Supplementary Materials

Article: Spatial but not temporal orienting of attention enhances the temporal acuity of human peripheral vision in an ecologically valid scenario

Results

No decision bias across cues nor SOA.

A two-way ANOVA with the factor SOA and Cue applied to the criterion (*c*) revealed an effect of the SOA ($F(2,68) = 283$, $p = 1.07 \times 10^{-33}$, $\eta^2_p = .893$), such as the larger the SOA the more liberal the decision criteria. The analysis revealed no effect of the Cue ($F(3,102)= 0.08$, $p = .97$, $\eta^2_p = .002$) nor interaction effect ($F(6,204) = 0.86$, $p = .52$) on the criterion.

Task parameters did not hinder the deployment of temporal attention.

Control analyses were performed to verify the absence of the effect of temporal attention on the temporal acuity of vision. First, we evaluated whether the effect of the cues on perceptual sensitivities varied across foreperiods (Fig. S1a). This evaluation is of potential interest to the reader given that spatial and temporal orienting can have different effects over time. Temporal expectations evolve over time given the conditional probability that the stimuli have not arrived yet. This means that, in our task, the benefit from explicit temporal orienting (i.e. the temporal cue) should decrease with the duration of the foreperiod because preparation and responses should be optimal at the longest delays (thanks to the hazard rate). Conversely, the benefit from spatial orienting remains stable across the foreperiods. We performed an additional analysis to verify the effect of the spatial and temporal orienting on perceptual sensitivities across foreperiods. A two-way ANOVA with the factors Cue and Foreperiod applied to the perceptual sensitivities (d') revealed an effect of the Cue ($F(3,102) = 4.028$, $p = .009$, $\eta^2_p = .106$) consistent with the main analysis reported in the manuscript. A main effect of the Foreperiod ($F(3, 102) = 4.833$, $p = .03$, $\eta^2_p = .124$) was found, such as the sensitivity to asynchronies is greater in trials with long foreperiods (1000 ms and 1250 ms) rather than with the short foreperiod (500 ms; two-sided *t*-tests; all $t(34) > 2.74$, $p < .048$, $BF_{10} > 4.4$, MSE < .01%). Thus, the effect of Foreperiod on sensitivities confirms that participants are better prepared to discriminate asynchronies in case of the longest foreperiods, given the increase of conditional probability of the target appearance as time elapses (i.e., hazard rate). However, no interaction effect between the Cue and the Foreperiod ($p = .157$) was found. Additionally, a two-way ANOVA with the factors Cue and Foreperiod applied to the decision bias (criterion *c*) revealed an effect of the Foreperiod ($F(3, 102) = 5.6$, $p = .001$, $\eta^2_p = .142$), with post-hoc analysis suggesting that the decision bias is also greater in trials with long foreperiods (1000 ms and 1250 ms) rather than short foreperiod (500ms; two-sided *t*-tests; all $t(34) > 2.75$, $p < .047$, $BF_{10} > 4.5$, MSE < .01%). Thus, participants become more liberal in their decision as time elapses.

Second, we evaluated whether temporal attention affected temporal acuity at any time during the experiment (Fig. S1c). Indeed, a possibility is that temporal attention requires more motivation than spatial attention, thus likely resulting in decreasing benefit from the temporal cue over the course of the experiment (i.e., later compared to earlier trial blocks). Contrasting with this possibility, a two-way ANOVA with the factors Cue and Trial Block applied to the perceptual sensitivities (d') revealed an effect of the Cue ($F(3,102) = 4.35$, $p = .006$, $\eta^2_p = .114$) and an effect of the Trial Block ($F(3,102) = 3.06$, $p = .032$, $\eta^2_p = .082$) but, crucially, no interaction effect ($p = .974$). Here, the effect of Trial Block indicates that participants sensitivity to asynchronies improved over the course of the experiment. Overall, these analyses revealed no evidence of a differential effect of temporal orienting on temporal acuity across SOAs, foreperiods, or trial blocks.

