*Article*

# Biases of Temporal Duration Judgements in Visual and Auditory System

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**Abstract:** Background: There is evidence that temporal duration is spatially represented on a horizontal mental timeline (MTL) with relatively short durations represented on the left and long duration on the right side. Most of this evidence comes from the visual domain. Objective: With the present study, we investigated whether temporal duration judgements of visual and auditory stimuli might be affected by spatial biases in time representation. Methods: Participants were asked to estimate the temporal duration of a target with respect to a reference stimulus. Two different exposure times were used for the reference (fast and slow), and three exposure times for the target with respect to the reference (shorter, equal, longer). Two versions of the task were implemented to probe visual and auditory temporal processing. Results: Participants showed enhanced performance when the target had longer duration than the reference independently of the type of task, but they were affected in opposite ways by the reference exposure time, in the two tasks. Best performance was observed for the fast reference in the visual domain and for the slow reference in the auditory one. Discussion: We argue that these findings provide evidence that temporal judgments of visual and auditory stimuli are affected by the duration of the reference stimulus, besides the duration of the target stimulus. Interestingly, they suggest putative leftward and rightward spatial biases in time representation for the visual and auditory domains, respectively, although future studies are necessary to further investigate these initial findings.

**Keywords:** auditory system; visual system; attention bias; exposure time; target; reference

## 1. Introduction

Mental representations of time, magnitude and space play a critical role in action planning and decision making in everyday life. The past literature has found evidence of a tight link between time and space in the brain. Here we further investigate putative interaction between time and space in the visual and auditory domains. According to Di Bono and colleagues [1] temporal duration of visual stimuli is spatially represented on a horizontal mental timeline with relatively short durations located on the left side and long duration on the right side, similarly to what occurs for spatial representation of numerical magnitudes (i.e., the mental number line or MNL) [2]. This evidence suggests that time, as numbers, is intimately linked to space at the cognitive level [2]. Spatial biases

in the mental representation of time may therefore affect time perception, as suggested by the finding that temporal duration of visual stimuli is overestimated or underestimated according to whether stimuli are presented on the right or left hemi-space, respectively [2]. Consistent with this finding, manipulation of visuospatial exploration by optokinetic stimulation affects temporal judgments: rightward attentional shifts induce overestimation and leftward attentional shifts underestimation of temporal features of visual stimuli [2].

Most research on the interaction of time and space has focused mainly on the visual domain [2], as described above, whereas little is known about the auditory system [1,3] or about differences between auditory and visual systems [4]. Retsa and colleagues [3] have observed that auditory stimuli are perceived as lasting longer than visual stimuli of the same duration. Burr and Alais [4] have shown that attentional resources for the two modalities are largely independent.

Here, we investigate the effects of spatial attention biases on time representation (i.e., duration judgments) and whether these effects might differ for visual and auditory stimuli, given that a leftward attentional bias is often observed in the visual modality (i.e., pseudoneglect) [5], while a rightward attentional bias might be observed in the auditory one [6].

To this end, we developed a novel paradigm in which participants estimated the temporal duration of a target stimulus (shorter-than, equal-to, and longer-than) compared to a reference stimulus. Two temporal durations (fast and slow) were employed for the reference stimulus, with the idea that short reference durations (i.e., fast Reference Exposure Time or RET) could anchor temporal estimation processing to the left side of the MTL and longer reference durations (i.e., slow RET) could anchor temporal estimation processing to the right side of the MTL. Specifically, visual and auditory versions of the temporal task were implemented to investigate whether the processing of stimulus temporal features might be affected by spatial attention biases that characterize each sensory modality [7]. If so, we would have expected to observe a different effect of stimulus duration on temporal judgements in the different modalities. In particular, we would have expected to observe better performance for fast references in the visual modality and for the slow references in the auditory modality. Since age may affect temporal perception (i.e., aging affects auditory and visual processing, resulting in a decline of temporal perception) [8] we investigate the above issues in healthy adults and healthy older adults.

## 2. Materials and Methods

### 2.1. Method

#### Participants

Thirty-eight healthy participants (W/M, 21/17 W-Mean age = 53.63, M-Mean age = 52.25) gave informed consent to participate in the study, which was approved by the local ethical committee (approval number UTE-0001).

