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Modality differences in timing and temporal memory throughout the lifespan

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ABSTRACT

The perception of time is heavily influenced by attention and memory, both of which change over the lifespan. In the current study, children (8 yrs), young adults (18–25 yrs), and older adults (60–75 yrs) were tested on a duration bisection procedure using 3 and 6-s auditory and visual signals as anchor durations. During test, participants were exposed to a range of intermediate durations, and the task was to indicate whether test durations were closer to the "short" or "long" anchor. All groups reproduced the classic finding that "sounds are judged longer than lights". This effect was greater for older adults and children than for young adults, but for different reasons. Replicating previous results, older adults made similar auditory judgments as young adults, but underestimated the duration of visual test stimuli. Children showed the opposite pattern, with similar visual judgments as young adults but overestimation of auditory stimuli. Psychometric functions were analyzed using the Sample Known Exactly-Mixed Memory quantitative model of the Scalar Timing Theory of interval timing. Results indicate that children show an auditory-specific deficit in reference memory for the anchors, rather than a general bias to overestimate time and that aged adults show an exaggerated tendency to judge visual stimuli as "short" due to a reduction in the availability of controlled attention.

1. Introduction

Timing and time perception are reliably affected by manipulations of attention and memory, and provide a powerful tool for studying the neurobiology of these cognitive constructs in humans and other animals (e.g., Buhusi, 2003; Buhusi & Meck, 2005, 2006a, 2006b, 2009; Buhusi, Perera, & Meck, 2005; Coull, Cheng, & Meck, 2011; Fortin, 2003; Fortin, Chérif, & Neath, 2005; Fortin & Massé, 2000; Fortin et al., 2009; Lustig, Matell, & Meck, 2005; Lustig & Meck, 2005; Meck, 2002, 2005, 2006; Meck & Benson, 2002; Meck, Penney, & Pouthas, 2008; N'Diaye et al., 2004; Penney, Gibbon, & Meck, 2008; Pouthas & Perbal, 2004). Here, we explore normal developmental changes in attention and memory in the context of temporal cognition. Interval-timing procedures have recently attracted interest as a method of studying cognition at both ends of the lifespan, childhood (e.g., Allman, DeLeon, & Wearden, 2011; Brannon, Libertus, Meck, & Woldorff, 2008; Brannon, Roussel, Meck, & Woldorff, 2004; Droit-Volet, 2002, 2003; Droit-Volet, Clément, & Wearden, 2001; Droit-Volet & Meck, 2007; Droit-Volet, Meck, & Penney, 2007; Rattat & Droit-Volet, 2001) and old age (e.g., Lustig & Meck, 2001; McCormack, Brown, Maylor, Richardson, & Darby, 2002; Perbal, Droit-Volet, Isingrini, & Pouthas, 2002; Rakitin, Stern, & Malapani, 2005; Wearden, Wearden, & Rabbitt, 1997; see Lustig, 2003 for review). However, thus far only one investigation (McCormack, Brown, Maylor, Darby, & Green, 1999) has directly compared the timing performance of children (age 5, 8, and 10 yrs), young adults (age 16–25 yrs), and older adults (age 63–99 yrs).

McCormack et al. (1999) tested participants on two interval-timing tasks that are frequently used with both humans and lower animals, the temporal generalization task (Church & Gibbon, 1982; Droit-Volet et al., 2001, 2007; Meck & Church, 1982) and the duration bisection task (Allan & Gibbon, 1991; Cheng, MacDonald, & Meck, 2006; Church & Deluty, 1977; Droit-Volet & Wearden, 2001; Kopec & Brody, 2010). The generalization task required participants to indicate whether the duration of each probe tone matched the duration of a previously learned standard. Both older adults and children were less accurate than were young adults. Children, especially 5-yr olds, showed an interesting additional effect: They were more likely than either adult group to overestimate the duration of the probe stimulus, calling the probe duration the "same" as the standard even when it was much shorter.

A similar pattern was found for the duration bisection task. Participants were first trained to call one standard duration (200 ms) of tone presentation "short" and another duration (800 ms) "long". They were then presented with probe tones of intermediate durations and asked to judge which standard

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duration the probe duration was closer to, ‘‘short’’ or ‘‘long’’. Here, older adults were approximately as accurate as young adults, and the youngest group of children showed the worst performance of all groups. Consistent with their tendency to overestimate probe durations in the generalization task, the 5-yr old participants were more likely than were other groups to overestimate short probe durations in the bisection task and call them ‘‘long’’. However, this youngest group was also more likely than the other groups to underestimate the duration of long probe durations and call them ‘‘short’’.