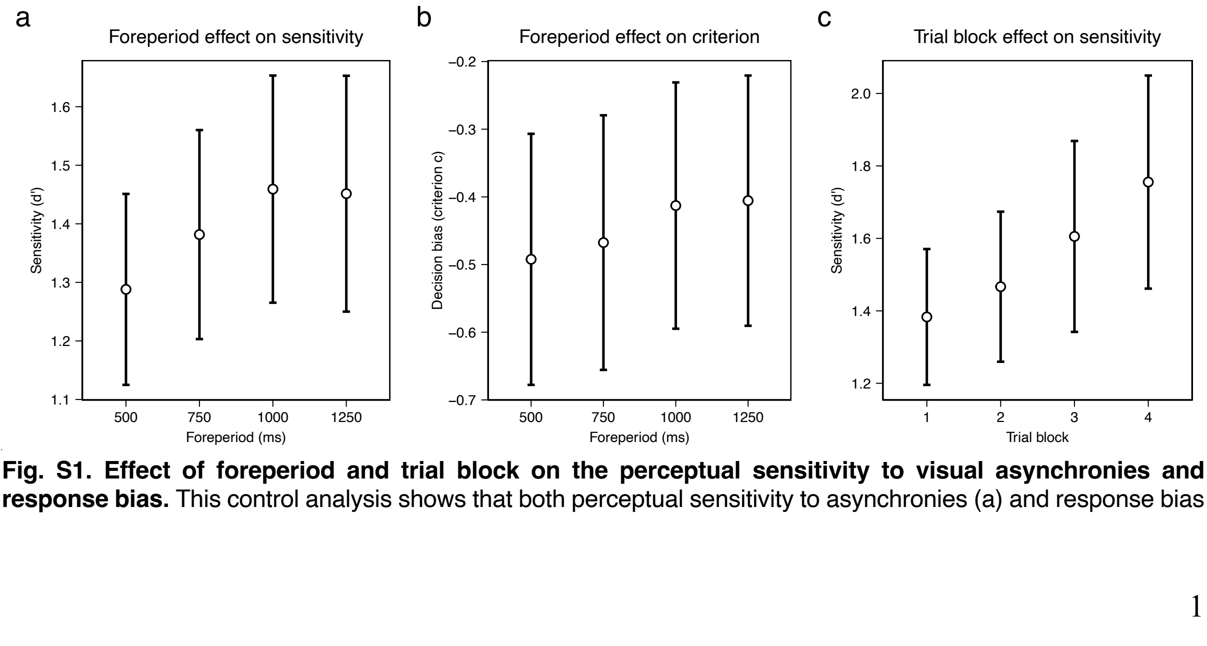

Fig. S1. Effect of foreperiod and trial block on the perceptual sensitivity to visual asynchronies and response bias. This control analysis shows that both perceptual sensitivity to asynchronies (a) and response bias

(b) increase with the duration of the foreperiod. Also, the perceptual sensitivity to asynchronies increases over the course of the experiment (c). Critically, no interaction effects with the cueing conditions was found, suggesting that temporal and spatial attention effects may have been relatively independent from the foreperiods and stable over the course of the experiment. Error bars represent one confidence interval from the mean.

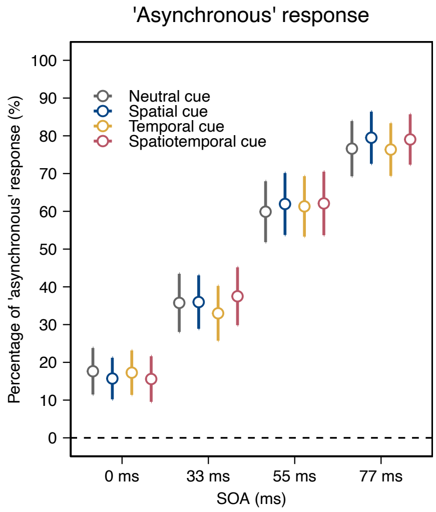

Fig. S2. Percentage of 'asynchronous' response across SOAs and cueing condition. In support of the analysis of the sensitivity to asynchronies, raw judgments show that participants increase their tendency to report seeing an asynchrony as the SOA increase. Neither floor nor ceiling performance effects are observed. Error bars represent one confidence interval from the mean.

