces the value of the $b$ parameter at similar levels in all age groups. Thus, feedback would seem to reduce the level of bias toward long responses by reducing the number of ambiguous cases.
This explains why the BP shifts from a value close to the geometric mean to a value closer to the arithmetic mean of the two anchor durations. Our model also suggests that feedback affects the memory representation of the anchor duration. However, the effect operates in opposite directions depending on the age group in question. In both the 8-year-olds and the adults in our study, feedback increased the noise in the memory representation of the anchor duration rather than decreasing it, as the feedback-related increase in the value of the $c$ parameter might suggest. Unlike in the 8-year-olds and the adults, in the 5-year-olds, the feedback reduced the variability in the memory representation of the anchor durations.

Our model suggests that providing feedback during the course of the testing in a bisection task might have affected not only the decision processes, but also the memory representation of the two anchor durations by decreasing and increasing its variability in the 5-year-olds and the older participants, respectively. This opposite effect of feedback on the memory representation of durations as a function of age group is discussed in more detail later. However, as suggested in the introduction, the adults in our study had a good memory representation of the anchor duration or did not need it to bisect probe durations. Consequently, for these adults, providing feedback during the testing for the anchor durations but not for the other probe durations close to the anchor duration (even though they were nevertheless forced to judge these probe durations as being similar to the short or the long anchor duration) increased rather than decreased the variability of their memory representation of the anchor durations.

It is therefore possible that forcing the participants to judge a probe duration as similar to $S$ or $L$ when they have doubts about this similarity is the cause of this increased noise in the representation of duration in reference memory. We therefore decided to run a second experiment in which the participants were not forced to choose between short and long. In Experiment 2, we used the same experimental conditions with feedback as in Experiment 1 but additionally allowed the participants to respond “I don’t know”. We assumed that the temporal performance would be better with than without the “I don’t know” responses, because the possibility of producing this response would reduce the variability of the representation of the anchor duration in memory.

<table>
<thead>
<tr>
<th>Age</th>
<th>Experiment</th>
<th>Condition</th>
<th>$c$</th>
<th>$b$</th>
<th>$p$</th>
<th>MAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 years</td>
<td>1</td>
<td>No-FB</td>
<td>.55</td>
<td>.30</td>
<td>.12</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FB</td>
<td>.50</td>
<td>.01</td>
<td>.12</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>FB</td>
<td>.50</td>
<td>.01</td>
<td>.12</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“I don’t know”</td>
<td>.49</td>
<td>.10</td>
<td>.12</td>
<td>0.02</td>
</tr>
<tr>
<td>8 years</td>
<td>1</td>
<td>No-FB</td>
<td>.30</td>
<td>.22</td>
<td>.03</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FB</td>
<td>.37</td>
<td>.01</td>
<td>.02</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>FB</td>
<td>.37</td>
<td>.01</td>
<td>.02</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“I don’t know”</td>
<td>.30</td>
<td>.01</td>
<td>.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Adults</td>
<td>1</td>
<td>No-FB</td>
<td>.26</td>
<td>.33</td>
<td>.00</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FB</td>
<td>.33</td>
<td>.09</td>
<td>.00</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>FB</td>
<td>.33</td>
<td>.09</td>
<td>.00</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“I don’t know”</td>
<td>.27</td>
<td>.00</td>
<td>.00</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Note: No-FB vs. FB = conditions without or with feedback. FB vs. FB “I don’t know” = conditions with feedback but without or with an additional “I don’t know” response. $c$ is the coefficient of variation of the memory representation of the short and long anchor duration; $b$ is the bias toward the long responses; $p$ is the probability of random responding. MAD is the mean absolute deviation: the sum of the absolute differences between the data points and the fitted functions divided by 7—that is, the number of data points.
EXPERIMENT 2

Method

Participants
A total of 141 participants were recruited subject to the same conditions as in Experiment 1: 49 five-year-olds (24 girls and 25 boys; mean age = 5.05 years, SD = 0.40), 50 eight-year-olds (30 girls and 20 boys; mean age = 8.15 years, SD = 0.26), and 42 psychology students from Clermont-Ferrand University (32 females and 10 males; mean age = 19.66 years, SD = 1.71).