McCormack et al. (1999) explained the reduced accuracy of children and older adults in the temporal-generalization task by suggesting that these groups have a ‘‘noiser’’ perception of duration than do young adults, leading to less accurate judgments of time. In order to explain the 5-yr olds’ tendency to overestimate the duration of probe durations relative to the standard, they proposed that young children have a distorted (shortened) memory representation of the standard duration. In this paper, we ask whether this memory distortion is a general phenomenon, or modality-specific.

Attention and memory effects in interval timing are typically explained using information processing models such as Scalar Timing Theory (Gibbon, Church, & Meck, 1984) or related frameworks (including that used by McCormack et al., 1999; see also Brown, McCormack, Smith, & Stewart, 2005). By these models, attention to a to-be-timed stimulus closes a switch, completing a circuit to allow the accumulation of pacemaker pulses that mark the passage of time (Lejeune, 1998, 2000). During training for the bisection task, participants learn to call the pulse accumulations associated with one anchor duration ‘‘short’’, and accumulations associated with the other anchor duration ‘‘long’’. The accumulation for each signal’s duration is passed into reference memory, and variability in the encoding and decoding of durations across trials leads to each label being associated with a distribution of values rather than a single discrete number (Gibbon & Church, 1984). At test, when participants are presented with a probe duration and asked to indicate which of the two anchor durations it is closer to, the decision is made by comparing the number of pacemaker pulses accumulated during the probe duration to samples drawn from the ‘‘short’’ and ‘‘long’’ distributions in reference memory (Allan, 2002; Gibbon, 1981).

This characterization of the duration bisection task has recently been used in combination with the classic finding that ‘‘sounds are judged longer than lights’’ to further examine the roles of attention and memory in duration judgments. If both modalities are used within the same experimental session and with the same anchor durations, participants are more likely to give ‘‘long’’ judgments to auditory than visual probes (Penney, Allan, Meck, & Gibbon, 1998; Penney, Gibbon, & Meck, 2000; Penney & Tourret, 2005; Wearden, Edwards, Fakhri, & Percival, 1998). This difference may occur because auditory stimuli capture and hold attention relatively automatically, whereas attending to visual stimuli requires controlled attention (Meck, 1984; Penney, 2003; Penney, Holder, & Meck, 1996; Penney et al., 2000). Auditory stimuli are therefore more efficient at holding the switch closed, allowing larger pulse accumulations. If reference memory distributions intermix relatively small visual and relatively large auditory values for the anchor durations, auditory probes have an increased probability of being judged ‘‘long’’ compared to the anchors (vice versa for visual probes).

This explanation of the classic ‘‘sounds are judged longer than lights’’ finding has been tested in an extensive series of duration bisection experiments using young adult participants (e.g., Penney et al., 2000) as well as rats (e.g., Cheng, Etchegaray, & Meck, 2007). Moreover, both children and older adults show an exaggerated modality effect compared to young adults, consistent with age-related modifications in attentional control (Cheng, Dyke, McConnell, & Meck, 2011; Cheng, Scott, Penney, Williams, & Meck, 2008; Droit-Volet et al., 2007; Lustig & Meck, 2001; McAuley, Miller, Wang, & Pang, 2010). In the current experiment, children, young adults, and older adults were tested in a duration bisection procedure with auditory and visual signal durations to determine how interval timing is affected by developmental changes in attention and memory over the lifespan.

2. Materials and methods

2.1. Participants

There were 36 participants: 12 children (6 males and 6 females, mean age = 8.24 yrs, SE = 0.08), 12 young adults (5 males and 7 females, mean age = 20.3, SE = 0.53), and 12 older adults (6 males and 6 females, mean age = 68.7, SE = 1.29) served in this experiment. Participants were screened for medical or psychiatric conditions with a potential detrimental effect on cognition and motor performance. The younger adults were college students and all of the older adults had completed at least 3 yrs of college. None of the participants had received formal musical training/practice within the last year.

2.2. Material and design

Stimuli were presented using an Apple Macintosh Quadra 700 computer with a 14” Apple color monitor and consisted of either an 880 Hz tone or 5.5” black square. The participants were tested individually in a quiet room with standard indoor fluorescent lighting. No fixation point was used for any of the conditions, neither was there any ramping of the auditory or visual stimulus presentations. Anchor durations were 3 s (‘‘short’’) and 6 s (‘‘long’’), with five intermediate signal durations (3.37, 3.89, 4.24, 4.76, and 5.35 s) also used during testing. Following each stimulus, participants pressed the ‘‘S’’ or ‘‘L’’ key on the computer keyboard to indicate whether its duration was closer to the ‘‘short’’ or ‘‘long’’ standard, and were instructed to silently focus on the task without counting, foot-tapping, singing, or subdividing the interval in any way.