Participants were categorized by age into two groups: the first group (adults) included 20 individuals with age ranging from 38 to 53 years (mean age = 46.94, SD = 5.03), the second group (older adults) included 18 individuals with age ranging from 61 to 71 years (mean age = 64.70, SD = 3.13). Participants were naive to the aims of the study.

The participants' hand dominance was assessed using the *Short form of the Edinburgh Handedness Inventory test* [9].

Dominant eye was determined by using a variant of the *Hole-in-the-Card test* [10]. On this test 27 subjects were right-eye dominant and 11 left-eye dominant.

### 2.2. Stimuli and Procedure

Participants were required to evaluate whether the duration of a target stimulus (Target Exposure Time-*TET*) was different from the duration of a reference stimulus (Reference Exposure Time-RET) in either the *Visuo-Temporal* task (VTT) or the *Audio-Temporal task* (ATT).

All participants underwent a training session for each task to become familiar with the procedure.

More details on the training session plan in Table 1:

**Table 1.** Training session plan.

| Timing | Activity | Description Activities | Resources/Materials |
|--------|----------|------------------------|---------------------|
| 5 m | Introduction | • Trainer introduces session<br>• Trainer hands out learning resources<br>• Learners follow trainer instructions | Learning resource |
| 10 m | Modelling of task | Trainer models task to be learnt | Learning resource andequipment |
| 25 m | Supported learning | Learners perform task with support from trainer | |
| 10 m | Close | • Trainer leads review of session (questioning)<br>• Trainer leads reflection of session (questioning) | |

Participants were instructed to keep their gaze on question mark at the center of the screen throughout the experiment. At each trial, the subject had to decide whether *TET* temporal duration was equal, shorter, or longer than RET duration. They were asked to respond as fast as possible after target presentation by using arrow keys of a standard computer keyboard (right arrow for longer, left arrow for shorter, down arrow for equal). A total of 72 trials equally distributed across conditions were presented, divided into two blocks, for each task. Within each block trials were presented in random order.

More details on the distribution of the 72 trials (in the two blocks) on the conditions of the within-subject independent variables are reported in Table 2:

**Table 2.** Block design: 2 (RET condition) * 3 (*TET* condition) * 6 (trials number) for visual and auditory stimuli separately.

| Block | Reference Type | Target Type | Number of Trials |
|-------|---------------|-------------|------------------|
| Visual | Fast RET (1400 ms) | Shorter *TET*: (800 ms−1100 ms range)<br>Equal *TET*: (1400 ms)<br>Longer *TET*: (1700 ms−2000 ms range) | 6 |
| | Slow RET (2000 ms) | Shorter *TET*: (1400 ms−1700 ms range)<br>Equal *TET*: (2000 ms)<br>Longer *TET*: (2300 ms−2600 ms range) | 6 |
| Auditory | Fast RET (1000 ms) | Shorter *TET*: (500 ms−750 ms range)<br>Equal *TET*:(1000 ms)<br>Longer *TET*: (1250 ms−14,500 ms range) | 6 |
| | Slow RET (1700 ms) | Shorter *TET*: (1200 ms−1450 ms range)<br>Equal *TET*: (1700 ms)<br>Longer *TET*: (1950 ms−2200 ms range) | 6 |

The exposure time (ET) of the visual and auditory stimuli was chosen based on previous work, in which time intervals similar to the ones we used were manipulated and shown to reflect short and long durations, respectively, in the cognitive processing of material presented on the specific modality (visual and auditory) (for more details, see [11–13].

The two tasks were implemented using the Psychopy software, version 1.81. Stimuli were presented on a Dell workstation running Windows 7 OS equipped with a 21-inch Dell monitor (resolution 1680 × 1050 pixels) and two speakers equidistant from the computer monitor. Participants were comfortably sitting in front of the monitor at a distance of 70 cm from the screen.

More details on the VTT and the ATT are reported in Figure 1.

