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Perception of the duration of auditory and visual stimuli in children and adults

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This experiment investigated the effect of modality on temporal discrimination in children aged 5 and 8 years and adults using a bisection task with visual and auditory stimuli ranging from 200 to 800 ms. In the first session, participants were required to compare stimulus durations with standard durations presented in the same modality (within-modality session), and in the second session in different modalities (cross-modal session). Psychophysical functions were orderly in all age groups, with the proportion of long responses (judgement that a duration was more similar to the long than to the short standard) increasing with the stimulus duration, although functions were flatter in the 5-year-olds than in the 8-year-olds and adults. Auditory stimuli were judged to be longer than visual stimuli in all age groups. The statistical results and a theoretical model suggested that this modality effect was due to differences in the pacemaker speed of the internal clock. The 5-year-olds also judged visual stimuli as more variable than auditory ones, indicating that their temporal sensitivity was lower in the visual than in the auditory modality.

In the framework of scalar timing theory, usually considered to be the most completely developed model of timing (Allan, 1998; Droit-Volet & Wearden, 2003), recent studies have investigated how temporal discrimination in children changes with age by using the temporal bisection method initially used in animals (Church & Deluty, 1977) and later modified for human adults (Allan & Gibbon, 1991; Wearden, 1991). In the bisection procedure commonly used with human adults, participants receive initial presentations of two standard durations, a *short* and a *long* standard duration. Then they are presented with comparison durations including these two standards as well as intermediate stimulus durations. Their task is to classify each presented duration as being more similar to the short or to the long standard duration.

The bisection task has obtained orderly data from children in the age range from 3 to 10 years, with durations both shorter (Droit-Volet & Wearden, 2002; McCormack, Brown, Maylor, Darby, & Green, 1999) and longer than 1 s (Droit-Volet, Clément, & Fayol, 2003; Droit-Volet & Wearden, 2001; Gautier & Droit-Volet, 2002b; Rattat & Droit-Volet, 2001). Indeed, whatever the age group and the duration tested, children have been observed to

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produce psychophysical functions with a proportion of long responses (i.e., identifying a duration as more similar to the long standard than to the short one) that increases with the stimulus duration. Furthermore, by using different duration ranges, Droit-Volet and Wearden (2001, 2002) succeeded in showing that young children's bisection performance exhibits the scalar property—that is, the requirement that the standard deviation of time judgements increases in proportion to the mean of the duration judged. These different results demonstrate that young children possess a fundamental ability to represent time, similar to that found in animals and human adults. Therefore, Droit-Volet and her colleagues concluded that a pacemaker–accumulator clock mechanism underlying time representations, like that proposed by scalar timing theory, is functional at an early age (Droit-Volet, 2002; Droit-Volet, Clément, & Wearden, 2001; Droit-Volet & Wearden, 2001, 2002).

However, although young children are able to represent time, some age-related changes have been observed in their temporal discrimination behaviour on bisection tasks. For example, the steepness of the slope of the psychophysical functions increased with age, the functions being flatter in the 3- and the 5-year-olds than in the 8-year-olds (for a review, see Droit-Volet, 2003). A measure of this steepness of the psychophysical function and, consequently, an index of temporal sensitivity is the Weber ratio. This is the difference limen (half the difference between the stimulus duration giving rise to 75% long responses and that giving rise to 25% long responses) divided by the bisection point (the duration giving rise to 50% long responses). High Weber ratios indicate low temporal sensitivity, and low Weber ratios high temporal sensitivity. Consequently, the studies in young children showed that the 3- and the 5-year-olds produced a higher Weber ratio than the older children and thus that their sensitivity to duration was lower.

To account for these developmental changes in bisection performance, Droit-Volet and Wearden (2001) presented a developmental version of Wearden's (1991) modified difference model (MD), which is itself based on scalar timing theory. We present and discuss this model later in this article. However, we should note at this point that according to this model, time judgements depend not only on a pacemaker–accumulator clock system, but also on memory and decision processes. The model uses three parameters: (1) a coefficient of variation of the long-term memory representation of the short and long standards; (2) a bias value toward making long responses in ambiguous cases; and (3) a proportion of random responses (for more details, see Droit-Volet & Wearden, 2001). Application of the model showed that developmental changes in bisection performance were related to the variation of two of these three parameters: (1) The proportion of random responses and (2) the coefficient of variation of the memory representation of the standards. Indeed, the number of responses made regardless of stimulus duration values was greater in the 3- and the 5-year-olds than in the 8-year-olds. Variability of the remembered standard durations was also greater in the younger children. In other words, their memory representation of the standard durations was "fuzzier". A series of experiments suggested that this fuzzier representation of durations in memory could, to a large extent, be attributed to young children's limited attentional control (Gautier & Droit-Volet, 2002a, 2002b). In particular, young children are known to be easily distracted by external context, and this might delay or/and disrupt the processing of temporal information. According to scalar timing theory (Gibbon, 1977; Gibbon, Church, & Meck, 1984), when the duration of a stimulus has to be estimated, the switch of the internal clock closes, and the pulses emitted by the pacemaker flow to the accumulator. However, in the case of attentional distraction, the variability of the switch latency closure increases, and this results in the number of pulses accumulated being more variable from one trial than another. Consequently, the variability of the representation of the stimulus durations increases in memory. In young children, the greater variability of the long-term representations of the standard durations therefore might be related to the variability in the memory process responsible for encoding durations.

Although memory representations of standard durations are more variable in young children in general, we can suggest that this variability is greater for visual than for auditory stimuli. Indeed, in the case of visual stimuli, children have to continuously direct the focus of attention on a physical source of presentation of visual information (i.e., computer screen), in order to begin the processing of duration at the onset of the presented stimulus. In contrast, auditory stimuli are perceived more directly. Thus, the variability of switch latency may be greater in younger children for visual than for auditory stimuli. However, until now, the modality effect has not been considered in developmental studies in the context of scalar timing theory. The aim of the present experiment was therefore to provide empirical data on modality effects in children's temporal discrimination on a bisection task and to use the developmental version of the modified difference model based on scalar timing theory in order to try to explain potential age-related differences in bisection behaviour.

Many previous studies have investigated the effect of sensory modality on temporal discrimination in human adults. Using various methods, these studies have provided contradictory results (e.g., Brown & Hitchcock, 1965; Goldstone & Goldfarb, 1964a, 1964b; Walker & Scott, 1981). Nevertheless, there is enough evidence that auditory stimuli are judged to be longer than equivalent duration visual stimuli and, conversely, that visual stimuli are judged to be shorter than auditory ones. For example, by varying contextual factors (e.g., intensity of lights and sounds, level of practice), as well as the procedures (e.g., production, reproduction, verbal estimation, pair comparison), Goldstone and Lhamon (1972, 1974) observed that participants systematically judged the auditory stimuli longer than the visual ones when they shared common durations. The robustness of this phenomenon led Goldstone and Lhamon (1972, p. 626) to conclude that the auditory-visual difference is a fundamental property of human temporal processing. However, at the time, they were still unable to explain why auditory-visual differences in temporal judgements occur.