Participants initially completed 12 training trials, consisting of three trials from each modality at each of the two anchor durations (3 and 6 s). If participants were correct on $\geqslant$75% of the trials during the training phase, training was terminated and was immediately followed by the testing phase. All participants reached this criterion within the first 12 training trials. In addition to the two anchor durations, for which feedback continued to be provided following response classification, five intermediate signal durations were also presented during the testing phase. No feedback was provided for the classification of these intermediate signal durations. Anchor durations consisted of 5 trials at each modality $\times$ duration combination, resulting in 20 trials. Intermediate duration test trials consisted of five trials at each modality $\times$ duration combination, resulting in 50 trials – for a total of 70 trials presented in a random order. Trials at the anchor durations during both training and testing were followed by onscreen feedback indicating a correct or incorrect response. For children this feedback consisted of a smiling (correct response) or frowning (incorrect response) clown face presented for 2 s. For young and older adults this feedback consisted of a 2-s presentation of the words ‘‘CORRECT’’ or INCORRECT’’ for correct and incorrect responses, respectively. Each trial or feedback screen was followed by a blank inter-trial interval, randomly varied between 0.5 and 2.5 s.

3. Results and discussion

Group bisection functions plotting the probability of a ‘‘long’’ response as a function of signal duration for each modality

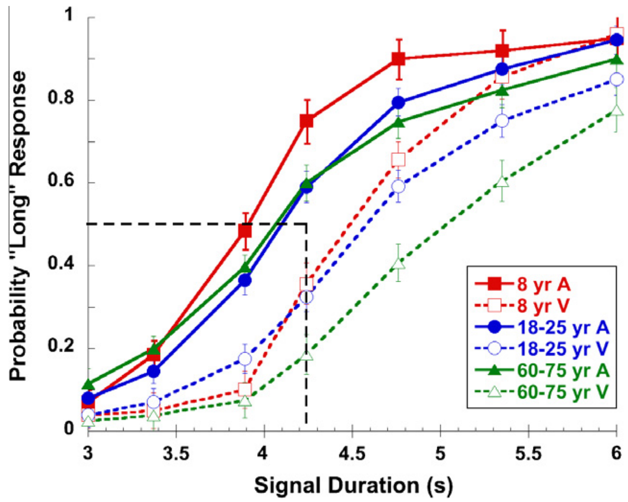

Fig. 1. Mean duration bisection functions averaged across participants in each age group: Children (8 yrs), young adults (18–25 yrs), and older adults (60–75 yrs). Probability of a "long" response is plotted as a function of auditory (A) and visual (V) signal durations. The perpendicular lines indicate the canonical point of subjective equality (PSE) at the geometric mean of the anchor durations (3 and 6-s anchors, geometric mean = 4.24 s).

(auditory, visual) are displayed in Fig. 1. These psychometric functions closely resemble previous timing data in their sigmoidal form and in the overall pattern of visual functions being shifted to the right of the functions for auditory signals (e.g., Cheng et al., 2008, 2011; Droit-Volet, Tourret, & Wearden, 2004; Droit-Volet et al., 2007; Lustig & Meck, 2001; Meck, 1991; Melgire et al., 2005; Penney, Meck, Roberts, Gibbon, & Erlenmeyer-Kimling, 2005; Penney et al., 2000). This replication of the classic "sounds are judged longer than lights" effect has been explained by the attention-driven differences in clock speed for the two modalities (i.e., the clock is slower for visual signals because they are less efficient at closing the attentional switch that allows the accumulation of pulses that mark the passage of time), combined with "mixed-modality" memory distributions for each anchor duration (e.g., Gu & Meck, 2011; Penney et al., 1998, 2000).

Inspection of the psychometric functions suggests that both children and older adults show a larger modality effect than do young adults, but for different reasons. Consistent with previous findings (e.g., Lustig & Meck, 2001), older adults have auditory functions that are similar to those of young adults, but their visual functions show an exaggerated rightward shift. In contrast, children have left-shifted auditory functions compared to young adults, replicating the results of McCormack et al. (1999), but visual functions that are similar to those of young adults. This pattern suggests that children's tendency to overestimate durations may be somewhat modality-dependent, rather than a general property due to poor memory for the standards (McCormack et al., 1999), inattention, or impatience (Block, Zakay, & Hancock, 1999; Droit-Volet et al., 2007).

