Multisensory integration and the pupil response: No superadditivity in pupil size

Notaro, C., Van der Stoep, N., Van der Smagt, M. J. & Naber, M.
Department of Experimental Psychology, Helmholtz Institute, Utrecht University, Utrecht, The Netherlands

Background

- Multisensory integration (MSI) is known to greatly facilitate perception. This can be seen, for example, through faster and more accurate responses to multisensory relative to unisensory stimuli[1, 2].
- Super (and sub) additivity (the response to multisensory stimuli being more or less than the sum of unisensory responses) have been observed in neurophysiological responses to multisensory stimuli[3].
- Pupil responses have been indicated to represent stimulus saliency in apes, and linear summation of pupil response to the unisensory components efficiently predicted the multisensory pupil response[4].
- Studies of pupil responses to multisensory stimuli in humans have shown superadditivity[5, 6]. However, these studies have failed to take into account the influence of arousal due to participant's task to respond the stimuli when adding unisensory pupil responses.
- This study investigated whether the human multisensory pupil response response is additive or superadditive, by correcting for the increase in pupil response due to the task demands.

Methods

Materials & stimuli

- Auditory: white noise burst, presented for 750ms, at around 80dB.
- Visual: either white (320 cd/m^2) or dark (51 cd/m^2) patch presented in the center of the screen on grey (132 cd/m^2) background for 750ms.

Conditions, Setup, and Procedure

- Demographics: 12 participants (M_{age} = 19, 9 female).

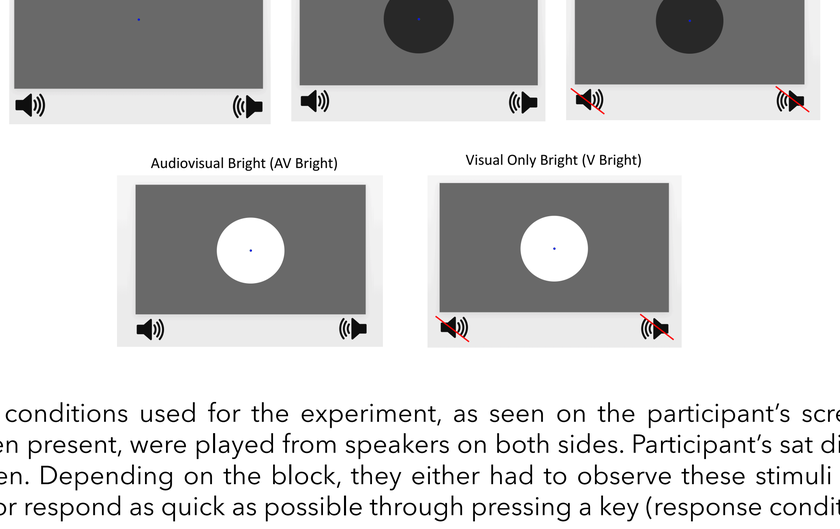

Fig. 1 The conditions used for the experiment, as seen on the participant's screen. Auditory stimuli, when present, were played from speakers on both sides. Participant's sat directly in front of the screen. Depending on the block, they either had to observe these stimuli (no response condition) or respond as quick as possible through pressing a key (response condition).

Results

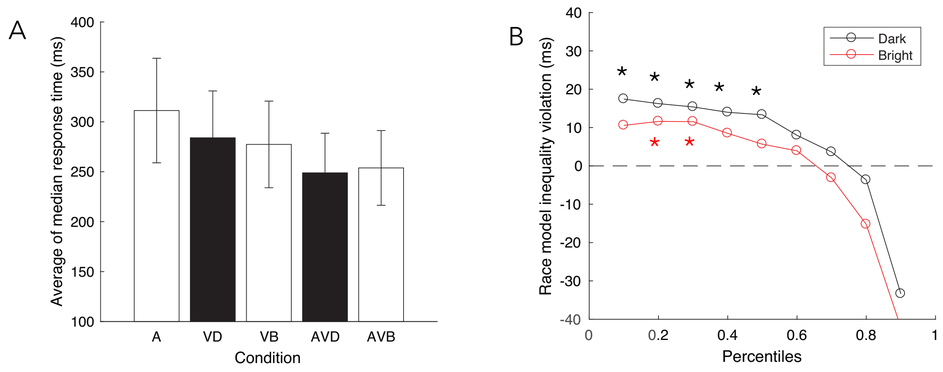

Fig. 2 A: The average of median response times to auditory, visual, and audiovisual targets in the bright and dark condition. B: Race model inequality violations for the bright and dark condition. Error bars indicate standard deviations including between subject variability. * p<0.05

Results (cont.)

Response times
All the multisensory conditions yielded Multisensory Response Enhancement over the unimodal conditions (repeated measures ANOVA, all p<0.01, see Fig. 2A).