Materials and procedure
The material was the same as that used in Experiment 1, except for the “I don’t know” condition in which there was an additional button-press for the “I don’t know” response—that is, “y” key on the computer keyboard. The procedure used was similar to that used in the feedback condition in Experiment 1. However, in the present study, in each age group, the participants were assigned to either the feedback condition (FB), equivalent to that used in Experiment 1, or the “feedback I don’t know” condition (FB “I don’t know”). In this latter condition, the participants performed the same bisection task as that in the FB condition. However, they were additionally told that when they did not know whether the stimulus duration was more similar to the short or to the long anchor duration, they had to press on the “I don’t know” button and not on the “short” or the “long” button. Different stickers on the keyboard allowed the participants to locate each button-response quickly and easily.

Results and discussion

Statistical analyses of the data
Proportion of “I don’t know” responses. Figure 2 shows the proportion of “I don’t know” responses plotted against the probe durations as a function of age group. This figure clearly shows that, unlike the children, the adults produced a large number of “I don’t know” responses for the stimulus duration at the arithmetic mean of the two anchor durations—that is, 0.6 s—and for the stimulus duration just shorter than the arithmetic mean—that is, 0.45 s. The ANOVA on the proportion of “I don’t know” responses did indeed reveal a significant main effect of probe durations, F(6, 402) = 28.99, p < .0001, and of age, F(2, 67) = 21.57, p < .0001, as well as a significant probe duration by age interaction, F(12, 402) = 10.20, p < .0001. When each age group was taken separately, the one-way ANOVA revealed no effect of probe durations for the 5-year-olds, F(6, 138) = 1.80, p = .14. Thus, in the youngest children, the proportion of “I don’t know” responses was equivalent for the different probe durations (.10 averaged over the different probe durations). Unlike in the 5-year-olds, the effect of probe durations reached significance in both the 8-year-olds and the adults, F(6, 144) = 3.59, p < .04; F(6, 120) = 48.82, p < .0001, respectively. As shown in Figure 2, for the last two age groups, the proportion of “I don’t know” responses peaked at the probe duration value (0.6 s), located at the arithmetic mean between the short and the long anchor durations, and decreased as the distance between this central value and the probe duration value.
increased, except in the adults in the case of the duration (0.45 s) slightly shorter than the 0.6-s duration. For the 8-year-olds and for the adults, the paired-samples t tests clearly showed that the proportion of “I don’t know” responses was greater for the 0.6-s probe duration than for either the shorter (averaged 0.15, 0.3, 0.45 s) or the longer (averaged 0.75, 0.9, 1.05 s) probe durations: 8 years, \( t(24) = 3.85 \), \( t(24) = 2.89 \); adults, \( t(20) = 6.26 \), \( t(20) = 11.66 \), respectively (all \( p s < .01 \)). The proportion of “I don’t know” responses was similar in the 8-year-olds between the shorter and the longer probe durations (.12 vs. .14), \( t(24) = 0.45 \), \( p = .66 \), as the symmetrical gradient of “I don’t know” responses suggests. However, as indicated by the left asymmetrical gradient in the adults, these participants responded “I don’t know” more often for the shorter than for the longer probe durations (.41 vs. 19), \( t(20) = 9.10 \), \( p < .0001 \). This was due to the large number of “I don’t know” responses for the 0.45-s probe duration, with the result that no significant difference was observed in the “I don’t know” responses between the 0.45-s and the 0.6-s probe duration, \( t(20) = 0.15 \), \( p > .88 \).

As far as the effect of age is concerned, there was a significant effect of age for the 0.6-s stimulus, \( F(2, 67) = 31.82 \), \( p < .0001 \), with the adults (.69) responding “I don’t know” more often than either the 5- (.12) or the 8-year-olds (.32), and the 8-year-olds more often than the 5-year-olds (Sheffe post hoc tests, all \( p s < .0001 \)). The effect of age was also significant for the 0.45-s, the 0.30-s, and the 0.75-s probe durations, \( F(2, 67) = 35.08 \), 18.96, 5.90, respectively, \( p < .004 \), while it was not significant for the short (0.15-s) and the long anchor durations (1.05 s) or for the 0.9-s stimulus duration (all \( p s < .05 \)). However, this significant effect of age for the 0.45-s, 0.30-s, and 0.75-s stimulus durations was due to the adults who responded “I don’t know” more often than either the 5- or the 8-year-olds (all \( p s < .03 \)), while the proportion of such responses was similar in these last two age groups.