**(a)**

# Visuo Temporal

| fast RET | [1400ms] | [1500ms] | [800-2000ms] | [1300-1900ms] |
|---|---|---|---|---|
| slow RET | [2000ms] | [1500ms] | [1400-2600ms] | [1300-1900ms] |



**(b)**

# Audio Temporal

| fast RET | [1000ms] | [1500ms] | [500-1500ms] | [2500-3500ms] |
|---|---|---|---|---|
| slow RET | [1700ms] | [1500ms] | [1200-2200ms] | [2500-3500ms] |



**Figure 1.** Example of a trial of VTT and ATT. (**a**) In VTT, the reference was a black square (size 190 × 190 pixels) appearing at the center of the screen for either 1400 ms (fast RET) or 2000 ms (slow RET). 1500 ms later (ISI), the target (a red square, 190 × 190 pixels) appeared in the same position. For the fast RET condition, *TET* exposure time was either between 800 ms and 1100 ms (shorter *TET*), or 1400 ms (equal *TET*), or between 1700 ms and 2000 ms (longer *TET*). For the slow RET condition, *TET* could either be between 1400 ms and 1700 ms (shorter *TET*), or 2000 ms (equal *TET*), or between 2300 ms and 2600 ms (longer *TET*). (**b**) In ATT, reference was a beep tone (WAV, 440 Hz, 46 dBA, duration 2000 ms, 16 BIT), which was presented either for 1000 ms (fast RET) or 1700 ms (slow RET) by two speakers arranged in line with the computer screen, to the right and left side of it. 1500 ms later (ISI), the target was presented. For the fast RET condition, *TET* could either be between 500 ms and 750 ms (shorter *TET*), or 1000 ms (equal *TET*), or between 1250 ms and 1500 ms (longer *TET*). For the slow RET condition, *TET* could either be between 1200 ms and 1450 ms (shorter *TET*), or 1700 ms (equal *TET*), or between 1950 ms and 2200 ms (longer *TET*). The time intervals for the response were between 2500 ms and 3500 ms for each block.

*2.3. Statistical Analyses*

Participants' accuracy (ACC) and reaction time (RT) were extracted and averaged for each condition. Moreover, ACC and RT were combined to generate a Performance Score (PS). To obtain this score, a two-stage procedure was adopted, as done similarly elsewhere [14]. First of all, separately for each subject, RTs were re-scaled to a value between 0 and 100, named rapidity, according to how close they were to the fastest (100) or

to the slowest (0) RT measured for that subject. Subsequently, the new rapidity score and accuracy rates were combined by using the following formula: performance_score = 0.5 × ACC + 0.5 × Rapidity. The final measure obtained encodes ACC-RT trade-off, since it assigns higher scores to both correct and fast responses while downweighting conditions either with low accuracy or with slow responses. Analyses were conducted on both tasks using Linear Mixed Models: *RET* (two levels: fast and slow) and *TET* (three levels: shorter, equal, longer) were used as within-subjects factors, while age (adult, older adult) was analysed as between-subject factor. "Subject" was the only random factor included in the models. The LMM was applied on PS, ACC and RT parameters.

For all analyses, gender and eye dominance were included as covariates in the model. In LMM-ANOVA, Greenhouse-Geisser degrees of freedom (df) correction was used to account for potential assumptions violation in the model. When necessary, Bonferroni correction was applied on post-hoc tests to obtain a global significance threshold of 0.05.

We did not explicitly compare visual versus auditory stimuli. First of all, this would not have been possible due to the relatively small sample size. However, directly contrasting scores of the two tasks was not our goal; indeed, knowing in which task subject were faster or more accurate in responding was not of our main interest, but rather how perception was driven in the two situations.

## 3. Results

*Visual temporal task: a* significant main effect for reference's exposure time (RET) was found for PS [F (1156.57) = 5.5, *p* = 0.02] and RT [F (1123.45) = 29.08, *p* < 0.001] (see Figure 2a,d). Moreover, a significant main effect for target's exposure time was observed for all variables analyzed: PS [F (2107.55) = 48.95, *p* < 0.001], ACC [F (2127.36) = 6.38, *p* = 0.002] and RT [F (2119.9) = 74.44, *p* < 0.001] (see Figure 2b,c,e). In detail, better performance and faster reaction times were obtained with FAST than SLOW RET and with longer *TET* in comparison to the other two *TET* (equal and shorter *TET*). Finally, a significant RET × *TET* interaction was also observed for RT [F (2112.77) = 15.05, *p* < 0.001] (see Figure 2f). Post-hoc analyses revealed that reaction time (corrected *p*-value < 0.001) was faster with SLOW than FAST RET when reference and target had equal durations. No significant difference was found between SLOW and FAST RET in the other two conditions of *TET*.