Each participant's data were fit to a 3-parameter sigmoidal function in MATLAB (Mathworks – Natick, MA) using a maximum likelihood method. A point of subjective equality (PSE), a measure of timing accuracy, was calculated for each participant by using this function to determine the signal duration that produced a "long" response 50% of the time. A difference limen (DL), a measure of variability, was also calculated from the sigmoidal function by subtracting the signal duration at which 25% of responses were "long" responses from the signal duration at which 75% were "long" responses, and then dividing this value by 2. The Weber fraction (WF), a measure of relative variability in responding, was also obtained by dividing the DL by the PSE. Statistical tests (ANOVAs and *t*-tests) for significant differences in behavior between sessions were calculated in Statistica (StatSoft – Tulsa, OK) using the PSE, DL and WF, of individual participants.

A repeated-measures ANOVA conducted on the DL measures indicated a significant effect of age, $F(2,33) = 5.73$, $p < 0.01$, but a non-significant effect of signal modality, $F(1,33) = 0.60$, $p > 0.05$; whereas the age × signal modality interaction was highly significant, $F(2,33) = 87.11$, $p < 0.0001$. A repeated-measures ANOVA conducted on the PSE measures indicated significant effects of age, $F(2,33) = 17.50$, $p < 0.0001$; signal modality, $F(1,33) = 75.01$, $p < 0.0001$; and the age × signal modality interaction, $F(2,33) = 6.36$, $p < 0.01$. A repeated-measures ANOVA conducted on the WF measures indicated significant effects of age, $F(2,33) = 3.92$, $p < 0.05$; signal modality, $F(1,33) = 19.97$, $p < 0.0001$; and the age × signal modality interaction, $F(2,33) = 33.49$, $p < 0.0001$. Group mean (±SEM) PSE, DL, and WF measures are shown in Table 1.

To more formally evaluate group differences in timing, we applied the *Sample Known Exactly-Mixed Memories* (SKE-MM) quantitative model of Scalar Timing Theory, developed for duration bisection data when auditory and visual signals are presented during the same session (see Penney et al., 2000, p. 1787, Appendix B for a full description of the SKE-MM model and Carroll, Boggs, O'Donnell, Shekhar, & Hetrick, 2008, 2009; Droit-Volet et al., 2007; Lustig & Meck, 2001; Penney et al., 1998, 2000, 2005 for applications of the SKE-MM model to different data sets). The model assumes that psychological time is linear with physical time. Auditory and visual signals are assumed to have separate clock speeds, with values from both modalities assigned to the anchor duration categories in reference memory ("memory mixing"). Sources of variability include encoding and decoding variability in the representation of the anchor durations as well as variability in the representation of the current clock reading – presumably due to between-trial differences in clock speed for both auditory and visual signals. Four model parameters were allowed to vary: (1) A sensitivity parameter, gamma [γ], which is the coefficient of variation of remembered time. (2) A location parameter, beta [β], representing bias to respond "long". The SKE-MM model assumes

Table 1
Point of subjective equality (PSE), difference limen (DL), and Weber fraction (WF) measures for the auditory and visual signal functions in the 3 vs. 6-s duration bisection task.

Groups	Auditory			Visual		
	PSE	DL	WF	PSE	DL	WF
Children (8 yrs)	3.83 s (0.07)	0.76 (0.03)	0.20 (0.01)	4.47s (0.08)	0.76 (0.03)	0.11 (0.01)
Young adults (18–25 yrs)	4.15 s (0.07)	0.52 (0.02)	0.13 (0.01)	4.62s (0.08)	0.62 (0.02)	0.14 (0.01)
Older adults (60–75 yrs)	4.16 s (0.08)	0.62 (0.02)	0.15 (0.01)	5.10s (0.13)	0.75 (0.04)	0.16 (0.02)

Note: Numbers are group means (±SEM) of the auditory [A] and visual [V] point of subjective equality [PSE], difference limen [DL] and Weber fraction [WF] measures.