Proportion of long responses. Figure 3 illustrates the bisection functions in the conditions with and without the additional “I don’t know” button-press. For the adults, when the number of “I don’t know” responses was subtracted from the number of trials, the number of trials remaining for the calculation of the proportion of long responses was reduced, especially in the case of
the 0.45-s and the 0.60-s stimulus durations. However, the individual performances revealed that the majority of the adults (71.4%, 15 out of 21) exhibited an abrupt transition in the proportion of long responses, which shifted from <.35 to >.75, with the bisection occurring between 0.60 s and 0.75 s in most cases (12 participants), although other participants bisected earlier. For the other adults (28.5%), the slope of the bisection curve was flatter. However, these participants also produced a lower proportion of “I don’t know” responses (for 0.45 s: \(M = .43, SD = .13\); for 0.6 s: \(M = .42, SD = .17\)).

Figure 3, which illustrates the mean group bisection curve, thus suggests that giving the participants the option to respond “I don’t know” affected bisection performance more in the adults than in the children. The overall ANOVA on the proportion of long responses revealed neither a significant effect of age, \(F(2, 135) = 0.35, p > .70\), nor a significant effect of the “I don’t know” condition, \(F(1, 135) = 0.40, p > .53\), but a significant main effect of probe duration, \(F(6, 810) = 778.37, p < .0001\). However, there was a significant three-way interaction between probe, age, and “I don’t know”, \(F(12, 810) = 8.43\); Age \(\times\) I Don’t Know, \(F(2, 135) = 3.43\), all \(ps < .04\).

When we considered each age group separately, the ANOVA on the proportion of long responses, with the probe duration and the “I don’t know” condition as factors, revealed a main effect of probe duration in all the age groups, thus indicating that the proportion of long responses increased with the probe duration value: 5 years, \(F(6, 282) = 187.23\); 8 years, \(F(6, 288) = 350.13\); adults, \(F(6, 240) = 256.51\); all \(ps < .0001\). However, in the 5-year-olds, there was neither an “I don’t know” effect, \(F(1, 47) = 2.33, p > .13\), nor an “I Don’t Know” \(\times\) Probe Duration interaction, \(F(6, 282) = 1.23, p > .29\). This revealed that the possibility of responding “I don’t know” did not affect the youngest children’s bisection performance in the feedback condition. Unlike in the 5-year-olds, in both the 8-year-olds and the adults there was an significant interaction between the probe duration and the “I don’t know” condition, \(F(6, 288) = 4.04, F(6, 240) = 5.13\), respectively, both \(p < .01\), with no significant main effect of “I don’t know” in the 8-year-olds, \(F(1, 48) = 0.52, p > .47\), and an effect that just reached significance in the adults, \(F(1, 40) = 4.11, p < .05\). These significant interactions indicate that the “I don’t know” responses affected the slope of the bisection function. Therefore, to further investigate the no-forced-choice effect on bisection performance, we calculated the BP and the WR as in Experiment 1 (Table 3).

**Bisection point.** The ANOVA on the BP found neither a main effect of age, \(F(2, 135) = 0.67, p > .51\), nor a main effect of “I don’t know”, \(F(1, 135) = 2.28, p > .13\), nor an age by “I don’t know” interaction, \(F(2, 135) = 1.56, p > .21\). The analysis, based on a priori hypothesis (Rosenthal & Rosnow, 1985) of an effect of “I don’t know” responses in the adults, revealed that the FB/FB “I don’t know” difference just reached significance in the adults, \(t(40) = 2.02, p = .05\). Adding an “I don’t know” response thus tended to shift the BP toward the right in the adults. The results of the present study indicate that a condition in which the participants were not required to choose between \(S\) and \(L\) in a bisection task mainly affected the adults’ bisection performance by pushing the BP beyond the arithmetic mean of the two anchor durations. The effects of feedback with or without no forced choice are clearly illustrated in Figure 4, in which the adults’ data from Experiments 1 and 2 are presented together. Indeed, Figure 4 shows a progressive shifting of the BP toward the right as a function of the experimental conditions used, from no-FB to FB “I don’t know”. The cross-experiment \(t\) tests showed that the BP value was smaller with no-FB than with FB, \(t(39) = 2.65, p = .01\), and with FB than with FB and “I don’t know” responses, \(t(39) = 5.22, p = .0001\).

**Weber ratio.** The statistical analyses on the WR revealed that adding an “I don’t know” response
increased sensitivity to time (.24 vs. .19). Indeed, the overall ANOVA on the WR found a main effect of “I don’t know”, $F(1, 135) = 4.79$, $p = .03$, while the Age × “I Don’t Know” interaction was not significant, $F(2, 135) = 1.04$, $p > .36$. The main effect of age was also significant, $F(2, 135) = 15.94$, $p = .0001$. This finding is consistent with the bisection data, which point to a developmental improvement in time sensitivity. However, post hoc analyses revealed that the WR value was lower in the FB “I don’t know” than in the FB condition in the adults, $t(40) = 4.34$, $p < .0001$, and in the 8-year-olds, $t(48) = 2.30$, $p < .03$, whereas it was similar in these two conditions in the 5-year-olds, $t(47) = 1.04$, $p > .36$. Consequently, giving the participants the possibility to respond “I don’t know whether the probe duration is more similar to the short or the long anchor duration” affected the sensitivity index to a greater extent in the adults and the 8-year-olds than in the younger children.

