Respiratory Phase and Visuospatial Attention: A Replication and Extension

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Abstract

Recent studies suggest that respiration may influence visuospatial processing. In two experiments, Belli and Fischer (2024) reported faster detection of targets on the right at inhalation peaks and targets on the left at exhalation troughs. We sought to replicate those findings and to test whether the influence of breathing phase on spatial responding would also extend to the vertical dimension. Experiment 1 used a visual probe detection task and Experiment 2 used an exogenous Posner cueing task. Targets appeared at horizontal and vertical locations, with trials manually triggered at visually identified inhalation peaks and exhalation troughs. Across both experiments, the predicted spatial pattern did not emerge on either axis. Experiment 1 yielded no reliable phase effect, whereas Experiment 2 showed shorter reaction times in the inhalation condition than in the exhalation condition across target locations, consistent with a general change in response speed associated with inhalation.

Keywords: respiratory cycle, visuospatial attention, Posner cueing task, visual probe detection task, spatial orienting, inhalation, embodied cognition

Introduction

For much of its history, cognitive science has tended to describe cognition at the level of computation or function while bracketing off the body that sustains it (Pylyshyn, 1980; Fodor, 1983). Embodied approaches have challenged that separation by arguing that cognitive activity unfolds within continuous exchanges between neural systems, bodily states, and action in the world (Barsalou, 2008; Chemero, 2009; Felisatti & Fischer, 2024). Respiration offers an especially useful case because it is a recurring bodily rhythm with growing evidence that it can organise neural activity and behaviour (Allen et al., 2023; Heck et al., 2022; Tort et al., 2025). It also remains experimentally tractable. Each respiratory cycle alters thoracic and abdominal mechanics and generates a recurrent bodily signal (Haouzi & Bell, 2009). For that reason, breathing is a theoretically important source of moment-to-moment variation in perception, attention, and responding.

Existing behavioural work suggests that performance can vary with breathing phase, but studies differ in their tasks, respiratory measures, and whether phase is indexed at stimulus onset or around the response. Early psychomotor studies reported phase-related variation in simple reaction time, often with slower responding during exhalation, and related work extended the question to perceptual detection (Beh & Nix-James, 1974; Flexman et al., 1974; Hildebrandt & Engel, 1963). More recent studies have linked respiratory phase to memory retrieval (Nakamura et al., 2018), perceptual awareness and reaction time in a visual decision task (Molle et al., 2023), multisensory integration (Saltafossi et al., 2025), and broader sensory and cognitive performance (Johannknecht & Kayser, 2022; Perl et al., 2019; Zelano et al., 2016). Recent work also suggests that respiration often aligns with task structure itself. Across multiple sensory and cognitive datasets, respiration showed systematic alignment to task events, while residual trial-

to-trial variation still predicted behavioural performance, especially reaction time, with the strongest relations emerging at a lag before responses (Harting et al., 2025). Related evidence suggests that this alignment is shaped by expected effort rather than passive entrainment alone (Kayser et al., 2026). These findings leave open whether a particular relation between breathing phase and performance generalises across tasks and procedures.

Recent visual work further suggests that coarse inhalation-exhalation contrasts may miss important temporal structure in the respiratory signal. In a near-threshold visual detection task, respiration modulated perceptual sensitivity and posterior alpha power, with respiration-linked changes in neural excitability preceding behavioural variation (Kluger et al., 2021). In humans, respiratory phase has also been linked to task-related neural representations during visual categorisation, with modulation emerging before the response in EEG signals (Stetza et al., 2025). In nonhuman primates performing a visual detection task, trial outcome was better predicted by measures of respiratory timing such as inhalation onset and cycle length than by measures of respiratory amplitude (Skog et al., 2026). Together, these findings suggest that respiratory timing may matter more than respiratory magnitude and that respiratory effects on behaviour may often involve sensory and cognitive processes, changes in neural excitability, or decision making rather than spatial attention specifically.

The most direct evidence for a respiratory influence on visuospatial processing comes from Belli and Fischer's (2024) respiratory phase studies. In their first experiment, stimuli were manually triggered at visually identified inhalation peaks and exhalation troughs in a lateralised probe detection task. They reported a left-right interaction, with faster responses to right-sided targets on trials triggered at inhalation peaks and to left-sided targets on trials triggered at exhalation troughs. This pattern suggests that respiratory phase altered the relative priority of left

and right space rather than simply speeding or slowing responses overall. The authors reported the same directional pattern in a second experiment using a Posner cueing task (Posner, 1980) that sampled endogenous and exogenous cueing, again with targets triggered at visually identified respiratory extrema. Right-sided targets were favoured on inhalation trials and left-sided targets on exhalation trials, suggesting that the interaction generalised to attentional orienting and reorienting.

Several broad classes of explanation could account for this pattern. One possibility is a spatially selective account, in which respiratory phase changes the relative priority of locations by modulating lateralised attentional selection or hemispheric asymmetries in spatial processing. The alternative empirical pattern (a main effect of phase without spatial interaction) would instead be consistent with a location-general facilitation account, in which breathing alters overall response efficiency without shifting spatial priority. The present design can discriminate these patterns. Given that the observed pattern is an interaction, the relevant mechanistic question is how respiratory phase could selectively modulate one spatial channel.

Several routes are plausible. Breathing is embedded in broader systems of arousal and state regulation that are partially lateralised. In humans, respiration covaries with pupil-linked and electrophysiological markers relevant to attentional state (Andrews et al., 2025; Kluger et al., 2024; Melnychuk et al., 2021). More generally, changes in physiological state could alter response efficiency without changing spatial priority itself (Aston-Jones & Cohen, 2005). Respiratory afference is also central to interoceptive monitoring (Craig, 2002). Any respiratory influence on visuospatial performance may therefore involve systems relevant to attentional reorienting and target detection (Corbetta & Shulman, 2002; Shulman et al., 2010). More broadly, breathing can organise large-scale neural activity across widespread cortical networks

(Tort et al., 2018; Tort et al., 2025), and recent work also links respiratory phase to latent decision dynamics and task-related visual representations (Brændholt et al., 2025; Stetza et al., 2025). Any of these pathways could, in principle, produce spatially selective effects if they interact with hemispheric asymmetries in attentional control.