Spatial and temporal orienting reduces parieto-occipital beta power.
Previous studies showed that spatial and temporal orienting induces alpha and beta power suppression [1,2]y. Given that the visual inspection of our data suggests likewise (Fig. 3a), a supplemental analysis was performed to test the specificity of the attentional orienting effects on the parieto-occipital alpha and theta power.

We evaluated the attentional orienting effects of the cues on the parieto-occipital beta power (Fig. S3a-b). A one-way ANOVA with the factor Cue applied to the pre-target (-200 to 0 ms) beta (16-22 Hz) power revealed an effect of the Cue (F(3,90)= 5.709, p = .001; η^2_p = .16). The contrast analysis revealed anecdotal evidence for an effect of spatial attention (one-sided t-test; t(30) = 1.99, p = .028, BF_{10} = 1.1, MSE < .01%), moderate evidence against an effect of temporal attention (one-sided t-test; t(30) = 1.17, p = .13, BF_{01} = 2.8, MSE < .01%), and moderate evidence for a synergistic effect of spatiotemporal attention on the pre-target beta power (two-sided t-test; t(30) = 2.64, p = .013, BF_{10} = 3.6, MSE < .01%). Consequently, pre-target beta power may primarily reflect orienting of attention in space rather than time.

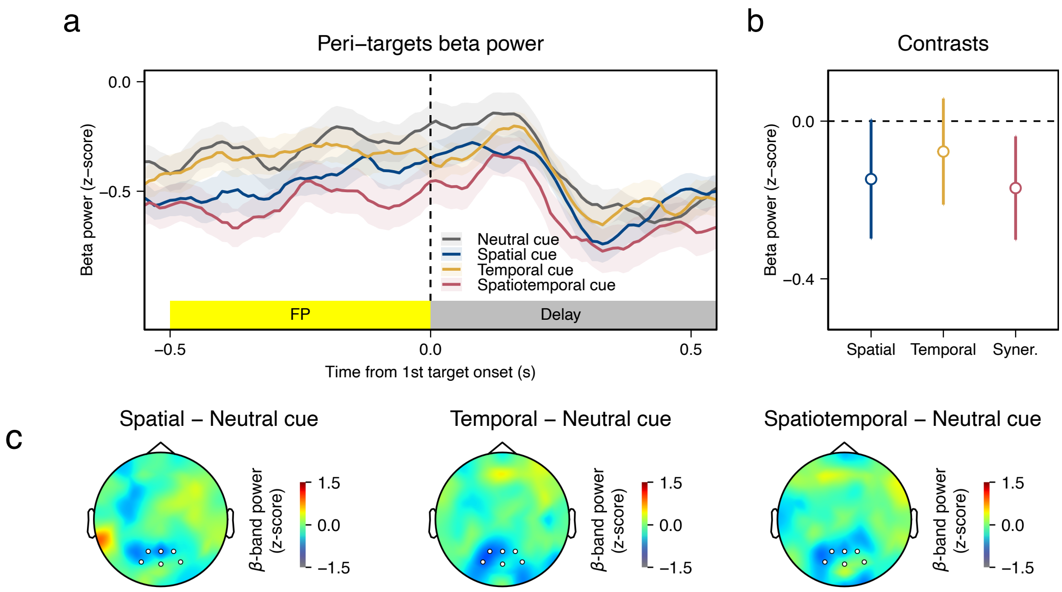

Fig. S3. Pre-target parieto-occipital beta suppression. a) Time series representing the beta-band power suppression through spatial, temporal and spatiotemporal orienting of attention. b) Means of spatial, temporal and synergistic effect of cueing on beta suppression (-200 to 0 ms pre-target interval). c) Like the alpha and theta suppression reported in the manuscript, topographic maps evidence a pre-target (-200 to 0 ms) beta-band power suppression recorded over parieto-occipital areas induced by attentional orienting. The white circles indicate the locations of the electrodes used for statistical analysis. Error bars represent one confidence interval from the mean. Colored shaded areas represent one standard error of the mean.