**Modelling of the data**

The model described in Experiment 1 was used in order to take account of the bisection data obtained in Experiment 2 (see Table 2). This model provided a good fit for our data, as it did in Experiment 1, and showed the same developmental trends—that is, higher $c$ and $p$ parameter values in the 5-year-olds than in the older participants. The most interesting finding here is that the model suggests that introducing the possibility to respond “I don’t know”, instead of forcing the participants to choose between short and long, reduced the variability of their memory representation of the anchor durations ($c$ parameters). However, this was true for the 8-year-olds and the adults, but not for the 5-year-olds for whom the availability of this type of response resulted in no further modification of bisection performance. Nevertheless, when we compare the $c$ parameter values across experiments, we observe that the $c$ values returned to their initial values—that is, those obtained in the no-feedback condition. Consequently, a no-forced-choice condition in a bisection test with feedback produced the same

### Table 3. The mean and standard deviation of individual bisection points and of individual Weber ratios in the feedback conditions with or without the additional “I don’t know” response for the 5-year-olds, the 8-year-olds, and the adults

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<tr>
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<th>BP</th>
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<td></td>
<td>$M$</td>
<td>$SD$</td>
</tr>
<tr>
<td>5 years</td>
<td>572</td>
<td>167</td>
</tr>
<tr>
<td>8 years</td>
<td>571</td>
<td>148</td>
</tr>
<tr>
<td>Adults</td>
<td>542</td>
<td>139</td>
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<tr>
<td></td>
<td>0.29</td>
<td>0.15</td>
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<td></td>
<td>0.23</td>
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**Note**: BP = bisection point. WR = Weber ratio. FB = feedback group. FB “I don’t know” = condition with feedback but with an additional “I don’t know” response. Geometric mean = 397. Arithmetic mean = 600.
time sensitivity in adults and 8-year-olds as had been obtained in a no-feedback condition. As far as the decisional parameter, $b$, is concerned, the “I don’t know” effect varied as a function of the age group. In the 5-year-olds, the “I don’t know response” increased the $b$ value. In the 8-year-olds, for whom the $b$ value was already particularly low in the FB condition, the $b$ value did not change when the “I don’t know” response was introduced. And in the adults, who obtained a higher $b$ parameter value than the 8-year-olds in the FB condition, the $b$ value decreased in the FB “I don’t know” condition. In the case of the adults, this was entirely consistent with the rightward shift of the BP described above. Our model therefore suggests that a no-forced-choice condition reduces the bias toward long responses, but only in adults.

**GENERAL DISCUSSION**

Our study using the temporal bisection task showed that providing feedback to the participants in the testing phase shifted the BP toward the right in all age groups and increased sensitivity to time only in the youngest children, as the lower WR value in the feedback than in the no-feedback condition indicates. Providing feedback to the 5-year-olds also reduced the interindividual variability in the sensitivity to time that was particularly high in the no-feedback condition. Furthermore, giving the participants the possibility to respond “I don’t know” in a bisection task with feedback improved sensitivity to time but had only a very limited effect on the younger children’s temporal performance. The modelling of our data indicated that these results could be attributed to the effects of feedback and of “I don’t know” responses on both the decisional and the memory processes.

According to the developmental version of the modified difference model used in the present study, the location of the BP depends on a decision rule that is based on the difference between the distances between $t$ and $S$ and $L$. When the participants cannot tell whether $t$ is more similar to $S$ or to $L$, with the distance between $t$ and $S$ and $L$ not being clearly discriminated, a bias toward long responses occurs. In all the age groups, giving the participants feedback would thus have reduced this bias toward long responses, thus pushing the BP toward the right and close to the arithmetic mean of the two anchor durations. Consequently, when feedback is provided in a bisection test, there should be fewer ambiguous cases, and the participants should become more conservative and use a lower decisional threshold, $b$, in the production of short and long responses. Although the temporal models include a decisional rule, only a small number of studies have specifically investigated the decisional processes involved in temporal judgement (Wearden & Grindrod, 2002; Wittman & Paulus, 2008). Nevertheless, our results are in accordance with those obtained in bisection studies showing that the BP occurs closer to the geometric mean of the anchor durations when it is difficult to discriminate between $S$ and $L$ (for example, in the case of small $S/L$ ratios) and falls closer to the arithmetic mean of the anchor durations when this task is easier (Wearden & Ferrara, 1996). We may thus assume that temporal discrimination is easier when feedback is provided, thus allowing the participants to be more conservative.