Recently, in the context of scalar timing theory, Penney and his colleagues succeeded in explaining the effect of sensory modality in time judgements by using a temporal bisection procedure (Penney, Allan, Meck, & Gibbon, 1998; Penney, Gibbon, & Meck, 2000). In this experimental condition, the psychophysical functions produced by human adults on auditory stimulus durations were shifted toward the left compared to the functions for the visual stimuli, thus showing that the former are judged to be longer than the latter. Furthermore, this leftward shift of the bisection function was proportional to the stimulus duration value to be estimated. That is to say, the auditory-visual differences in the bisection functions increased with the duration values, being larger for the longest durations. As explained in more detail later, this proportional effect with the duration values supports the assumption that differences in the clock speed were the cause of the modality effect on time judgements. As discussed in Penney et al. (1998, 2000), the internal clock is considered to run faster for auditory than for visual stimuli. Therefore, for one and the same objective duration, more pulses are accumulated, and the subjective time seems longer. Using other methods (i.e., temporal generalization, verbal time estimation), Wearden, Edwards, Fakhri, and Percival (1998) obtained results consistent with this clock speed interpretation. However, unlike Penney et al. (2000), they also found that the temporal judgements were less variable for the auditory stimuli than for the visual stimuli, possibly due to differences in the variance of switch latency as described above. Thus, the clock speed difference is probably not the only difference that is operative in the processing of temporal information when the subjects have to compare auditory and visual stimuli.

Within a developmental perspective, we might assume that if the pacemaker–accumulator clock system is functional at an early age, the modality difference observed in adults should also be observed in children whatever the age group tested. However, if the variability in the memory encoding process for standard durations is greater in the 5-year-olds than in older children, the psychophysical functions would be relatively flatter in the visual than in the auditory modality, and the modified difference model would attribute this to a greater coefficient of variation for the memory representation of the visual standards.

In the experiment reported here, children aged 5 and 8 years, as well as adults, were tested during two temporal bisection sessions, each consisting of three phases: pretraining, training, and testing. In the pretraining and the training phase, the participants were presented with a short and a long standard duration and then learned to discriminate these two standard durations. In the testing phase, they had to compare a just-presented duration with their representations of these standards stored in long-term memory. In the first session, the standard durations and the comparison stimulus durations were presented in the same sensory modality, either visual or auditory (visu/visu and audi/audi). In the second session, the standard durations were presented in the same modality as in Session 1, but the comparison stimulus duration was presented in the other modality (visu/audi and audi/visu). Therefore, Session 1 required a within-modality comparison, and Session 2 a cross-modality comparison.

EXPERIMENT

Method

Participants

The final sample consisted of 75 participants: 22 five-year-olds (10 girls and 12 boys, mean age = 5.42 years, *SD* = 0.25), 27 eight-year-olds (15 boys and 12 girls, mean age = 8.5 years, *SD* = 0.33), and 26 adults (25 females and 1 male, mean age = 19.5 years, *SD* = 2.09). The data for five 5-year-olds and one 8-year-old were not included in the final sample because they did not produce differentiated proportions of long responses in the first session. The children came from nursery and primary schools, and the adults from Blaise Pascal University, where they were psychology undergraduates, all in Clermont-Ferrand, France.

Materials

The participants were tested individually in a quiet room in their school in the case of the children and at the university for the adults. A PowerMacintosh computer controlled the experiment, and the data were recorded using Psyscope software. The auditory and the visual stimuli had identical temporal specifications. The auditory stimulus used was a 500-Hz sinusoidal tone (synthetic piano tone, C4, SoundEdit software) produced by the computer speaker at a sound pressure level of approximately 30 dB. The visual stimulus was a blue filled circle (4.5 cm in diameter) presented in the centre of the computer screen. Responses were made on the left and the right buttons of a Psyscope response box. During the training phase, postresponse feedback was given in the form of the picture of a clown who was either smiling (correct response) or frowning (incorrect response). The clown was presented for 2 s on the computer screen.

Procedure

The participants were given two bisection sessions with the same short and long standard durations lasting 200 and 800 ms. The nonstandard comparison durations were 300, 400, 500, 600, and 700 ms. Each session consisted of three successive phases: pretraining, training, and testing phases.

In the pretraining phase, the participant was presented with the short and the long standard durations, three times each in alternation. The experimenter said for the short standard, "Look/Listen, it's the short circle/music. It stays on for a short time", and for the long standard, "Look/Listen, it's the long circle/music. It stays on for a long time."

In the training phase, the participant was trained to press one button after the short standard and the other button after the long one. The button press order was counterbalanced. The participant was given successive blocks of eight trials, with each standard having a 50% probability of appearance on each trial. The intertrial interval was randomly chosen between 1 and 3 s. In the training phase, a correct response resulted in the appearance of the smiling clown, and an incorrect one in the display of the frowning clown. When the participant finished a training block with eight correct responses, the training phase terminated.

The testing phase used the same experimental conditions as the training phase, except that no feedback was given. The experimenter said "It's the same game, but now the clown is not here to tell you whether or not you've played well." The participants received 10 blocks of seven trials, two for the two standard durations and five for the nonstandard stimulus durations. The stimulus durations within each block were presented in a random order.

In each age group, the participants were arbitrarily assigned to one of two groups (visual standard group or auditory standard group) depending on the modality of the stimuli presented during the different experimental phases of the two bisection sessions. For each standard group, in Session 1, the participants were presented with the stimulus durations in the same sensory modality in the pretraining, training, and testing phases, either visual or auditory (visu/visu and audi/audi). In Session 2, they were presented with the stimuli in the same modality as that in Session 1 for the pretraining and training phases, but in another modality for the testing phase (visu/audi and audi/visu). The experimenter said: "It's the same game, with the same short and long durations, but now the short duration and the long duration will be presented in the form of a music/circle. Thus, to correctly identify the short and the long music/circle, you have to compare the duration of this circle/music with the duration of the music/circle that you have learned." Therefore, Session 1 required a within-modality comparison (visu/visu or audi/audi), and Session 2 a cross-modal comparison (visu/audi or audi/visu). In Session 2, the participants were therefore required to make temporal judgements relating an auditory comparison stimulus to a visual standard for one group (visual standard group) and a visual comparison stimulus to an auditory standard for the other group (auditory standard group).

Results

Training

Table 1 shows the number of training blocks required in the first bisection session by the 5-year-olds, the 8-year-olds, and the adults in order to meet the learning criterion (eight consecutive correct responses) for the visual standard group and the auditory standard group. A

TABLE 1
Number of training blocks required by each age group to meet the learning criterion[a] in the training phase

	Visual standard			*Auditory standard*		
Age group	*M*	*SD*	*MAXI*	*M*	*SD*	*MAXI*
5-year-olds	1.91	0.70	3	2.18	0.87	3
8-year-olds	1.38	0.65	3	1.14	0.36	2
Adults	1.00	0.00	1	1.00	0.00	1

Note: *M* = Mean; *SD* = Standard deviation; *MAXI* = Maximum number of training blocks.
[a]Eight consecutive correct responses.

Mann–Whitney U test showed that the number of training blocks required to differentiate the short from the long standard was similar in the visual and the auditory modality for each age group (5-year-olds, $U = 75.0$; 8-year-olds, $U = 48.5$; adults, $U = 84.5$, all $p > .05$). However, whatever the sensory modality of the standard, there was a significant effect of age: Kruskal–Wallis test, $\chi^2(2) = 31.81$, $p = .0001$. Between-age comparisons revealed that the 5-year-olds required more training to learn to differentiate the short from the long standard than did the 8-year-olds and the adults (Kolmogorov–Smirnov, $Z = 1.76$; $Z = 2.51$, all $p < .01$), whereas no difference was observed between the 8-year-olds and the adults ($Z = 0.81$, $p > .05$).