that there is no variability in β, or in x_T, the percept of current time. (3) A relative rate parameter, [RR] representing the ratio of the visual clock speed to the auditory clock speed. RR equals 1.0 when the auditory and visual clock speeds are equivalent and is less than one when the auditory clock speed is faster than the visual clock speed. (4) A memory mixture parameter, [$P(a)$], representing the proportion of the anchor duration reference memory distributions that is contributed by the auditory signals. $P(a)$ can range from zero, meaning no auditory contribution to the memory, to 1.0, meaning complete auditory dominance of the memory. Consequently, a $P(a)$ value of 0.5 would indicate that equal contributions are made by auditory and visual signal durations. The SKE-MM model was fit to individual participant's response functions using a simplex fitting algorithm (Press, Teukolsky, Vettering, & Flannery, 1994). This model accounted for a relatively large proportion of the variance (90–95%) in the mean psychometric functions for each of the age groups. The major advantage of this theoretical model is that it allows for the simultaneous fit of both the auditory and visual functions of each participant and to determine which combination of model parameters (which are tied to psychological constructs) are required to account for the horizontal displacement of the psychometric functions – which is a somewhat surprising result given that the durations of the auditory and visual signals are physically identical.

Group mean values for each of the four SKE-MM model parameters are presented in Table 2. Gamma [γ] measures variability in the representation of the current accumulated time and in the encoding and decoding of representations of anchor durations. Lower values indicate less variability and thus greater sensitivity to signal duration. The three age groups did not differ on this measure: $F(2,33) = 1.34$, $p > 0.05$. There were also no group differences in bias towards a "long" response [β], $F(2,33) = 2.91$, $p > 0.05$. These patterns are not consistent with the idea that young children and older adults are generally more insensitive to time, or that children are generally biased to overestimate intermediate probe durations relative to the standards.

RR values were less than 1.0 for all groups, replicating typical findings of a faster auditory clock. However, as suggested by the psychophysical functions, the gap between auditory and visual clock speeds varied across groups, with larger differences found for children and older adults than for young adults, $F(2,33) = 14.99$, $p < 0.001$. The results for the auditory dominance measure [$P(a)$] also revealed differential modality effects across the three age groups, $F(2,33) = 83.23$, $p < 0.001$. Older adults showed a somewhat greater auditory dominance of memory than did young adults, Fisher's protected LSD = 0.10, $p < 0.01$. Children showed the opposite effect, with a much-reduced auditory dominance of memory compared to young adults, Fisher's protected LSD = 0.25, $p < 0.0001$.

This pattern of results suggests that the exaggerated modality effects that occur for both children and older adults occur for quite different reasons. For children, the modality effect seems to be largely based in memory, with the auditory contribution to the mixed-modality representations of the anchor values playing a reduced role compared to young adults. The findings for young and older adults replicate previous data suggesting that the visual stimuli require more controlled attention and that the tendency to judge visual stimuli as "short" is exaggerated by factors that reduce the availability of controlled attention, such as divided attention or advanced age (e.g., Lustig, 2003; Lustig & Meck, 2001; Penney et al., 1998, 2000). It is possible that age-related vision declines contributed to the increased modality effects for older adults. However, this seems unlikely given that the visual stimulus was highly salient and easily perceived (a large, high-contrast square presented in the middle of the screen). An attention-based explanation for the older adults' increased tendency to judge visual stimuli as "short" is also bolstered by previous findings that this tendency is also increased in young adults by factors that limit the availability of controlled attention (e.g., divided attention and circadian influences – see Lustig & Meck, 2001; Penney et al., 1998, 2000), and that older adults' timing performance is in general quite sensitive to attentional manipulations (e.g., Perbal et al., 2002; see Lustig, 2003 for a review).

The reduced $P(a)$ values for children suggest that reference memory samples for the anchor durations are more influenced by visually-presented durations than for the other age groups, perhaps in combination with a systematic distortion (shortening) of auditory reference values. The data do not support the idea of modality-general reduced attention or sensitivity to the probe or reduced memory for the anchors. Overall sensitivity (γ) values are similar across the different age groups. In contrast to the findings reported by Droit-Volet et al. (2007) using an 8-yr old age group and the same 3 vs. 6-s anchor durations, children's visual functions are similar or even better than young adults', with a sharper rise and a midpoint closer to the canonical unbiased PSE at the geometric mean (Allan & Gibbon, 1991 – see Allan, 2002 and Meck, 1983 for a discussion of the influence of response bias, clock speed, and a memory translation constant on the PSE). The reason for the children's poorer timing performance in the Droit-Volet et al. (2007) study is unclear, but may be related to the lack of feedback given during the test phase in this earlier study. Nevertheless, the basic finding of a larger "modality effect" for 8-yr olds than for young adults, primarily as a result of changes in their visual functions, as reported by Droit-Volet et al. (2007) is consistent with the pattern of results observed in the current study.