*Auditory temporal task: a* significant main effect for RET was found for PS only [F (1131.85) = 10.76, *p* = 0.001] (see Figure 2g). As for the VTT, a significant main effect for target's exposure time was observed for all variables analyzed: PS [F (2,17.32) = 28.68, *p* < 0.001], ACC [F (2119.16) = 3.36, *p* = 0.038] and RT [F (298.87) = 21.13, *p* < 0.001] (see Figure 2h,j,k,). Performance was better with SLOW than FAST RET. Again, better performance and faster was obtained with Longer *TET* (see Figure 2b,d). Furthermore, a significant RET x *TET* interaction was also observed for PS [F (2116.81) = 5.33, *p* = 0.006] and RT [F (2122.32) = 3.24, *p* = 0.043] (see Figure 2i,l). Post-hoc analyses revealed that performance (corrected *p*-value < 0.001) was better and reaction time was faster with SLOW than FAST RET when reference and target had longest durations. No significant difference between SLOW and FAST RET was found in the other two *TET* conditions.

No significant difference was found between the adult group and the older adult group.

Participants showed improved performance when the target had a longer duration than the reference, regardless of the type of task and the reference duration. Thus, the duration of the target affected performance in both modalities in a similar manner. This finding is consistent with a previous study in the visual domain [15], which showed that the best visual object representation occurred with long exposure times. Our study extends this finding [15], to auditory stimuli.

Interestingly, the duration of the reference stimulus affected performance on the two tasks in opposite ways. Temporal judgments were facilitated by a short reference duration in the visual domain and by a long reference duration in the auditory domain.
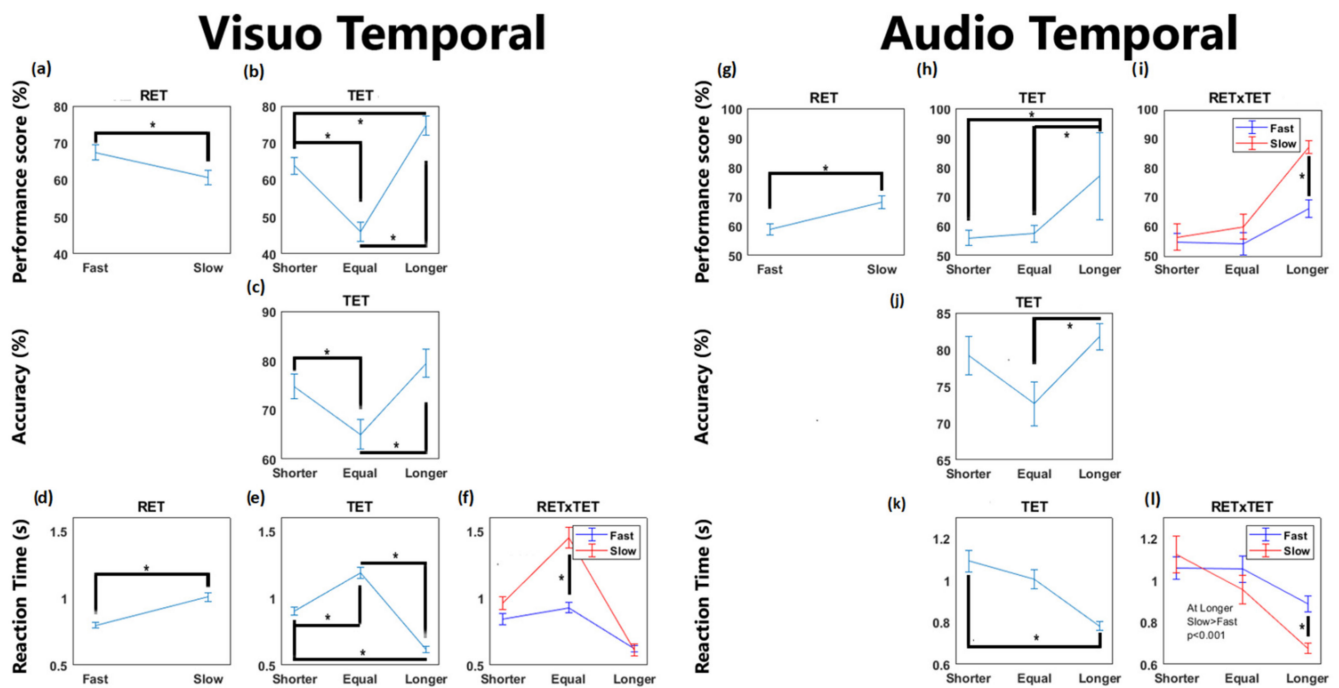
**Figure 2.** Participants' performance score, accuracy and reaction time for visual temporal task and Audio temporal task. RET scores are represented both for VTT (**a**,**d**) and ATT (**g**). The panels show results over the *TET* conditions, both for VTT (**b**,**c**,**e**) and ATT (**h**,**j**,**k**). RET × *TET* scores are presented for VTT (**f**) and ATT (**i**,**l**). Asterisks indicate significant results ($p = 0.05$), corrected for multiple comparisons. Error bars represent average and standard deviations. Note: The figure does not show plots for non-significant results. The factor age was not significant in any of the above analyses.