Pupil diameter reflects attentional orienting beyond changes in luminance.
To verify that our modulations of pupil diameter were not merely due to different luminance levels and not spatial and temporal orienting, we compared the post-cue pupil constriction before (task-free passive viewing) and during the asynchrony detection task (task-induced; Fig. S4). To this aim, a two-way ANOVA with the factor Cue and Task (task-induced vs task-free pupil dilation) applied to the pre-cue offset time-interval (-500 to 0 ms) pupil diameter revealed an effect of the Cue ($F(3,102) = 10.11$, $p = 6.86 \times 10^{-06}$, $\eta^2_p = .229$), the Task ($F(1, 34) = 49.06$, $p = 4.41 \times 10^{-08}$, $\eta^2_p = .591$), and an interaction effect ($F(3, 102) = 10.12$, $p = 6.82 \times 10^{-06}$, $\eta^2_p = .229$). The contrast analysis revealed evidence against effects of spatial and temporal attention on task-free pupil constriction (all $p > .18$, all $BF_{01} > 1.58$) while providing strong evidence for an effect of both spatial (one-sided *t*-test; $t(34) = 4.85$, $p = 1.36 \times 10^{-05}$, $BF_{10} = 821$, MSE < 0.01%) and temporal (one-sided *t*-test; $t(34) = 4.57$, $p = 3.09 \times 10^{-05}$, $BF_{10} = 388$, MSE < 0.01%) cues on task-induced pupil constriction. In accordance with our main analysis, moderate evidence against a synergistic effect on task-induced pupil constriction was found (two-sided *t*-test; $t(34) = 0.62$, $p = .27$, $BF_{01} = 4.62$, MSE < 0.04%). This analysis confirms that the effect of spatial and temporal expectations on the pupil size presented in the manuscript cannot be attributed to the different patterns of luminance delivered by the cue.

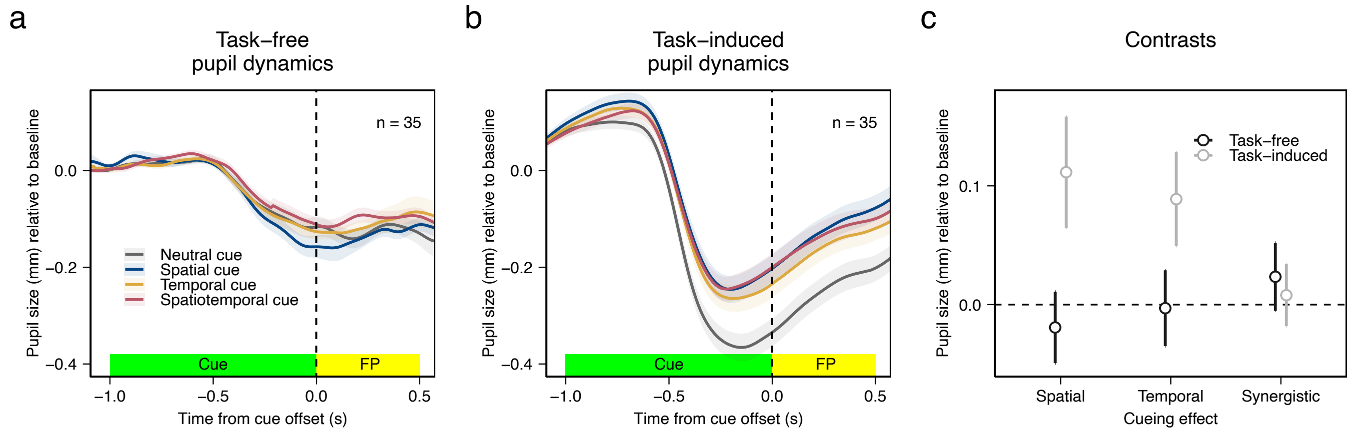

Fig. S4. Phasic pupil dynamics. Pupillary response to attentional cues during task-free (passive viewing; a) and task-induced (asynchrony detection task; b). The analysis of the pupil diameter during the pre-cue offset time-interval (-500 to 0 ms; c) suggests that pupil dynamics depend on attentional cueing rather than minimal differences of luminance between cues. Colored shaded areas represent one standard error of the mean. Error bars represent one confidence interval from the mean.