Follow-up work by Belli and Fischer (2025) using line bisection and landmark tasks reported the opposite pattern, with greater leftward bias during inhalation and greater rightward bias during exhalation. Line bisection and landmark judgements require comparative spatial evaluation and, especially in the landmark task, may place greater demands on spatial representation (Seydell-Greenwald et al., 2019). The opposite direction of these later findings raises the possibility that respiratory influences on spatial behaviour depend on task demands. It also makes it difficult to know whether the originally reported phase × target location effect is a stable feature of probe detection and cueing performance. The present study therefore began by replicating the two paradigms from Belli and Fischer (2024).

Alongside this replication aim, the present study also asked whether any respiratory effect extends to the vertical axis. Upper and lower visual fields differ in perceptual sensitivity, attentional performance, and their relation to action, favouring the upper visual field (Previc, 1990; Levine & McAnany, 2005; Kraft et al., 2011). The vertical axis therefore provides a theoretically informative extension of the left-right design. Horizontal respiratory effects could, in principle, be attributed to hemispheric lateralisation of breathing-related autonomic control; if one hemisphere exerts stronger modulation, attention may be biased contralaterally. The vertical axis disassociates this possibility because hemispheric differences cannot produce upper-lower asymmetries. A significant respiratory modulation along the vertical dimension would therefore rule out a hemispheric account, leaving top-down mechanisms as the more plausible explanation.

From an embodied perspective (Barsalou, 2008; Meteyard et al., 2012) and a conceptual metaphor perspective (Lakoff & Johnson, 1980), inhalation involves thoracic expansion, whereas exhalation involves contraction (Haouzi & Bell, 2009). If such bodily states are recruited during visual orienting, inhalation may favour processing of targets in upper space and exhalation processing of targets in lower space. We refer to this second possibility as the thoracic lift hypothesis. The present experiments therefore tested whether the original lateralised pattern would generalise to a second spatial dimension grounded in the bodily experience of breathing.

Probe detection and cueing paradigms are well suited to distinguishing these possibilities because different reaction time patterns support different theoretical interpretations. A main effect of phase across locations would be more consistent with a location-general facilitation account, whereas a phase × target location interaction would be more consistent with a spatially selective account. The present experiments therefore treated the spatial interaction as the primary replication target while also testing for location-general changes in processing efficiency. Experiment 1 provided the closer replication test of the original probe detection finding, with upper and lower targets added as an extension. Experiment 2 tested the same predicted pattern in a simplified exogenous cueing context that preserved the original visually identified peak/trough triggering procedure while restricting the design to exogenous cues and a single 150 ms stimulus onset asynchrony.

Experiment 1

Method

Participants

We preregistered a target of 30 participants, compared with 21 and 26 in Belli and Fischer's (2024) two experiments. The target also reflected participant availability and the

feasible recruitment period. Thirty participants (M_{age} = 20.7, SD = 3.9, three were left handed) were recruited from the University of Hull's BSc Psychology undergraduate programme. An effect size sensitivity analysis indicated that the final sample of 29 provided 80% power at α = .05, two-tailed, to detect a standardised difference-of-differences effect of approximately d_z = 0.54 or larger.

All reported normal or corrected-to-normal vision and no history of neurological or respiratory disorders. Ethical approval to conduct this research was granted by the Faculty of Health Ethics Committee of the University of Hull (24-25.006).

Procedure

Stimuli were presented using PsychoPy (Peirce et al., 2019) on a 24-inch monitor at a resolution of 1920 × 1080 pixels, with participants seated 60 cm from the screen. Target centres were 8.8° from fixation, and the stars subtended approximately 2.9° × 2.9° of visual angle. A central fixation cross remained on screen throughout each trial. On target-present trials, a black five-pointed star that matched the stimulus used by Belli and Fischer (2024) was briefly presented for 300 ms (see Figure 1). On catch trials, which comprised 20% of all trials, no stimulus appeared. Participants were instructed to press the space bar with their dominant hand as quickly as possible when they detected a target and to withhold responses on catch trials. Between target presentations, participants maintained central fixation while the experimenter monitored the respiratory trace and waited for the appropriate respiratory phase. The experimenter then manually initiated stimulus presentation by pressing the up arrow key at a visually identified inhalation peak and the down arrow key at a visually identified exhalation trough. The prestimulus fixation period therefore varied with each participant's breathing pattern. Each trigger immediately began the trial routine: on target-present trials, a black star

appeared for 300 ms at one of the four peripheral locations. No intertrial interval was programmed. Responses were accepted for 1,000 ms from target onset, and a valid space bar response ended the trial immediately and advanced the task to the next respiratory monitoring period. If no response was made, the task remained in the post-trigger response monitoring period for up to 3,000 ms before advancing to the next respiratory monitoring period. Thus, the respiratory phase aligned pre-trigger interval was variable, whereas the target duration, response window, and post-trigger cut-offs were fixed in software.

Figure 1

Schematic of Experimental Display and Stimulus Target Locations



Note. The figure provides a schematic representation of the target locations used in Experiment 1. The four panels illustrate the proportional spatial positioning of the black five-pointed star stimulus in the right, left, lower, and upper target locations.

The experimental session consisted of an initial practice phase (10 trials, including 2 catch trials), followed by two main blocks of 60 trials each (12 catch trials per block). This yielded 120 experimental trials in total, or 96 target-present trials before exclusions. Each trial lasted approximately 4 s, and a 1-minute rest period was provided between blocks.