However, the original feature of the present study is that it suggests that the effect of feedback on bisection performance differs between age groups as a function of the quality of the representation of the anchor durations in memory, with the temporal representation being more variable in children than in adults. As demonstrated by Delgado and Droit-Volet (2007), this fuzzier memory representation of durations in children results from an initial processing of time more subject to attentional interference. Whatever the case may be, the bisection models suppose that the decisional and the memory processes operate separately on temporal judgement (Wearden, 1991). Our model suggests that this might apply to bisection performance in adults who are confident about their memory representation of the anchor durations, but not in the children. Indeed, in our study, the adults become more conservative when feedback was provided, while feedback
increased rather decreased the coefficient of variation of their memory representations of the anchor durations. In contrast, the younger children also became more conservative with the provision of feedback, but the feedback effectively decreased the amount of noise in the memory representations of $S$ and $L$.

The meta-analysis of the effects of feedback on performance conducted by Kluger and DeNisi (1996) revealed that providing feedback does not systematically improve performance. There is considerable variability in the effect of feedback on performance depending on tasks used. Generally, feedback in memory tasks improves performance (e.g., Lane, Roussel, Villa, & Morita, 2007). This is consistent with the results observed in our young children who had a fuzzier representation of the anchor durations. Indeed, as our models suggest, providing the children with feedback reduced the coefficient of variation of their temporal reference memory. It is also consistent with the results of other studies of time estimation in adults that have found a decrease in the variability of memory representations of the standard durations when feedback is provided (Droit-Volet & Izaute, 2005; Fransen & Vandierendonck, 2002; Montare, 1985, 1988; Ryan & Robey, 2002), although Wearden and Farrar (2006) did not observe this feedback-related decrease. However, as indicated in the introduction, these studies in adults have used temporal reproduction and temporal generalization tasks in which the role of remembered time is particularly important because the participants have to compare a probe duration with a standard duration, rather than to categorize the probe durations as short or long. Finally, our bisectiion study revealed that feedback did not improve the memory representation of duration in adults, but, instead, seemed to interfere with the processing of the task and certain decisional processes. Indeed, in the bisectiion task, feedback could correct little or nothing in the adults because their discrimination of durations was accurate and their representation of the anchor duration precise. As Koriat argues (1993), with feedback, the experimenter imposes his perspective, thus interfering with the natural course of the decision involved in producing an answer.

However, when the adults were given the possibility of responding “I don’t know whether the probe duration is more similar to $S$ or $L$” in the feedback condition, the variability of their memory representations of the anchor durations returned to that observed in an earlier condition—namely, that found without feedback. The feedback-related interference in the memory representation of anchor durations thus disappeared. This raises the question of the meaning of the “I don’t know” responses for adults in a temporal bisection task. In our adult participants, the proportion of “I don’t know” responses peaked at the probe stimulus duration close to the arithmetic mean of the two anchor durations where it reached a value of .70. This would indicate that when adults respond “I don’t know” it does not mean that they don’t know, but that they know—that is, that they are confident in the fact that the probe duration is neither the long nor the short anchor duration. On the contrary, in the children, the proportion of “I don’t know” responses was approximately .10 whatever the probe duration value. This proportion appears to be close to the proportion of random responses obtained in the no-feedback condition. This suggests that, in young children, “I don’t know” really means that they don’t know. The question is “why?” It seems likely that this is related to their limited attentional capacities, which resulted in the fact that they did not process the stimulus duration in a small number of trials. Numerous studies have stressed the important role of the development of attention in children’s abilities to process time (e.g., Droit-Volet, 2003; Gautier & Droit-Volet, 2002; Smith, Taylor, Rogers, Newman, & Rubia, 2002; Yang et al., 2007). To conclude, our study of temporal bisection shows that the effect of feedback on time performance depends on the level of development of temporal skills, with feedback improving bisection performance only in the children. It also clearly indicates the important role in bisection performance of the decisional strategies used in humans and the
changes they undergo during cognitive development, with the shape of the psychophysical functions being particularly sensitive to these decisional strategies.

REFERENCES


DROIT-VOLET AND IZAUTE