Testing

Psychophysical functions. Figure 1 shows the mean proportion of long responses during the testing phase, plotted against the stimulus durations in the within-modality comparison sessions (visu/visu and audi/audi) and the cross-modal comparison sessions (visu/audi and audi/visu) for the visual standard groups (left panels), and for the auditory standard groups (right panels). The top two panels show the data for the 5-year-olds, the centre two panels data for the 8-year-olds, and the bottom two panels data for the adults. Inspection of Figure 1 suggests that the psychophysical functions were orderly in all age groups with the proportion of long responses increasing with the stimulus duration, although the slopes of the bisection functions were flatter in the 5-year-olds than in the 8-year-olds and the adults. Furthermore, in these three age groups, the bisection functions on auditory comparison stimuli were left-shifted compared to the visual comparison stimuli, and this occurred irrespective of the transfer modality order tested, both from visual to auditory (visu/audi) and from auditory to visual (audi/visu). However, the magnitude of the modality difference between the bisection functions seemed to be larger when the visual stimulus durations were compared to the auditory standard stored in long-term memory (audi/visu vs. audi/audi) than when the auditory stimulus durations were compared to the visual standard (visu/audi vs. visu/visu), and especially in the 8-year-olds and the adults. The subsequent statistical analyses[1] supported these different suggestions.

[1]All previous analyses of variance (ANOVAs) in children had found neither an effect of sex or press-button order nor any significant interactions between these two factors and other factors. Therefore, sex and press-button were excluded from subsequent statistical analyses.

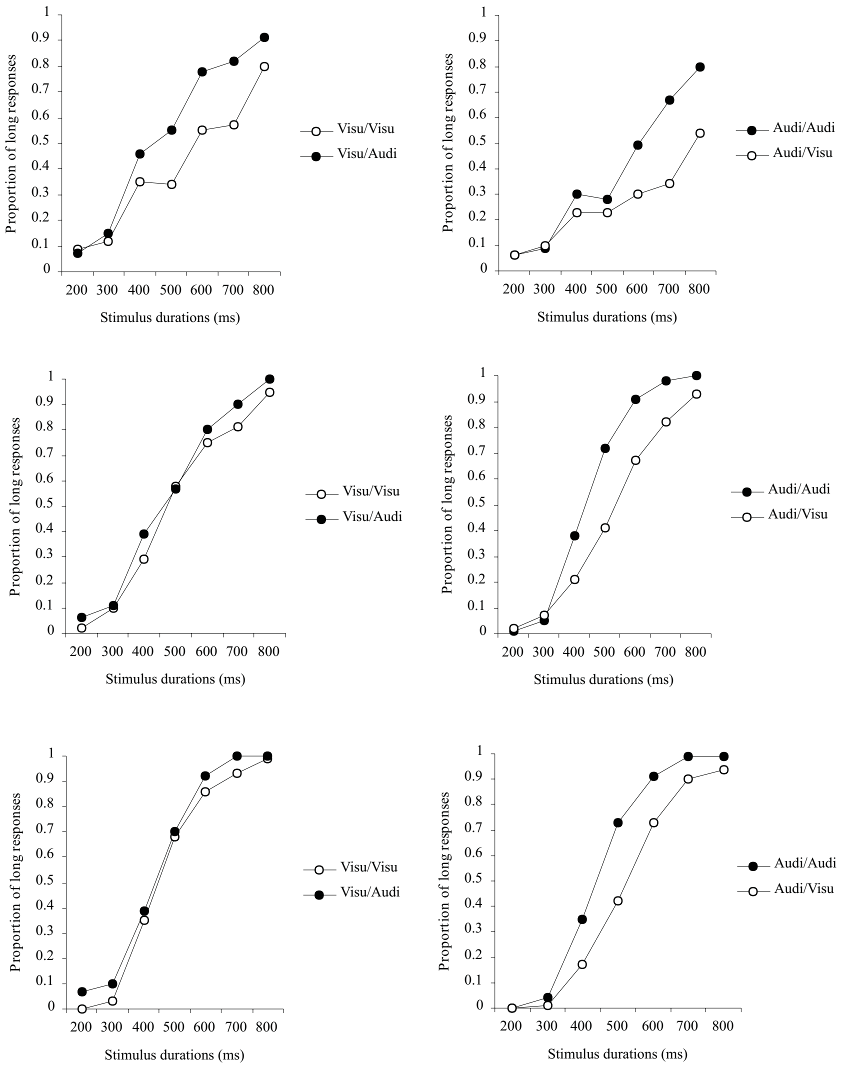

Figure 1. Proportion of long responses plotted against comparison stimulus durations in the visual standard group (left panels) and the auditory standard groups (right panels) for the within-modality comparison sessions (visu/visu, audi/audi) and the cross-modal comparison sessions (visu/audi, audi/visu). Top two panels: data from 5-year-olds; centre two panels: data from 8-year-olds; bottom two panels: data from adults.

An initial overall analysis of variance[2] (ANOVA) was run on the proportion of long responses with two between-subjects factors, age (5-year-olds, 8-year-olds, or adults) and the standard group (visual or auditory standard), and two within-subjects factors, the session (within-modality session or cross-modality session) and the stimulus duration. The ANOVA

[2]When the ANOVAs with repeated measures showed evidence of a departure from the sphericity assumption (Mauchly sphericity test), the reported probability levels have been adjusted by means of Greenhouse–Geisser corrections.

found both a significant main effect of age, $F(2, 69) = 18.73$, $p = .0001$, and stimulus duration, $F(6, 414) = 815.69$, $p = .0001$, and a significant interaction between age and stimulus duration, $F(12, 414) = 21.61$, $p = .0001$, indicating that the steepness of the psychophysical functions increased with age. The effect of standard group was also significant, $F(1, 69) = 12.16$, $p = .001$, whereas the effect of session only approached significance, $F(1, 69) = 3.52$, $p = .07$. However, there was a four-way interaction between age, standard group, session, and stimulus duration , $F(12, 414) = 1.93$, $p = .03$, which subsumed several significant two- and three-way interactions.[3] Therefore, we conducted an ANOVA on the proportion of long responses for each age group taken separately.

In the case of the 5-year-old group, the ANOVA revealed a significant effect of standard group, $F(1, 20) = 12.55$, $p = .002$, and stimulus duration, $F(6, 120) = 115.67$, $p = .0001$, and a significant standard group by stimulus duration interaction, $F(6, 120) = 3.59$, $p = .003$. The effect of session, $F(1, 20) = 0.003$, $p = .95$, was not significant. However, there was a Session × Standard Group interaction, $F(1, 20) = 15.30$, $p = .001$, and a Session × Standard Group × Stimulus Duration interaction, $F(6, 120) = 5.77$, $p = .0001$. The session by stimulus duration interaction did not reach significance. In the 5-year-olds, when we consider the visual and auditory standard groups separately, we found similar patterns of results. Indeed, in the two standard groups, we obtained significant effects of session, $F(1, 10) = 11.03$; $F(1, 10) = 5.78$, respectively; both $p < .03$, and stimulus duration, $F(6, 60) = 71.91$; $F(6, 60) = 45.87$, both $p < .0001$, and a significant interaction between session and stimulus duration, $F(6, 60) = 3.01$; $F(6, 60) = 3.93$, both $p < .01$. The first significant result indicated that, in the 5-year-olds, the auditory comparison stimuli were judged longer than the visual comparison stimuli, both when the visual stimulus durations were compared to the auditory standard durations in memory and when the auditory stimulus durations were compared to the visual standards. The second significant result showed that the proportion of long responses differed as a function of the stimulus duration, and the third that the psychophysical functions were flatter with the visual than with the auditory comparison stimuli, whatever the standard group tested.