Adding upper and lower targets to the original left-right display would have doubled the number of experimental trials if breathing phase had been blocked. To keep the session length manageable, Experiment 1 presented inhalation- and exhalation-triggered trials in a single alternating sequence within each block rather than presenting them in separate respiratory phase blocks.

Respiratory Monitoring

Breathing was monitored in real time using LabChart Pro V8 with ADInstruments TN1132/ST Respiratory Belt Transducers (thoracic and abdominal), connected to an ADInstruments PowerLab 26/T data acquisition system. Participants were instructed how to place the belts before the task began. One belt was positioned around the upper thorax (at the level of the armpits) and the second around the abdomen (at the level of the navel). Stimuli were manually triggered via keyboard input using the procedure described by Belli and Fischer (2024), with presentation timed online to visually identified respiratory peaks and troughs on a monitor. This procedure was retained to reproduce the original method as closely as possible.

Data Preprocessing

Across all 30 participants, 720 catch trials and 55 incorrect target-present trials were first excluded, leaving 2,825 correct target-present trials. One participant then met the preregistered exclusion criterion of at least 30% incorrect responses. Removing that participant eliminated a further 52 otherwise analysable trials, leaving 2,773 trials in the final dataset from 29 participants. Overall, 827 of the original 3,600 trials (23.0%) were excluded before analysis. To reduce the influence of extreme reaction times and to match the preprocessing pipeline used by Belli and Fischer (2024), winsorisation at ±2 standard deviations was applied within each participant. Reaction times beyond each participant's mean ±2 SDs were set to the corresponding boundary value. In total, 115 trials (4.1% of the final dataset) were winsorised.

Data Analyses

Experiment 1 was preregistered (see OSF repository). Deviations from the preregistration are summarised in the Preregistration, Deviations, and Data Availability section.

Analyses were conducted in R (version 4.5.2). Repeated-measures ANOVAs were run in afex (Singmann et al., 2025) using *aov_ez* with Type III sums of squares. Effect sizes are reported as partial eta squared (η_p^2). Estimated marginal means were obtained with emmeans (Lenth & Piaskowski, 2026), and pairwise comparisons among the factorial cell means were Bonferroni adjusted. Cohen's d_z was computed from the corresponding t-ratio and degrees of freedom.

Preregistered confirmatory analyses used repeated-measures ANOVAs. Because a nonsignificant *p* value does not distinguish evidence for absence from data insensitivity, we added a Bayesian test of the critical phase × target location interaction contrast on the horizontal axis. For each participant, we calculated the left-minus-right reaction time difference during

inhalation and subtracted the corresponding difference during exhalation. Positive values corresponded to faster right-sided responses on inhalation and faster left-sided responses on exhalation (Belli & Fischer, 2024). The contrast was evaluated with a Bayesian one-sample *t* test against zero using a Cauchy prior on the standardised effect size ($r = 0.5$), implemented in BayesFactor (Morey & Rouder, 2018; Rouder et al., 2009).

Results

Mean reaction times (RTs) and standard deviations for all conditions are summarised in Table 1 and visualised in Figure 2.

Table 1

Descriptive Statistics for Experiment 1 Reaction Times (ms)

Phase	Position	M (ms)	SD (ms)	SE (ms)	95% CI (ms) Lower	Upper
Exhalation	Left	391	64	12.0	367	416
	Right	394	68	12.7	368	420
	Upper	390	58	10.8	368	412
	Lower	390	50	9.3	371	409
Inhalation	Left	387	53	9.8	367	407
	Right	385	55	10.2	364	406
	Upper	378	48	9.0	359	396
	Lower	395	62	11.6	371	419

Confirmatory analyses were conducted separately for the horizontal and vertical axes, using 2 × 2 repeated-measures ANOVAs with respiratory phase (inhalation, exhalation) and target position as within-subjects factors.

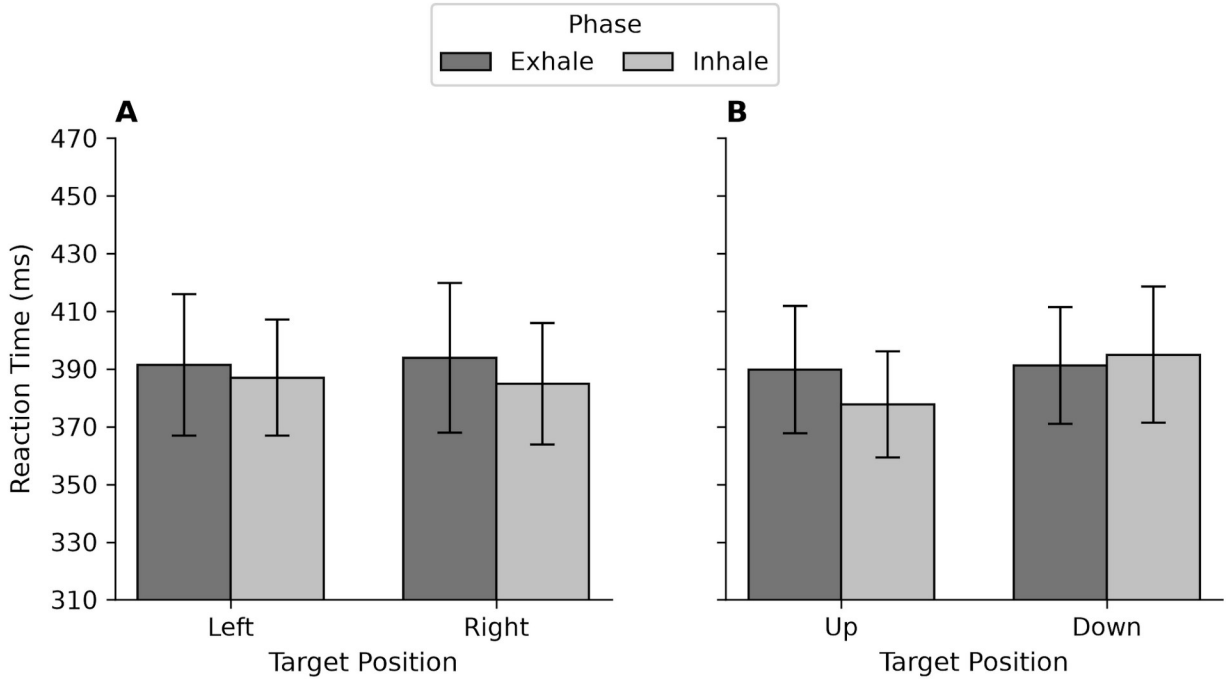
Horizontal Axis

On the horizontal axis, there was no evidence that respiratory phase modulated spatial orienting. The critical phase × position interaction was not significant, $F(1, 28) = 0.03$, $p = .855$,