## 4. Discussion

According to the mental timeline theory [2], shorter durations are spatially encoded on the left side of the mental timeline, while longer durations are represented on the right side [2]. Thus, in the present study, short reference durations might have anchored temporal estimation processing to the left side of the MTL and longer duration to the right side of it. If this were the case, then best performance for the fast reference in the visual task and best performance for the slow reference in the auditory task might reflect possible attentional directional biases in spatial representation of time within each modality. Even though these assumptions would be considerably subjective, they would still be very useful in interpreting research claims and putting them in context.

The existence of an attentional directional bias for spatial processing is widely supported by a consistent body of literature (i.e., pseudoneglect) [5]. Recent evidence also suggests that this bias may be modality-specific [14], with a leftward bias occurring in the visual modality and a rightward bias in the auditory one [6]. However, it is unclear if such biases might also exist in the context of spatial representation of temporal judgment. A possible interpretation could be that because there is a leftward and rightward attentional bias in the visual and auditory domains, shorter and longer RETs are favored in these two conditions, respectively. A longer auditory RET is represented on the right of the mental timeline, and thus receives more attention and is represented with more fidelity in auditory memory. A shorter visual RET is represented on the left of the mental timeline, and thus receives more attention and is represented with greater fidelity in visual memory.

Taking together the abovementioned considerations, we propose that a possible interpretation of the present findings—showing facilitation effects for shorter duration of the visual reference and longer duration of the auditory reference—might relate to modality-specific biases for temporal processing, analogously to what occurs for the spatial domain. If the temporal domain is spatially organized, then the similarities we observed between

temporal and spatial biases should come as no surprise. Thus, temporal processing may be facilitated for visual stimuli represented on the left side of the MTL and for auditory stimuli represented on its right side.

## 5. Limitations

One of the limitations of the study consists in the heterogeneity and the relative small size of our sample.

Another limitation of the present study that needs to be entertained is that response buttons are not balanced. Although this variable might have affected participants' performance (e.g., pressing the left button is generally faster, so choosing the shorter response may have led to faster responses independently of stimulus exposure time), it cannot entirely explain the observed findings. Indeed, a motor response bias would have led to consistent results within and across tasks independently of types of stimuli or stimuli durations (e.g., it would have led to best performance for targets with short duration and references with long duration in both tasks, while this occurs only for references with long duration in the auditory task).

Studies using balanced response buttons and/or other types of protocol such as, for example, a two-alternative forced-choice experiment, may further elucidate the present findings.

In some situations, we found significative effects for PS, whereas no significance was detected for the single measures alone. This aspect has to be better addressed in future studies.

## 6. Conclusions and Future Perspective

Results of the present study provide evidence that temporal judgments of visual and auditory stimuli are affected by the duration of the reference stimulus, besides the duration of the target stimulus. Interestingly, they suggest putative leftward and rightward spatial biases in time representation for the visual and auditory domains, respectively.

Future studies are necessary to specifically investigate this possibility and the potential relevance that spatial biases in time perception might have in healthy individuals and neurological patients with disorders of spatial attention.

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