For both the 8-year-olds and the adults, the ANOVA also found significant Session × Standard Group, $F(1, 25) = 12.55$; $F(1, 24) = 14.17$, all $p < .002$, respectively, Session × Stimulus Duration, $F(6, 150) = 3.81$; $F(6, 144) = 2.53$, all $p < .02$, and Session × Stimulus Duration × Standard Group interactions, $F(6, 150) = 3.68$; $F(6, 144) = 2.58$, all $p < .02$, subsumed significant main effects of stimulus duration, $F(6, 144) = 526.61$, $p = .0001$, standard group, $F(1, 24) = 4.93$, $p = .04$, and session, $F(1, 24) = 4.22$, $p = .05$, for the adults, and of stimulus duration for the 8-year-olds, $F(6, 150) = 311.99$, $p = .0001$. When we considered each standard group separately, the 8-year-olds and the adults produced the same patterns of results. Indeed, for the visual standard group, there was an effect of stimulus duration in the two age groups, $F(6, 72) = 119.72$, $F(6, 72) = 305.04$, respectively, both $p = .0001$, but neither session effect, nor session by stimulus duration interaction. In contrast, in the auditory standard group, the effect of stimulus was significant for each age group, $F(6, 78) = 207.02$; $F(6, 72) = 232.30$, $p < .001$, but also the effect of session, $F(1, 13) = 13.79$; $F(1, 12) = 24.53$, all $p < .003$,

[3]Session × Standard Group, $F(1, 69) = 42.65$, $p = .0001$; Standard Group × Age, $F(2, 69) = 3.87$, $p = .03$; Stimulus × Standard Group, $F(6, 414) = 2.26$, $p = .04$; Stimulus × Age × Standard Groups, $F(12, 414) = 1.95$, $p = .03$; Session × Stimulus × Age, $F(12, 414) = 2.45$, $p = .004$; Session × Stimulus × Standard Group, $F(6, 414) = 9.40$, $p = .0001$.

and the session by stimulus duration interaction, $F(6, 78) = 5.97$; $F(6, 72) = 4.68$, all $p < .0001$. These statistical results indicated that it was only in the experimental condition in which the standard duration in long-term memory was auditory that the 8-year-olds and the adults judged the stimulus durations to be significantly longer (.58 vs. 45; .57 vs. .45, respectively) and produced steeper bisection functions for the auditory than for the visual stimuli.

Testing the modality differences: d′ scores. In the present bisection task, the effect of sensory modality reached significance in the two standard groups for the 5-year-olds, but only in one standard group (i.e., the auditory standard group) for the 8-year-olds and for the adults. Therefore, to explore the modality differences of participants' responses further, we transformed the proportion of long responses for each participant to z scores. Following a signal detection analysis (Macmillan & Creelman, 1990), we calculated the d' scores by taking the difference between the z score of the proportion of long responses produced for the comparison stimulus in the within-modality session (Session 1) and the z score produced for the same comparison stimulus duration in the cross-modality session (Session 2). Each of these d' scores expresses the extent to which the stimulus duration of Session 1 was over- or underestimated relative to Session 2. Positive d' scores reflect overestimation and negative d' scores underestimation.

Figure 2 shows the d' scores plotted against the stimulus durations for the auditory and the visual standard group. For most comparison stimulus durations, the d' scores were positive in the auditory standard groups—that is, audi/audi (Session 1)–audi/visu (Session 2)—and negative in the visual standard groups—that is, visu/visu–visu/audi. These positive and negative scores in the auditory and the visual standard group, respectively, suggested that the auditory stimuli were systematically overestimated relative to the visual ones. Therefore, for each standard group, we first averaged the d' scores obtained with the different comparison stimulus durations and tested whether this averaged d' score was significantly greater than zero in all age groups. This is indeed the case in the auditory standard group for the 5-year-olds, $M = 0.39$, $t(10) = 2.43$, the 8-year-olds, $M = 0.41$, $t(13) = 3.67$, or the adults, $M = 0.38$, $t(12) = 4.93$, all $p < .03$. However, in the visual standard group, the overestimation significantly differed from zero in the 5-year-olds, $M = –0.40$, $t(10) = –3.30$, $p = .008$, but not in the 8-year-olds and the adults, $M = –0.16$, $t(13) = –1.4$; $M = 0.12$, $t(12) = –1.18$, all $p > .05$. Thus, the d' score analyses support previous data suggesting that auditory stimuli were considered to last longer than the visual stimuli in all age groups, except in the two oldest ones when a visual stimulus was in the reference memory as a standard.

However, according to the internal clock models, the overestimation of times for auditory stimuli relative to visual stimuli can be produced either by the pacemaker speed of the clock, which is faster for auditory than for visual stimuli, or by the switch between the pacemaker and the accumulator, which closes earlier with auditory than with visual stimuli. Indeed in each case, more pulses are accumulated in the counter, and the subjective time seems to be longer. However, the mathematics of internal clock models predict distinct effects for the "clock speed" and for the "switch-latency" interpretations (Burle & Casini, 2001). For the first, they predict a multiplicative effect with real time, so that if the pacemaker runs faster, the effect should be greater for longer than for shorter times. For the second, they predict not a multiplicative but an additive effect—that is to say, an effect independent of the judged durations and therefore constant whatever the duration values used.

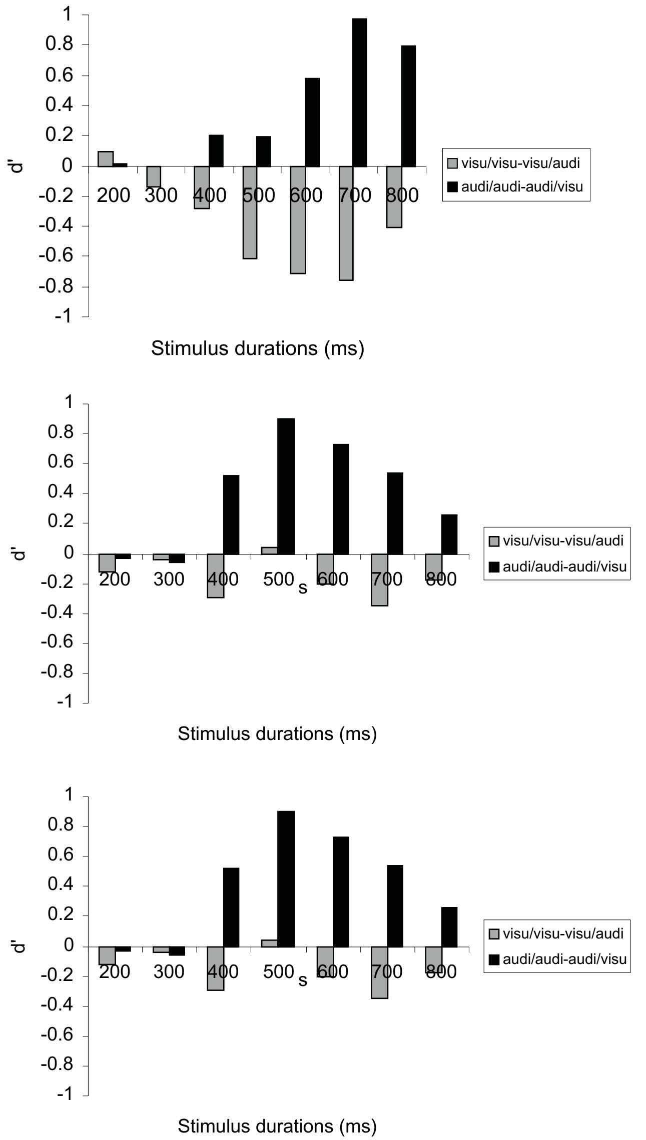

Figure 2. The d' scores plotted against stimulus durations for the auditory standard group (audi/audi–audi/visu) and the visual standard group (visu/visu–visu/audi) in 5-year-olds (top panel), 8-year-olds (centre panel), and adults (bottom panel).