η_p^2 = .001, and the supplementary Bayesian test on the preregistered interaction contrast yielded BF_{10} = 0.27, indicating approximately 3.7 times greater support for the null model than for the specified alternative model. The mean horizontal interaction contrast was 1.4 ms, 95% CI [−14.3, 17.1], with positive values indicating the crossover direction reported by Belli and Fischer (2024). There was also no main effect of target position, $F(1, 28) = 0.00$, $p = .970$, $\eta_p^2 < .001$, and no main effect of respiratory phase, $F(1, 28) = 0.20$, $p = .662$, $\eta_p^2 = .007$.

Figure 2

Mean Reaction Times by Target Position and Respiratory Phase in Experiment 1



Note. Error bars show 95% confidence intervals.

Vertical Axis

On the vertical axis, there was again no evidence that respiratory phase modulated the positional effect. The position × phase interaction was not significant, $F(1, 28) = 0.84$, $p = .366$, $\eta_p^2 = .029$. There was also no significant main effect of phase, $F(1, 28) = 3.24$, $p = .083$, $\eta_p^2 = .104$, although responses were numerically 8 ms faster during inhalation than exhalation. RTs were 10 ms shorter for upper than lower targets, yielding a main effect of position, $F(1, 28) = 15.55$, $p < .001$, $\eta_p^2 = .357$.

Discussion

Experiment 1 replicated Belli and Fischer's (2024) probe detection paradigm while adding upper and lower targets and alternating inhalation- and exhalation-triggered trials within

each block. The previously reported horizontal interaction did not replicate in the present data, and the vertical extension likewise yielded little support for phase-linked spatial modulation. The task nonetheless remained sensitive to target position on the vertical axis, showing an upper-field advantage across phases (Previc et al., 2005), but respiration did not systematically reshape that effect.

This absence of a spatial interaction is broadly consistent with a growing literature in which respiratory effects appear more robust for general response speed or decision timing than for spatially selective effects on performance (Brændholt et al., 2025; Harting et al., 2025). It also leaves open the possibility that response-linked effects were present but not well captured by a design focused on inhalation peaks and exhalation troughs at stimulus onset (Harting et al., 2025). Effects during transitions between respiratory phases may likewise have been missed when stimuli were triggered only at peaks and troughs (Saltafossi et al., 2025).

One procedural difference from Belli and Fischer (2024) may be relevant. Introducing upper and lower targets would have doubled the number of trials, so inhalation- and exhalation-triggered trials were intermixed within each block instead of retaining separate respiratory phase blocks. Although this kept the session manageable, it may also have altered expectancy or task pacing in ways relevant to any effect of respiration on spatial responding. Experiment 2 therefore returned to a blocked breathing phase arrangement.

Experiment 2

Experiment 2 used an exogenous Posner cueing task based on Belli and Fischer's (2024) second experiment, extended to include upper and lower target locations. Because restoring blocked respiratory phase while adding the vertical dimension would otherwise have made the session impractically long, the design was simplified to a single-session exogenous cueing task

with one 150 ms stimulus onset asynchrony. This reduced trial burden while retaining the exogenous cueing condition used to assess rapid spatial orienting. Belli and Fischer reported no evidence that the predicted spatial pattern depended on cue type or stimulus onset asynchrony.

Method

Participants

A preregistered minimum of 32 participants was set to exceed the 26 participants tested in the corresponding experiment by Belli and Fischer (2024), to ensure even condition distribution (divisible by 8), and to reflect practical recruitment within a reasonable period. Recruitment continued during the available data collection period, yielding fifty-four participants (M_{age} = 21 years, SD = 2.6, 7 left handed) recruited from the University of Hull's Psychology programme. Inclusion criteria were identical to those in Experiment 1. Following exclusion, a sensitivity analysis indicated the final sample of 53 provided 80% power to detect approximately d_z = 0.39.

Materials and Apparatus

The viewing distance, monitor, target eccentricity, and target size were identical to Experiment 1. Each placeholder box was 0.182 × 0.182 height units (approximately 197 × 197 px, 54 × 54 mm, and 5.2° × 5.2° of visual angle); the 50 ms cue flicker had the same spatial extent.

Design

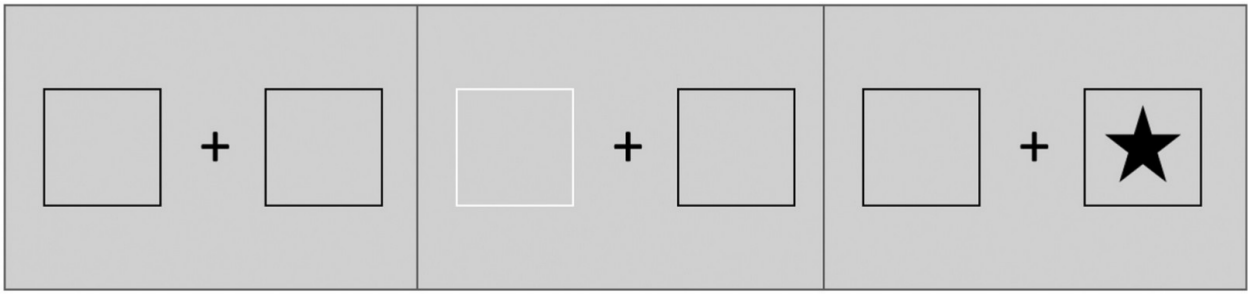
Experiment 2 used a within-subjects blocked design. Respiratory phase and axis were blocked and counterbalanced across participants. Within each axis, targets could appear at one of two locations on valid or invalid trials. As in Experiment 1, the preregistered analyses focused on respiratory phase × target position effects within each axis.