Race model inequality violation
Race model analysis yielded significant violations at the 20th and 30th percentile for the bright condition (one sample t-test, t(11), all p<0.01), and the 10th to 50th percentile for dark stimuli (one sample t-test, t(11), all p<0.01). The positive area under the curve was significantly different from zero for dark and bright stimuli (one sample t-tests, t>5, p<0.01). There was no difference in RMI violation between conditions. These results are indicative of MSI.

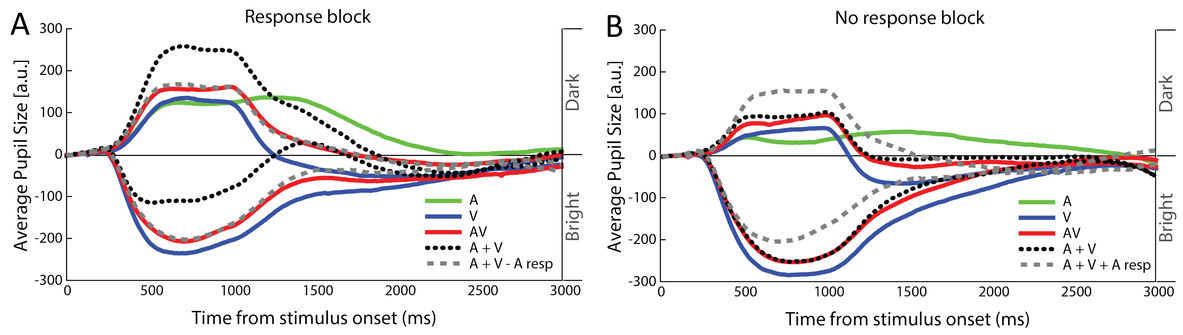

Fig. 3 Average pupil trace over time for the auditory, visual, audiovisual, and the sum of the unisensory conditions for the bright (A) and dark (B) condition. A: Response B: No response.

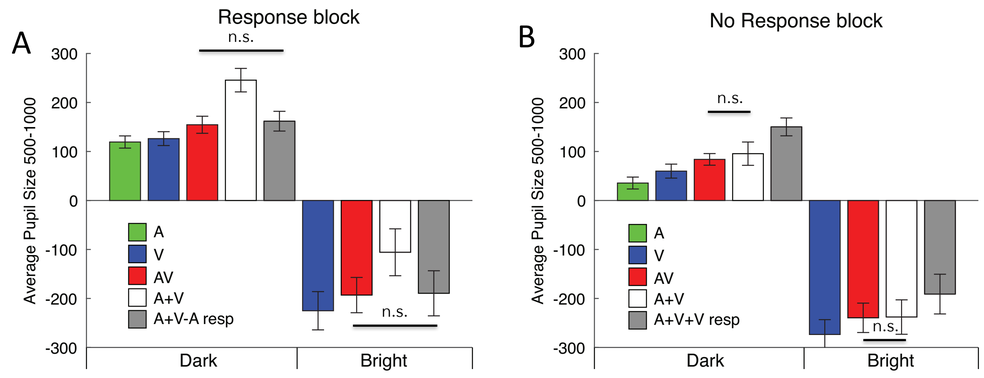

Fig. 4. Average pupil size per condition in time 500-1000. A: Response. B: No response.

Pupil response

In the response condition, the multisensory pupil response was not equal to the sum of the individual auditory and visual responses (Figure 2). This suggests an interaction between the senses.
Interestingly, additivity was found in the no response condition (Figure 3). After correcting for the response component, the multisensory pupil response did not differ from the sum of the unisensory pupil responses from the response block (p > 0.05).

Conclusion & Discussion

- We observed MSI in the response time data.
- After correcting the unimodal pupil responses for the response component, the multisensory pupil response was equal to the sum of the unisensory pupil responses.
- We can conclude that the human multisensory pupil response is not superadditive once the sum of the unisensory conditions has been adequately corrected.

References

1. Calvert, G., Spence, C., & Stein, B. E. (Eds.). (2004). *The handbook of multisensory processes*. MIT press.
2. Miller, J. (1986). Timecourse of coactivation in bimodal divided attention. *Attention, Perception, & Psychophysics*, *40*(5), 331-343.
3. Meredith, M. A., & Stein, B. E. (1983). Interactions among converging sensory inputs in the superior colliculus. *Science*, *221*(4608), 389-391.
4. Wang, C. A., Boehnke, S. E., Itti, L., & Munoz, D. P. (2014). Transient pupil response is modulated by contrast-based saliency. *Journal of Neuroscience*, *34(2)*, 408-417.
5. Wang, C. A., Blohm, G., Huang, J., Boehnke, S. E., & Munoz, D. P. (2017). Multisensory integration in orienting behavior: Pupil size, microsaccades, and saccades. *Biological Psychology*, *129*, 36-44.
6. Rigato, S., Rieger, G., & Romei, V. (2016). Multisensory signalling enhances pupil dilation. *Scientific Reports*, *6*.

Utrecht University
Helmholtz Institute
MULTISENSORY SPACE LAB
Contact: N.VanderStoep@uu.nl