To choose between these two types of interpretation ("clock-speed" and "latency-switch"), we explored how the auditory-visual difference changed as a function of the stimulus duration values by conducting an ANOVA on the d' scores with the stimulus duration as within-subject factor and the age as between subject-factor. The visual and the auditory standard group were considered separately. In the auditory standard group, the ANOVA found no significant effect of age, $F(2, 34) = 0.08$, $p > .05$, but a significant main effect of stimulus duration, $F(6, 204) = 3.17$, $p = .0001$, and a significant age by stimulus duration interaction, $F(12, 204) = 2.33$, $p = .008$. When each age group was taken separately, polynomial contrast analyses revealed a significant linear trend showing that the visual–auditory difference increased with the stimulus duration value in the 5-year-olds, $F(1, 9) = 9.73$, $p = .01$, and the 8-year-olds, $F(1, 13) = 8.64$, $p = .01$. However this did not reach significance in the adults: linear component, $F(1, 12) = 2.20$, $p > .05$. A comparison by t tests for pair-sample between the mean d' score from the three shortest stimulus durations (i.e., 200, 300, 400 ms) and that from the three longest stimulus durations (i.e., 600, 700, 800 ms) confirmed that the auditory–visual difference was larger for the longest than for the shortest stimulus durations in the 5-year-olds (.78 vs. .07), $t(10) = -3.05$, $p = .01$, and the 8-year-olds (.51 vs. .15), $t(13) = 2.35$, all $p < .04$. In the adults, the magnitude of the auditory–visual difference was also greater for the longest than for the shortest duration values, but this did not reach significance (0.39 vs. 0.22), $t(12) = 0.80$, $p > .05$. In the visual standard group, there was also a significant effect of stimulus duration, $F(6, 204) = 2.36$, $p = .03$, but neither the effect of age, $F(2, 34) = 1.79$, $p > .05$, nor the interaction between age and stimulus duration, $F(12, 204) = 2.33$, $p > .05$, were significant. Thus, whatever the age group tested, the difference between visual and auditory increased with the increase in the stimulus duration value: linear component, $F(1, 68) = 4.16$, $p = .04$. The over-estimation of auditory stimuli relative to visual stimuli was effectively greater for the longest durations (i.e., 600, 700, 800 ms) than for the shortest ones (i.e., 200, 300, 400 ms; –.32 vs. –12), $t(36) = 2.16$, $p = .04$. In summary, our different results on the d' scores support the "clock-speed" interpretation but not the "latency-switch" interpretation for all age groups, although no clear evidence was provided by this measure for the adults in the auditory standard group, ever though this is hinted at by Figure 2.

Testing the superimposition between psychophysical functions. Perhaps a better method of testing the proportional shift of the bisection functions with the auditory stimuli relative to the visual stimuli is to test, as Penney et al. (2000) did, the superimposition between the auditory and visual bisection functions when the mean bisection point for each group is used to normalize stimulus durations. This has been done in Figure 3. Figure 3 shows that in all the standard groups, the data superimposed reasonably well for the 5-year-olds, and perfectly for the 8-year-olds and the adults, even in the auditory standard condition. On the whole, the different results (d' score and superimposition test) suggest that a faster clock speed for the auditory than for the visual stimuli was in large part responsible for the shifting of bisection functions toward the left in the auditory modality. However, in the 5-year-olds, there were small deviations between the auditory and visual bisection curves. As our data suggested no developmental changes in the basic functioning of the clock (i.e., the clock was faster for the auditory stimuli in all age groups), we have to look for the origins of age-related changes in bisection behaviour elsewhere in the processing of temporal information.

Bisection point. Differences between the psychophysical functions were examined further by calculating the bisection point from the individual psychophysical functions. The bisection point is the comparison stimuli producing 50% of long responses (point of subjective equality). There are various ways of calculating the bisection point, but they lead to very similar results (Wearden & Ferrara, 1995). In our experiment, the bisection points were calculated from the slope and intercept parameters obtained in the individual linear regressions.

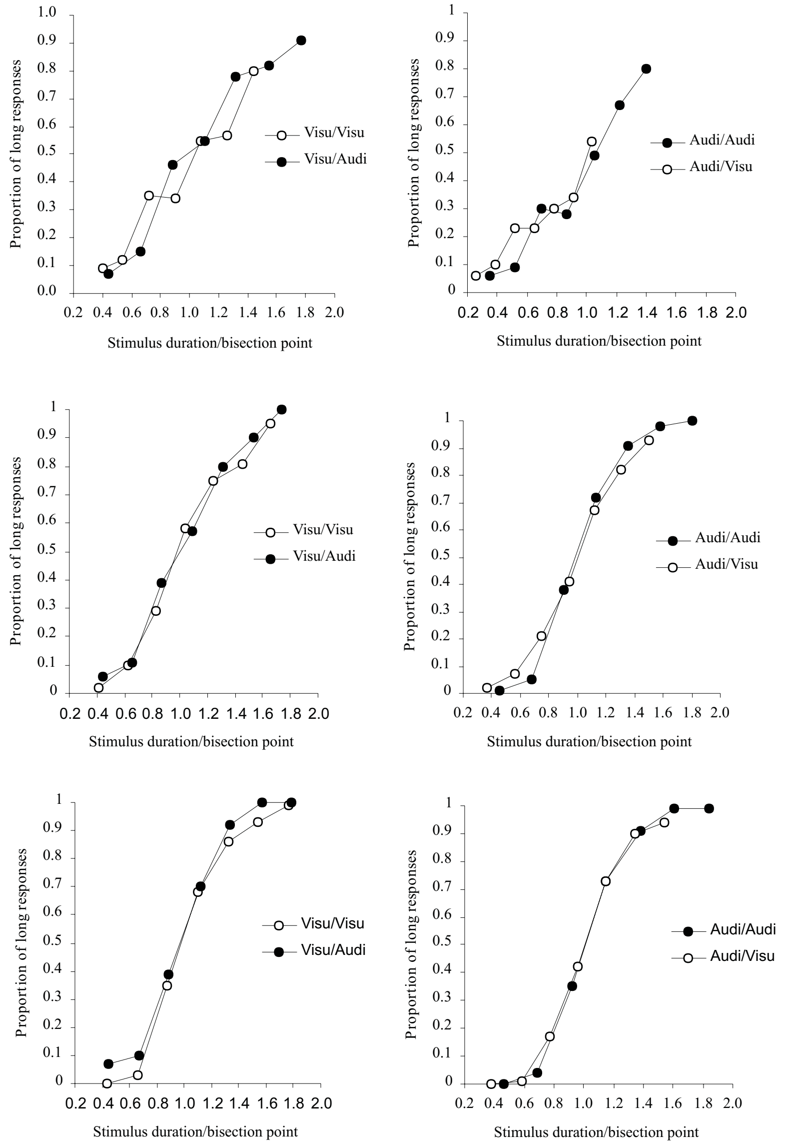

Figure 3. Proportion of long responses plotted against comparison stimulus durations expressed as a fraction of the bisection point in the visual and the auditory standard groups for the within- and cross-modal comparison sessions. Top two panels: data from 5-year-olds; centre two panels: data from 8-year-olds; bottom two panels: data from adults.