Finally, we evaluated whether the effects of spatial and temporal cueing on transient pupil dynamics found at the level of the trial (from 500 ms post-cue presentation to the target appearance) rely on tonic pupil states sustained over the whole duration of the trial block rather than the cue presentation, given the block-wise presentation of the attentional cues. A two-way ANOVA with the factor Cue and Task (task-induced vs task-free pupil dilation) was applied to the pre-cue onset time-interval (-500 to 0 ms) non-baseline corrected pupil diameter (Fig. S5). The analysis only revealed a main effect of the Task ($F(1, 34) = 4.14$, $p = 0.05$, $\eta^2_p = .109$), such as the non-baselined pre-cue pupil diameter was reduced during the asynchrony detection task, as found in the previous analysis. Crucially, no effect of the Cue ($F(3,102) = 0.86$, $p = 0.46$, $\eta^2_p = .025$) nor interaction effect ($F(3, 102)= 1.04$, $p = 0.38$, $\eta^2_p = .03$) was revealed. Thus, the effects of covert attention on pupil constriction reported in the manuscript cannot be explained by the experimental design to deliver the attentional cues.

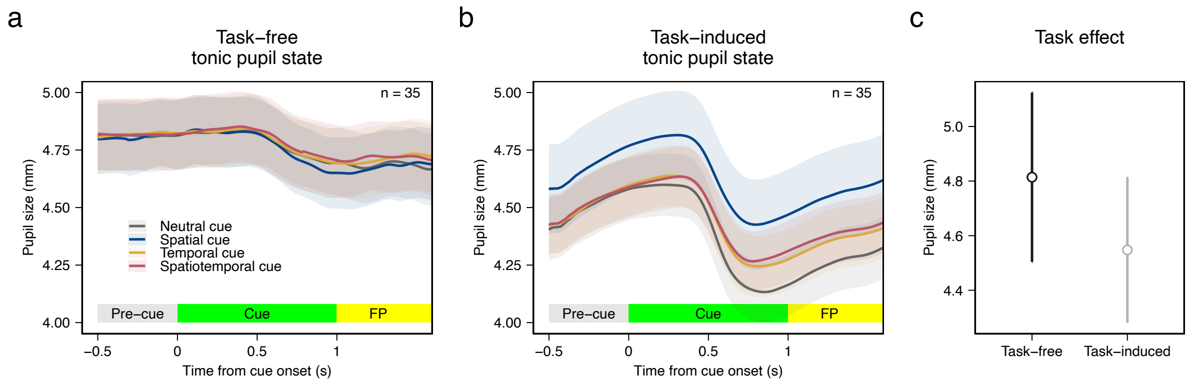

Fig. S5. Tonic pupil states. Tonic pupil state (non-baseline corrected) to attentional cues during task-free (passive viewing; a) and task-induced (asynchrony detection task; b). The analysis of the pupil diameter during the pre-cue onset time-interval (-500 to 0 ms; c) suggests that the tonic pupil state was reduced during the asynchrony detection task, but did not vary across the block-wise attentional cueing conditions. Colored shaded areas represent one standard error of the mean. Error bars represent one confidence interval from the mean.

References

1. Heideman, S. G. *et al.* Anticipatory neural dynamics of spatial-temporal orienting of attention in younger and older adults. *NeuroImage* **178**, 46–56 (2018).
2. Van Ede, F., De Lange, F., Jensen, O. & Maris, E. Orienting attention to an upcoming tactile event involves a spatially and temporally specific modulation of sensorimotor alpha- and beta-band oscillations. *J. Neurosci.* **31**, 2016–2024 (2011).