Procedure

In vertical blocks, black placeholder boxes were presented above and below the fixation cross. In horizontal blocks, the placeholder boxes were presented to the left and right. An exogenous cue flickered for 50 ms, and the target star was scheduled to appear 150 ms after cue onset, either at the cued location on valid trials or at the opposite location on invalid trials (see Figure 3). The experimental session consisted of a practice phase (11 trials) followed by four counterbalanced blocks of 60 trials (20% catch trials), yielding 240 experimental trials in total and 192 target-present trials before exclusions. A 1-minute rest was provided after two blocks. Participants had up to 3 s to respond.

Figure 3

Stimulus Image and Schematic Representation



Note. Schematic representation of event sequences on the screen over time during the exogenous blocks. Adapted from Belli and Fischer (2024).

Data Preprocessing

Across all 54 participants, 2,592 catch trials and 101 incorrect target-present trials were first excluded. One participant then met the preregistered exclusion criterion of at least 30%

incorrect responses. Removing that participant eliminated a further 97 otherwise analysable trials, leaving a final dataset of 10,170 trials from 53 participants. Overall, 2,790 of the original 12,960 trials (21.5%) were excluded before analysis. Following the same preprocessing pipeline as Experiment 1, winsorisation at ±2 standard deviations was applied within each participant, affecting 410 trials (4.0% of the final dataset).

Data Analyses

Experiment 2 was preregistered on OSF. The confirmatory analyses collapsed across cue validity because the replication target was the overall respiratory phase × target position pattern reported by Belli and Fischer (2024). Analyses by cue validity were added on an exploratory basis to test whether any respiratory effect was concentrated in attentional capture, reorienting, or cueing magnitude. Belli and Fischer also reported related cueing analyses when arguing that respiratory phase influenced attentional orienting and reorienting.

Results

Mean RTs and standard deviations for Experiment 2 are summarised in Table 2 and visualised in Figure 4.

Table 2

Descriptive Statistics for Experiment 2 Reaction Times (ms)

Phase	Position	M (ms)	SD (ms)	SE (ms)	95% CI (ms) Lower	Upper
Exhalation	Left	425	53	7.3	410	440
	Right	428	52	7.1	414	442
	Upper	432	53	7.3	418	447
	Lower	428	51	7.1	413	442
Inhalation	Left	413	53	7.2	399	428
	Right	418	50	6.8	404	432
	Upper	419	49	6.7	406	433

				95% CI (ms)	
Lower	413	49	6.7	399	427

Main Analyses

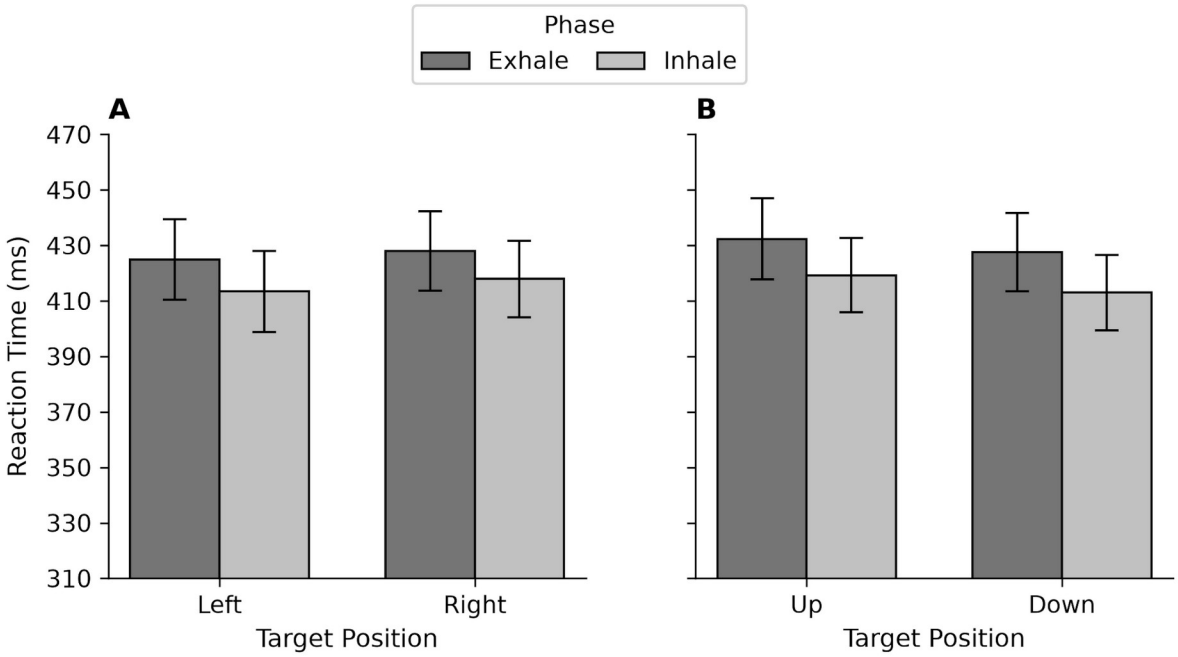
Confirmatory analyses were conducted separately for the horizontal and vertical axes, using 2 × 2 repeated-measures ANOVAs with respiratory phase (inhalation, exhalation) and target position as within-subjects factors.