The resulting points values are shown Table 2. The ANOVA performed on the bisection point with three factors (age, session, standard group) found a main effect of age, $F(2, 69) = 19.54$, $p = .0001$, indicating that the bisection point was significantly greater for the 5-year-olds (589.27) than for the 8-year-olds (479.96) and the adults (464.35), post hoc Scheffé tests, all $p < .05$, whereas it did not differ between the two oldest age groups ($p > .05$). However, the main effects of session, $F(1, 69) = 8.17$, $p = .006$, and standard group, $F(1, 69) = 17.24$,

TABLE 2
Bisection points and Weber ratios for each age group for the visual standard group and the auditory standard group in the within-modality[a] and cross-modal[b] comparison sessions

		5-year-olds		*8-year-olds*		*Adults*	
	Groups	*BP*	*WR*	*BP*	*WR*	*BP*	*WR*
Visual standard	Visu/visu	557	0.33	483	0.20	454	0.16
	Visu/audi	453	0.25	459	0.19	447	0.15
Auditory standard	Audi/audi	573	0.23	443	0.18	435	0.15
	Audi/visu	773	0.54	534	0.17	521	0.17

Note: Arithmetic mean = 500. Geometric mean = 400. BP = Bisection point. WR = Weber ratio.
[a]Visu/visu and audi/audi.
[b]Visu/audi and audi/visu.

$p = .0001$, were also significant, as well as the different two- and three-way interactions, except the session by age interaction—that is, Standard Groups × Age, $F(2, 69) = 7.55$; Session × Standard Group, $F(1, 69) = 36.28$; Session × Standard Group × Age, $F(2, 69) = 5.38$, all $p <$ .007. In the visual standard group, the bisection point was significantly lower for the auditory stimuli than for the visual stimuli in the 5-year-olds, $t(10)= 2.47$, $p = .03$, but not in the 8-year-olds or the adults, $t(12) = 0.94$; $t(12) = 0.30$, all $p. > 05$. In contrast, in the auditory standard group, the bisection point was lower for the auditory stimuli in each of the three age groups: 5-year-olds, $t(10) = –3.15$; 8-year-olds, $t(13) = –3.32$; adults, $t(12) = –4.20$, all $p < .01$. The results of analyses of the bisection points support those found by the ANOVAs of the proportion of long responses by indicating a leftward shift of the psychophysical functions with the auditory modality in all age and standard groups, with the exception of the 8-year-olds and the adults in the visual standard groups.

Weber ratio. The Weber ratio is a measure of the steepness of the bisection function and therefore an index of temporal sensitivity. This was calculated with the same individual linear regressions as those used for the bisection point and by determining the difference limen (half the difference between the stimulus that gives rise to 75% of long responses and the stimulus that gives rise to 25% of long responses) divided by the bisection point value. An ANOVA, using the same factorial design as that for the bisection point, revealed a main effect of age, $F(2, 69) = 28.88$, $p = .001$. Indeed, the 5-year-olds (.33) produced a greater mean Weber ratio than the 8-year-olds (.19) and the adults (.16), post hoc Scheffé tests, all $p < .05$. In contrast, the Weber ratio was similar in the two oldest age groups ($p > .05$). The ANOVA also showed that there was neither an effect of session, $F(1, 69) = 2.50$, $p > .05$, nor an effect of standard group, $F(1, 69) = 1.74$, $p > .05$. However, the interaction between age, session, and standard group reached significance, $F(2, 69) = 7.35$, $p = .001$, and subsumed a significant and a nearly significant two-way interaction between session and standard group, $F(1, 69) = 10.63$, $p = .002$, and session and age, $F(2, 69) = 2.92$, $p = .06$.

When we considered the three age groups separately, for the 5-year-old group, we obtained neither an effect of session, $F(1, 20) = 2.42$, $p > .05$, nor an effect of standard group, $F(1, 20) = 2.18$, $p > .05$, but a significant session by standard group interaction, $F(1, 20) = 7.32$, $p = .01$.

The 5-year-olds produced a higher Weber ratio for the visual than for the auditory stimuli whatever the standard in reference memory, visual or auditory: $t(10) = 2.59$; $t(10) = -2.18$, respectively, all $p < .05$. Thus, the 5-year-olds had a lower sensitivity to time for the visual than for the auditory modality. Unlike the 5-year-olds, in the 8-year-olds and the adults, the ANOVA indicated neither a significant main effect nor a significant interaction: Session, $F(1, 25) = 0.67$; standard group, $F(1, 25) = 1.60$; Session × Standard Group, $F(1, 25) = 0.11$; $F(1, 24) = 1.76$, all $p > .05$. Therefore, from the age of 8 years old, the Weber ratio was similar for the auditory and the visual stimuli. In other words, temporal sensitivity was equivalent in the auditory and visual modalities.

The lack of significant effects on the Weber ratio in the 8-year-olds and the adults supports our previous results suggesting a multiplicative effect of modality and, consequently, the "clock-speed" interpretation of auditory-visual differences in duration judgement. However, in the youngest children, the Weber ratio differed significantly between the two sensory modalities. Rather than rejecting the clock-speed interpretation in the youngest children, which would contradict all our data, we can assume that in the 5-year-olds, not only was the clock speed slower in the visual than in the auditory modality, but also that the children's memory representation of the visual stimuli was more variable. To better explain these age-related changes in bisection behaviour, we used the developmental version of the modified difference model adapted for bisection performance (Droit-Volet & Wearden, 2001, p. 153).

Modelling

The developmental version of the MD model. The MD model proposes that to make the *short* and *long* responses, the participants calculate two differences. The first, $D(s^*, t)$, is the absolute difference between the comparison stimulus duration, t, assumed to be timed without error, and s^*, a sample drawn from the long-term memory of the short standard. The second, $D(l^*, t)$ is the absolute difference between t and a sample drawn from the memory of the long standard, l^*. The values s^* and l^* differ from trial to trial and are drawn from Gaussian distributions, with means equal to the values of the short and the long standards, respectively, and some coefficient of variation c. If the difference between $D(s^*, t)$ and $D(l^*, t)$ is less than a threshold value b, the model responds long. That is to say, the model responds long when faced with ambiguous cases, when it cannot tell whether t is closer to the short or long standard. In contrast, when the difference between $D(s^*, t)$ and $D(l^*, t)$ is greater than b, and thus more clearly differentiated, the model responds short if $D(s^*, t) < D(l^*, t)$ and long if $D(s^*, t) > D(l^*, t)$.

Thus, c is the first parameter of the MD model, and b the second. This last parameter is a sort of bias toward responding long, which is the default in ambiguous conditions (see Droit-Volet & Wearden, 2001). Increasing the value of b shifts the proportion of long responses for intermediate comparison stimulus durations to the left and lowers the bisection point, without altering the slope of the bisection function. In contrast, the parameter c (the coefficient of variation of the memory representation of the standards) affects the slope of the psychophysical function. A greater value of c indicates a less precise representation of the standard durations, and thus the psychophysical function flattens; a smaller value of c indicates a more precise representation and steeper psychophysical function.

In the developmental version of the MD model, Droit-Volet and Wearden (2001) added a third parameter, p, the proportion of responses emitted at random (i.e., short and long responses are equiprobable) on each trial without reference to the stimulus duration value. Random responses are rare in human adults, but frequent in young children (Droit-Volet, 2002). The parameter p is the third parameter of this model. To account for the modality effect on bisection performance, we added a fourth parameter, x, which acts as a multiplier of the comparison stimulus duration. Thus, if x was 1.0, the stimulus comparison duration was perceived in the same way as the standard duration. If x was less than 1.0, the stimulus comparison duration was perceived as shorter than the standard duration, and if x was more than 1.0 it was perceived as longer. In the visual standard group, if the clock runs faster for the auditory than for the visual stimuli, then the auditory comparison stimuli are judged longer than the visual standards, and the parameter x increases. In this case, $x = 1.20$ would indicate that the clock runs 20% faster for the auditory than for the visual stimuli. Conversely, in the auditory standard group, if the visual comparison stimuli are judged shorter than the auditory standards, the parameter x should be relatively smaller. Thus, $x = 0.90$ would indicate that the clock for visual stimuli runs 10% slower than for auditory stimuli. Therefore, four parameters were used in our model: c, a coefficient of variation of the remembered standard; b, a bias toward long responses; p, a proportion of random responses; and x, a multiplier for the speed of the clock.