Some caution is also needed in applying our interpretation of the children's results to those of McCormack et al. (1999), given the different age groups and stimulus durations. However, findings from other tasks also suggest that while auditory information may have an advantage in attention or immediate memory, as is the case for young and old adults, at this stage of development auditory stimuli may be disadvantaged relative to visual stimuli in long-term memory. Auditory signals appear to access attention more automatically, even for very young children (Napolitano & Sloutsky, 2004; Robinson & Sloutsky, 2004). Comparing third, sixth, and ninth graders, Dempster and Rowher (1983) did not find age × modality effects for immediate recall, but third graders (approximately the same age as children in the current study),

Table 2
Parameter values from the Sample Known Exactly-Mixed Memories model of duration bisection.

	γ	β	RR	$P(a)$
Children (8 yrs)	0.25 (0.01)	0.90 (0.01)	0.82 (0.01)	0.12 (0.01)
Young adults (18–25 yrs)	0.28 (0.01)	0.89 (0.01)	0.90 (0.01)	0.37 (0.03)
Older adults (60–75 yrs)	0.28 (0.02)	0.85 (0.02)	0.81 (0.01)	0.47 (0.02)

Note: Numbers are group means (±SEM) of the four Sample Known Exactly-Mixed Memories (SKE-MM) model parameters *s* described in the text: (1) Gamma [γ] – a sensitivity parameter that reflects the coefficient of variation of remembered time. (2) Beta [β] – a location parameter that represents the bias to respond "long". (3) Relative rate [RR] – a modality difference parameter that corresponds to the ratio of the visual clock speed to the auditory clock speed. RR equals 1.0 when the auditory and visual clock speeds are equivalent and is <1.0 when the auditory clock speed is faster than the visual clock speed. (4) Proportional weight of auditory durations [$P(a)$] – a memory mixture parameter representing the proportion of the reference memory distributions that is contributed by the auditory anchor durations. $P(a)$ can range from 0, meaning no auditory contribution to the memory distribution, to 1.0, meaning complete auditory dominance of the memory distribution for the 3 and 6-s anchor durations.

showed a differential disadvantage for auditory stimuli in long-term memory.

Cowan and colleagues have shown that the period over which auditory information can be retained continues to increase until about the age of 12 yrs, as demonstrated by memory for ignored syllables and tone pitch, and by electrophysiological responses to mismatched tones (e.g., Cowan, Nugent, Elliott, & Saults, 2000; Gomes et al., 1999; Keller & Cowan, 1994). In younger groups, auditorily-presented information also shows a disadvantage relative to visually-presented information in narrative recall, particularly if the auditory information is in conflict with the visual information, or if the to-be-remembered information is of a temporal nature (Hayes & Kelley, 1984; Pezdek & Hartman, 1983; Pezdek & Stevens, 1984; Rolandelli, Wright, Huston, & Eakins, 1991).

In summary, our data revealed greater modality effects on interval timing for both children and older adults as compared to young adults, but in opposing directions. Older adults underestimated the duration of visual stimuli, whereas children overestimated the duration of auditory stimuli. The children's data suggest a differential developmental bias for visual versus auditory information in long-term memory, and join with those from studies of verbal and narrative recall to suggest that representations of auditory stimuli are disadvantaged relative to visual stimuli in children's long-term memory and age-related changes in arousal, attention, and motor timing throughout the lifespan (e.g., Bortoletto, Cook, & Cunnington, 2011; McAuley, Jones, Holub, Johnston, & Miller, 2006; Mella, Conty, & Pouthas, 2011). Additional support for this hypothesis comes from observations across a variety of domains (e.g., verbal memory, reality monitoring/source memory, TV presentations) in which a pattern seems to emerge where auditory information is better remembered for very short-term/working memory tasks (which are mostly mediated by online processing and represent the "current contents of consciousness"; e.g., Morra, 2000), whereas visual information is better remembered for more long-term memory tasks (e.g., Pezdek & Hartman, 1983). Future work will need to consider the possibility that children utilize an entirely different strategy than adults that relies more on working memory than long-term memory processes as well as asymmetries in cross-modal comparisons.

4. Conclusions

The present data make two important contributions. First, they suggest that previous estimates of children's distortions in temporal processing may have been exaggerated by the use of auditory stimuli. Second, they demonstrate the value of interval timing procedures for studying not only the basic aspects of memory and attention, but also the changes in brain and cognitive processes that occur throughout childhood and into old age.

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