Horizontal Axis

On the horizontal axis, there was no evidence that respiratory phase modulated spatial orienting. The critical phase × position interaction was not significant, $F(1, 52) = 0.14$, $p = .705$, $\eta_p^2 = .003$, and the supplementary Bayesian test on the preregistered interaction contrast yielded $BF_{10} = 0.22$, indicating approximately 4.5 times greater support for the null model than for the specified alternative model. The mean horizontal interaction contrast was −1.4 ms, 95% CI [−9.1, 6.2]. There was no main effect of position, $F(1, 52) = 2.45$, $p = .124$, $\eta_p^2 = .045$. However, responses were 11 ms faster during inhalation than exhalation, reflected in a significant main effect of phase, $F(1, 52) = 8.59$, $p = .005$, $\eta_p^2 = .142$.

Figure 4

Mean Reaction Times by Target Position and Respiratory Phase in Experiment 2



Note. Error bars show 95% confidence intervals.

Vertical Axis

On the vertical axis, there was again no evidence that respiratory phase modulated the positional effect. The phase × position interaction was not significant, $F(1, 52) = 0.18$, $p = .672$, $\eta_p^2 = .003$. In the same direction as the small numerical trend in Experiment 1, responses were faster during inhalation than exhalation, here by 14 ms, reflected in a significant main effect of phase, $F(1, 52) = 9.30$, $p = .004$, $\eta_p^2 = .152$. In addition, responses were 6 ms slower for upper than lower targets, reflected in a main effect of position, $F(1, 52) = 4.66$, $p = .035$, $\eta_p^2 = .082$. This positional effect was opposite in direction to the upper-target advantage observed in Experiment 1.

Across both axes, the same qualitative pattern emerged. Reaction times were shorter during inhalation, whereas the predicted respiratory phase × target location interaction was absent.

Exploratory Cueing Analyses and Follow-Up Contrasts

To characterise whether the phase effect observed in the main analyses depended on cue validity, we first examined overall validity effects, then analysed valid and invalid trials separately, and finally tested cueing benefit scores directly.

Responses were slower on invalid than valid trials, and this validity cost varied by axis. A 2 × 2 repeated-measures ANOVA showed no overall effect of axis, $F(1, 52) = 0.27$, $p = .607$, $\eta_p^2 = .005$, but did show a main effect of validity, $F(1, 52) = 24.24$, $p < .001$, $\eta_p^2 = .318$, qualified by an axis × validity interaction, $F(1, 52) = 7.55$, $p = .008$, $\eta_p^2 = .127$.

Collapsed across axis, responses were 9 ms slower on invalid than valid trials, $t(52) = 4.92$, $p < .001$, $d_z = 0.68$. This validity effect was evident on both the horizontal axis, where invalid trials were slower than valid trials, $t(52) = 5.02$, $p < .001$, $d_z = 0.69$, and the vertical axis,

$t(52) = 3.30$, $p = .002$, $d_z = 0.45$. By contrast, horizontal and vertical trials did not differ reliably within either validity condition. Within invalid trials, horizontal responses were 1 ms slower than vertical responses, $t(52) = 0.30$, $p = .764$, $d_z = 0.04$; within valid trials, horizontal responses were 5 ms faster than vertical responses, $t(52) = -1.23$, $p = .223$, $d_z = -0.17$.

Valid Trials

For valid trials, inhalation was associated with faster responses on both axes. On the horizontal axis, responses were also slower for left than right targets, yielding main effects of position, $F(1, 52) = 12.17$, $p < .001$, $\eta_p^2 = .190$, and phase, $F(1, 52) = 6.49$, $p = .014$, $\eta_p^2 = .111$, with no position × phase interaction, $F(1, 52) = 1.03$, $p = .315$, $\eta_p^2 = .019$. Responses were 10 ms slower for left than right targets ($d_z = 0.48$), and 11 ms faster during inhalation than exhalation ($d_z = 0.35$).

On the vertical axis, the phase effect was again reliable, with responses 12 ms faster during inhalation than exhalation ($d_z = 0.34$), $F(1, 52) = 6.18$, $p = .016$, $\eta_p^2 = .106$. The effect of position was small, $F(1, 52) = 4.03$, $p = .050$, $\eta_p^2 = .072$, and there was no position × phase interaction, $F(1, 52) = 0.41$, $p = .523$, $\eta_p^2 = .008$.

Invalid Trials

For invalid trials, both axes showed position effects as well as faster responses during inhalation than exhalation, with no evidence that position and phase interacted.

On the horizontal axis, responses were 18 ms slower for right than left targets ($d_z = 0.68$) and 11 ms faster during inhalation than exhalation ($d_z = 0.36$), corresponding to main effects of position, $F(1, 52) = 24.23$, $p < .001$, $\eta_p^2 = .318$, and phase, $F(1, 52) = 6.89$, $p = .011$, $\eta_p^2 = .117$. The interaction was not significant, $F(1, 52) = 1.59$, $p = .212$, $\eta_p^2 = .030$.

On the vertical axis, responses were 18 ms slower for upper than lower targets ($d_z = 0.75$) and 15 ms faster during inhalation than exhalation ($d_z = 0.43$). These patterns were reflected in main effects of position, $F(1, 52) = 29.65$, $p < .001$, $\eta_p^2 = .363$, and phase, $F(1, 52) = 9.68$, $p = .003$, $\eta_p^2 = .157$, with no interaction, $F(1, 52) = 0.02$, $p = .886$, $\eta_p^2 < .001$.

Cueing Benefit Scores

Cueing benefit varied by target position on both axes, but there was no evidence that it depended on respiratory phase. On the horizontal axis, cueing magnitude was 28 ms greater in the right than the left position ($d_z = 0.84$), reflected in a main effect of position, $F(1, 52) = 37.67$, $p < .001$, $\eta_p^2 = .420$. There was no main effect of phase, $F(1, 52) = 0.00$, $p = .959$, $\eta_p^2 < .001$, and no position × phase interaction, $F(1, 52) = 2.43$, $p = .125$, $\eta_p^2 = .045$.