Modelling of data. The model described above was implemented in a program written in Visual Basic 6 (Microsoft Corporation), and the experimental conditions were simulated with 1000 trials for each stimulus duration. Table 3 shows the parameter values from fits of this model. The mean absolute deviations (i.e., *ad*) indicate that the model fits the data reasonably well in the three age groups, with mean deviations smaller than .05. The model fitted our data on the differences between the sensory modalities. The x parameter was stable in the within-modality session (close to 1.0) in the three age groups. However, this parameter increased or decreased in the cross-modality session as a function of the cross-modal order. Indeed, the x parameter was greater in the visu/audi session (i.e., when the auditory comparison stimuli were compared to the visual standards) than in the visu/visu session (within visual modality comparison). Conversely, it was smaller in the audi/visu session (i.e., visual stimuli compared to the auditory standards) than in the audi/audi session. These two results demonstrated that the clock speed was faster for the auditory than for the visual stimuli and, consequently, that the participants judged the auditory stimuli as longer. Furthermore, our model proposed that the difference in the clock speed between the auditory and the visual modality would be slightly larger for the 5-year-olds than for the 8-year-olds and the adults, which might indicate that the speed of the internal clock runs relatively more slowly for the visual modality in the youngest children.

The model also captured other developmental trends. First, the coefficient of variation of the memory representation of the standards, c, decreased with increasing age, but did so to a greater extent between 5 and 8 years than between 8 years and adulthood. Second, this coefficient of variation was also greater for the visual standard durations than for the auditory standard durations in the children, but not in the adults. Thus, the remembered standard durations were generally more variable in the younger children, and this variability was greater for the visual than for the auditory sensory modality. Third, no random responses were

TABLE 3
Parameter values derived from fits of the developmental version of Wearden's (1991) modified difference model and data from each age group in the visual standard group and the auditory standard group for the within-modality[a] and cross-modal[b] comparison sessions

		5-year-olds					*8-year-olds*					*Adults*				
Groups		*c*	*b*	*p*	*x*	*ad*	*c*	*b*	*p*	*x*	*ad*	*c*	*b*	*p*	*r*	*ad*
Visual standard	visu/visu	.81	.35	.06	0.99	*.04*	.42	.40	.00	1.05	*.03*	.25	.40	.00	1.05	*.04*
	visu/audi	.81	.35	.06	1.20	*.04*	.42	.40	.00	1.11	*.03*	.25	.40	.00	1.15	*.04*
Auditory standard	audi/audi	.70	.35	.06	0.98	*.04*	.30	.40	.00	1.05	*.03*	.25	.40	.00	1.05	*.03*
	audi/visu	.70	.35	.06	0.70	*.03*	.30	.40	.00	0.90	*.04*	.25	.40	.00	0.92	*.04*

Note: *c* is the coefficient of variation of the memory representation of the short and long standard durations, *b* the bias toward the long response, *p* the probability of random responding, and *x* the multiplier factor for the comparison stimulus duration. *ad* is the mean absolute deviation, the sum of absolute differences between the data points and the fitted functions divided by 7, the number of data points.

[a]Visu/visu and audi/audi.

[b]Visu/audi and audi/visu.

required to account for bisection performance in the 8-year-olds and the adults, whereas 6% random responses were required for the youngest children. However, here, the proportion of random responses remained fairly low compared to the 10 and 15% found by Droit-Volet and Wearden (2001) with longer duration values, respectively 1–4 s and 2–8 s. This suggests that the proportion of random responses emitted by young children increases with the length of the durations to be judged. Finally, Table 3 indicates that the bias toward long responses did not significantly differ with age or sensory modality, the between-condition variation being less than or equal to 5%.

Discussion

The present experiment examined temporal bisection in 5- and 8-year-olds and adults when they were required to compare stimulus durations to memory representations of short and long standards presented either in the same sensory modality as the stimulus comparison duration (within-modality comparison) or in another modality (cross-modal comparison). Our results showed that, in the three age groups, participants judged the auditory stimuli to be longer than the visual ones. However, the auditory-visual difference in bisection appeared more marked when the participants compared the visual comparison stimuli to the auditory standards than vice versa—that is, when they compared the auditory comparison stimuli to the visual standards. In line with previous studies, our results also showed that the bisection task produced orderly data in children as young as 5 years old, but that the sensitivity to duration was lower in the 5-year-olds than in the 8-year-olds, an age at which temporal sensitivity approached that of adults. Furthermore, our data indicated that the sensitivity to duration was lower for visual than for auditory stimuli in the 5-year-olds, but not in the 8-year-olds and the adults. The modified difference model used to fit our data suggested that this lower temporal sensitivity for the visual durations in the youngest children was related to the fact that their memory representations of the short and long standard durations were more variable in the visual than in the auditory modality.

The present experiment showed that the subjective duration of auditory stimuli was longer than that of visual stimuli of the same objective duration, and this was found whatever the age group tested. According to scalar timing theory, two operations can produce this lengthening effect: one at the level of the pacemaker of the internal clock and the other at the level of the switch between the pacemaker and the accumulator. Indeed, if the pacemaker runs faster or the switch closes earlier with auditory stimuli, the result in both cases is a greater number of accumulated pulses and, consequently, a longer subjective time. Nevertheless, these two operations can be dissociated (Burle & Casini, 2001). As explained previously, the validation of the pacemaker hypothesis requires a multiplicative effect of the modality with the stimulus duration values, whereas an additive effect is required to validate the switch hypothesis. Therefore, the data obtained in the present study (i.e., the ANOVAs on the proportion of long responses, d' scores), as well as our model, provide clear support for the clock speed hypothesis. First, the auditory-visual difference was larger for the longest stimulus duration values. Second, the multiplier parameter x used in our model increased and decreased respectively when the auditory stimuli were compared the visual standards and the visual stimuli to the auditory standards. Thus, the longer subjective time in the auditory modality found in our study in all age groups was due to the fact that the pacemaker of the internal clock runs faster for the auditory than for the visual stimuli. This finding is entirely consistent with most studies conducted with human adults (e.g., Goldstone & Lhamon, 1972, 1974; Penney et al., 1998, 2000; Wearden et al., 1998). The original contribution of our experiment was to show that this modality phenomenon in temporal discrimination exists as of the age of 5 years.

In their model, Penney et al. (2000) evaluated the visual clock rate as being 10% slower than the auditory clock rate. The developmental version of the modified difference model used in our study found similar differences in the clock rate for the adults as well as for the younger children aged 8 years. Indeed, in these two age groups, the multiplier parameter x indicated that the visual clock rate was from 6 to 15% slower than the corresponding auditory rate. In addition, our model suggests that the magnitude of this difference in the clock speed should be larger in the 5-year-olds than in the 8-year-olds and the adults (i.e., 21 to 28%). It is therefore reasonable to suppose that the clock speed runs even slower in the visual than in the auditory condition in the youngest children.