The same overall pattern appeared on the vertical axis. Cueing magnitude was 24 ms greater in the upper than the lower position ($d_z = 0.81$), yielding a main effect of position, $F(1, 52) = 34.39$, $p < .001$, $\eta_p^2 = .398$. Neither the main effect of phase, $F(1, 52) = 0.58$, $p = .448$, $\eta_p^2 = .011$, nor the position × phase interaction, $F(1, 52) = 0.30$, $p = .587$, $\eta_p^2 = .006$, was significant.

General Discussion

Across the two experiments, there was no evidence that respiratory phase interacted with target location on either the horizontal or vertical axis. Bayesian analyses of the horizontal contrast also favoured the null over the predicted interaction pattern reported by Belli and Fischer (2024). Experiment 1 did not show a reliable phase effect on either axis, although the vertical analysis showed a small numerical inhalation advantage. In Experiment 2, responses were clearly faster in the inhalation condition across target locations, while cueing benefits remained stable across respiratory phase. Together, these findings point more strongly to a location-general effect of respiratory phase on response speed than to a stable spatial bias.

The phase effect observed in Experiment 2 is more consistent with a location-general effect on response speed than with the specific spatial interaction reported previously. A clear phase effect on cueing benefit would have been more consistent with an effect on spatial orienting or reorienting. Instead, cueing benefits were stable across phases, which is more consistent with an influence on processes shared by valid and invalid trials, such as sensory encoding, decision formation, or response readiness. This interpretation fits well with respiration research in visual, sensory and cognitive tasks.

In near-threshold vision, respiration modulated perceptual sensitivity and posterior alpha power, with excitability-linked changes preceding behavioural effects (Kluger et al., 2021). Chalas et al. (2026) likewise found enhanced visual sensitivity during inspiration and showed that participants adjusted their breathing to predictable stimulus timing, highlighting the interaction between respiratory state and task demands. Across several sensory and cognitive paradigms, reaction time covaries with respiration more consistently than accuracy, especially when analysed relative to responses rather than only to stimulus onset (Harting et al., 2025; Johannknecht & Kayser, 2022). Other studies are also consistent with an influence of respiration on latent decision dynamics (Brændholt et al., 2025).

Separate work further suggests that respiratory phase may modulate task-related neural representations before the response is executed (Stetza et al., 2025). Although the present data cannot isolate a single stage or mechanism, the shorter RTs during inhalation are more readily interpreted in terms of sensory evidence, neural excitability, decision formation, or response readiness than as a stable, spatially selective pattern across target locations. Due to respiratory phase being blocked in Experiment 2, this pattern could also reflect broader state or expectancy effects that acted similarly on valid and invalid trials.

The present findings diverge from Belli and Fischer's (2024) report in two related ways, so no single explanation is likely to account for both differences. We did not reproduce the reported phase × target location interaction, and in Experiment 2 we instead observed faster responses during inhalation across target locations. One obvious possibility is that phase blocking mattered, because Experiment 1 intermixed inhalation- and exhalation-triggered trials within blocks whereas Belli and Fischer used blocked respiratory phases. That cannot be the whole explanation, however, because Experiment 2 reinstated phase blocking and still did not reproduce the reported interaction. Experiment 2 nevertheless differed from the original cueing study in other respects, most notably in restricting the task to exogenous cueing with a single 150 ms stimulus onset asynchrony, and such changes could plausibly influence whether any respiratory modulation appears as a spatially selective pattern or as a more general change in response speed. The larger sample in the present Experiment 2 may also have increased sensitivity to a modest location-general inhalation advantage, but Belli and Fischer's reported means do not clearly suggest such an effect, so greater power is only a partial explanation. A cautious interpretation is therefore that the behavioural expression of any respiratory effect may be sensitive to procedural context. For example, responses in Experiment 2 were approximately 80 ms slower than the roughly 340 ms reported by Belli and Fischer (2024), placing responses later relative to the respiratory trigger.

The vertical findings also bear on the thoracic lift hypothesis. A body-based influence of respiration on spatial attention need not be confined to the horizontal axis, and the thoracic lift account specifically predicted an upper-lower effect. However, the position effects, averaged across phases, differed in direction across experiments, with responses faster to upper targets in Experiment 1 and to lower targets in Experiment 2. Neither experiment showed evidence that

respiratory phase modulated vertical position. The vertical findings therefore constrain the thoracic lift account by indicating that the theorised upper-lower mapping did not emerge with the present procedure for triggering stimuli at peaks and troughs. This reduces concerns about metaphorically associated performance patterns (“more is up”; e.g., Lakoff & Johnson, 1980).

The main limitations of the present design concern temporal precision and the operational definition of respiratory phase. Respiratory phase was estimated online, with stimuli manually triggered at visually identified peaks and troughs. This matched the procedure used in the original studies and therefore preserved procedural comparability. Manual triggering may have introduced a delay between the intended respiratory landmark and stimulus onset, with the size of that delay varying across trials. The relevant issue, however, extends beyond the contrast between manual and automated triggering. Breathing also varies from breath to breath. In the present experiments, respiratory phase was inferred from thoracic and abdominal belt signals. More generally, peak-based estimators may fail to capture atypical but physiologically meaningful breaths (Harrison et al., 2021; Oku, 2022; Power et al., 2020).