However, in the present bisection task, the 5-year-olds judged the visual stimuli to be shorter than the auditory ones. However, their temporal judgements were also more variable for visual stimuli, as shown by the fact that their psychophysical functions were flatter and their Weber ratios greater for visual than for auditory stimuli. Their sensitivity to duration was lower in the visual than in the auditory modality. According to scalar timing theory, clock speed can be a cause of variability differences. Indeed, this theory proposes that the time estimates depend upon a count of pulses generated by a Poisson source that emits pulses at random but at some constant mean rate (Gibbon, 1977, p. 284). Consequently, on the basis of the mathematics of such a Poisson pacemaker, Gibbon explained that a slower pacemaker rate produces more variable temporal estimates. Consequently, because the clock speed was slower for the visual than for the auditory stimuli in the 5-year-olds, their temporal discrimination was more variable and their bisection functions flatter coupled with a larger Weber ratio.

However, it has been argued that the differences in the pacemaker speed are not the main source of variability of the timing system (Gibbon et al., 1984). In line with this argument, although investigating the modality effect in bisection performance, Penney et al. (see 1998, 2000) proposed low variability in temporal accumulation. In fact, according to scalar timing theory, the main source of variance is in the memory-encoding process as we now discuss. In both a temporal generalization and a verbal estimation task, Wearden et al. (1998) observed that adults' temporal judgements, like those of the youngest children in our bisection task, were more variable with the visual than with the auditory stimuli. They then suggested that this modality effect on the variability of temporal judgements is produced by the greater variance of the switch latency for the visual than for the auditory stimuli. In order to dissociate the pacemaker speed effect (slower speed for visual signal) and this switch-latency effect on the variability of temporal judgements, Wearden et al. (1998) combined both the sensory modality of presentation of stimulus durations (visual or auditory) and the presence or absence of a 5-s sequence of clicks, which was thought to increase the pacemaker speed (see, e.g., Treisman, Faulkner, & Naish, 1992). In these experimental conditions, they showed that the presence or absence of clicks changed the length of the mean estimates in the same way as the modality, but only the modality produced significant differences in the coefficient of variation of time judgements. Thus, Wearden et al. (1998) concluded that the greater variance in the switch latency for the visual stimuli explained the greater variability of temporal judgements for the visual than for the auditory signal.

In the present bisection task, a greater Weber ratio for the visual than for the auditory stimuli was obtained in the 5-year-olds, but not in the 8-year-olds or the adults. This observation was consistent with the data found in human adults by Penney et al. (2000) using a similar bisection task. Several theories suggest that young children have limited attentional capacity to resist interference from external stimuli (for a review, see Dempster & Brainerd, 1995). In other words, young children are easily distracted. Following this line of reasoning, Gautier and Droit-Volet (2002b) showed that introducing an attentional distractor in a bisection task disrupted the processing of duration to a greater extent in 5-year-olds than in 8-year-olds. According to attentional models of time perception, attention acts on the closure and the opening of the switch allowing the flow of pulses to be accumulated (for a review, see Lejeune, 1998). Furthermore, some studies of human adults have revealed that a high level of attention to time reduces the variability of switch latency and improves temporal discrimination. Conversely, a lower level of attention increases the variability of the switch latency and, thus, the variability of the representation of signal duration in memory (Allan, 1992; Whiterspoon & Allan, 1985). Consequently, as suggested by our model, young children have less precise representations of the standard durations in memory, and these representations are even less precise for visual than for auditory standard durations, as a result of the children's limited attentional control capacities. Indeed, in the task used here for young children, processing the duration of visual stimuli requires particularly great attentional effort. As explained in the introduction, the processing of this duration effectively requires subjects to direct their attention towards a physical source of information (i.e., the computer screen) in order to detect the onset of the visual signal, but also to maintain the attentional focus. Of course, processing the duration of auditory stimuli also requires attention, but in a less constrained way for young children. In summary, since their memory representations of the standard durations are less precise for visual than for auditory stimuli because of their reduced attention capacity, the 5-year-olds had a lower temporal sensitivity for the visual than for the auditory stimuli.

In young children, the greater sensitivity to duration for the auditory than for the visual stimuli suggests a sort of a dominance of audition over vision in the processing of time. This idea links to that put forward by experiments in another field of research, that of infants' perception of the temporal characteristics of speech sounds and rhythms (for a review, see Pouthas, Droit, & Jacquet, 1993). In this field of research, Eimas, Siqueland, Jusczyk, and Vigorito (1971) showed that infants can distinguish elementary speech segments (i.e., Pa, Ta, Ba, Da) on the basis of their temporal acoustic characteristics. Lewkowicz (1988a, 1988b) also showed that 6-month-old infants detect changes in temporal rate in the auditory modality but not in the visual modality when static visual stimuli are used, whereas 10-month-olds respond to rate changes in both modalities. As he stated, the audition is specialized for the processing of temporal information, whereas vision is relatively more specialized to detect motion (Lewkowicz, 1989, 1992). Friedman (1990, p. 87) added that "the early sensitivity to the temporal characteristics of sound may be a special biological adaptation that allows infants to process information about speech."

This dominance of auditory modality over visual modality in temporal processing allows us to explain in part the greater magnitude of the auditory-visual difference in our bisection task when the visual stimuli were compared to the memory representation of the auditory standard durations (i.e., auditory standard group) than when the visual stimuli were compared to memory representation of the auditory standards (visual standard group). However, this does not clearly explain why there was no marked evidence of a visual–auditory difference in the visual standard group for the 8-year-olds and the adults. As discussed previously, scalar timing theory suggests that the short and the long standard durations are represented in memory in the form of Gaussian distributions with means equal to the standard values. In our experiment, this average representation of the standards was constructed in the training trials during which the participants received feedback. Then, in the test phase, the participants were given no feedback and were explicitly instructed to compare the visual comparison stimulus durations to the auditory standards stored in long-term memory. However, we could suggest that the representation of the standards progressively changed in the course of the bisection test. Penney et al. (2000) showed that, in a bisection task, when auditory and visual comparison stimuli were presented simultaneously, a process of memory mixing occurred. That is to say, the participants constructed an averaged memory representation including both the visual and the auditory stimuli, rather than separated representations for each stimulus modality. However, in this condition, the representation of the standard durations in memory is often dominated by the auditory modality. In this perspective, we can suggest that in the visu/audi condition, the participants adjusted their memory representation of the standard durations in the course of the testing phase by including auditory samples in their initial representation of the standards. Consequently, in the visual standard group, the probability that the auditory comparison stimuli would judged to be significantly longer than the memory representation of the standard durations was smaller. However, in the auditory standard group, even if such a process occurred, the integration of visual samples in the memory representation of the standards did not modify the averaged representation of the standard durations, due to the auditory dominance. Thus, in this auditory standard group, the visual comparison stimuli were always judged to be significantly shorter than the auditory standards.

The question that can be raised here is why these changes in the memory representation of the standard durations did not occur in the youngest children in the visual standard group. To understand developmental changes in the construction of long-term memory representations of the standards in a bisection task further studies are needed. However, we can hypothesize that the process of construction of the memory representation of the standards would be less flexible in the 5-year-olds than in the 8-year-olds or the adults. In other words, the youngest children would have more difficulties in constructing a new representation of the standard durations. Thus, because they simply compared the current stimulus duration to the standard durations learned in the training phase, they judged the former to be shorter than the latter when the stimulus was visual and the standard auditory.

In conclusion, our results showed that the auditory stimuli were judged longer than the visual stimuli whatever the age group tested and that this was probably due to the faster clock rate for the auditory stimuli. Thus, these results provided support for the idea that the modality differences in the pacemaker speed were present at an early age. The age-related changes in the modality effect on time judgements would be explained by the temporal sensitivity that was lower for the visual than for the auditory stimuli in young children, related to the development of attentional control that itself affects the variance of the switch latency of the internal clock.

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