Triggering stimuli only at peaks and troughs samples two points in the respiratory cycle, which may oversimplify the signal most relevant for behaviour. Responses occur after the respiratory trigger, so differences in reaction time also change their timing relative to that landmark. Recent work also suggests that relationships between respiration and performance are often better captured when respiratory timing is modelled continuously and at lags relative to behaviour, rather than only by classifying trials at stimulus onset into inhalation versus exhalation (Harting et al., 2025). Related evidence indicates that the alignment of breathing to task events varies with anticipated task demands, so respiratory phase at stimulus onset may capture only part of the relevant coupling between breathing and performance (Kayser et al.,

2026). If respiratory modulation is strongest during transitions, earlier cycle segments, or response-linked intervals, sampling only peaks and troughs may underestimate its magnitude or alter its apparent form. The present findings therefore bear most directly on the reproducibility of the effect originally reported with stimuli triggered at peaks and troughs, while leaving open finer-grained respiratory influences that may require both greater temporal precision and richer modelling of the respiratory signal.

These limitations were likely greatest in Experiment 1, where phase and location were interleaved. Respiration is also physiologically coupled to cardiovascular dynamics via respiratory sinus arrhythmia and broader cardiorespiratory coupling, so any inhalation advantage may reflect a compound cardiorespiratory influence (Dick et al., 2014; Vinogradova et al., 2024). An additional unmeasured boundary condition concerns breathing route. Some reported effects of respiration on cognition appear attenuated during oral compared with nasal breathing (Zelano et al., 2016), and oral breathing can impair performance on visual attention tasks under demanding conditions (Yoshimura et al., 2019; but see Richards et al., 2026, who did not replicate this finding). As breathing route was not monitored here, spontaneous variation between nasal and oral breathing may have added further noise to the phase-based analyses.

Future research should therefore compare manual triggering at peaks and troughs with automated triggering while also moving beyond event marking alone. Standardising trigger detection would likely improve consistency, but it would not by itself determine which respiratory feature is behaviourally relevant or whether peaks and troughs are the most informative landmarks for these tasks. Alternatively, post hoc sorting of a large number of responses into temporal bins along the breathing cycle would permit a fuller assessment. Concurrent measures of cardiac activity, gaze stability, breathing route, and pupil-linked arousal

would help distinguish spatial orienting from broader changes in physiological state (Andrews et al., 2025). Designs that include multiple stimulus onset asynchronies and endogenous orienting conditions could be valuable. Richer respiratory predictors could also be worth testing, including cycle length (Skog et al., 2026), transition phases (Saltafossi et al., 2025), and response-locked phase (Harting et al., 2025). Overall, the present findings fit a global facilitation account in which inhalation was associated with faster responses in Experiment 2 without a reproducible spatially specific pattern across target locations.

Preregistration and Deviations

Preregistration documents for both experiments are available on OSF at https://osf.io/u58z9/. Deviations from the preregistrations included the use of pseudorandomised lists in Experiment 1. In Experiment 2, recruitment continued during the available data collection period beyond the preregistered minimum of 32, yielding 54 recruited participants (53 after exclusion). We also applied within-participant winsorisation to align preprocessing with Belli and Fischer (2024). We added Bayesian analyses of the primary horizontal phase × target location interaction contrasts and exploratory cueing analyses in Experiment 2, including the validity ANOVA, separate analyses of valid and invalid trials, and cueing benefit analyses. Data and analysis code for both experiments are available at https://osf.io/u58z9/.

References

Allen, M., Varga, S., & Heck, D. H. (2023). Respiratory rhythms of the predictive mind. *Psychological Review, 130*(4), 1066-1080. https://doi.org/10.1037/rev0000391

Andrews, R., Melnychuk, M. C., Moran, C. N., McGovern, D. P., Holfelder, A., Moran, S., & Dockree, P. M. (2025). Arousal and sustained attention fluctuate differently with respiration in younger and older adults. *Imaging Neuroscience, 3*, IMAG.a.26. https://doi.org/10.1162/IMAG.a.26

Aston-Jones, G., & Cohen, J. D. (2005). An integrative theory of locus coeruleus-norepinephrine function: Adaptive gain and optimal performance. *Annual Review of Neuroscience, 28*, 403-450. https://doi.org/10.1146/annurev.neuro.28.061604.135709

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology, 59*, 617-645. https://doi.org/10.1146/annurev.psych.59.103006.093639

Beh, H. C., & Nix-James, D. R. (1974). The relationship between respiration phase and reaction time. *Psychophysiology, 11*(3), 400-402. https://doi.org/10.1111/j.1469-8986.1974.tb00563.x

Belli, F., & Fischer, M. H. (2024). Breathing shifts visuo-spatial attention. *Cognition, 243*, 105685. https://doi.org/10.1016/j.cognition.2023.105685

Belli, F., & Fischer, M. H. (2025). Respiratory phases modulate visuo-spatial attention: Evidence from line bisection and landmark tasks. *Laterality, 29*(5-6), 527-554. https://doi.org/10.1080/1357650X.2025.2491319

Brændholt, M., Nikolova, N., Vejlø, M., Banellis, L., Fardo, F., Kluger, D. S., & Allen, M. (2025). The respiratory cycle modulates distinct dynamics of affective and perceptual

decision-making. *PLoS Computational Biology, 21*(5), e1013086. https://doi.org/10.1371/journal.pcbi.1013086

Chalas, N., Saltafossi, M., Berther, T., Balestrieri, E., Abbasi, O., & Kluger, D. S. (2026). Respiration as a dynamic modulator of sensory sampling. *Nature Communications, 17*, Article 3261. https://doi.org/10.1038/s41467-026-71604-8

Chemero, A. (2009). *Radical embodied cognitive science*. MIT Press.

Corbetta, M., & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews Neuroscience, 3*, 201-215. https://doi.org/10.1038/nrn755

Craig, A. D. (2002). How do you feel? Interoception: The sense of the physiological condition of the body. *Nature Reviews Neuroscience, 3*(8), 655-666. https://doi.org/10.1038/nrn894

Dick, T. E., Hsieh, Y.-H., Dhingra, R. R., Baekey, D. M., Galán, R. F., Wehrwein, E., & Morris, K. F. (2014). Cardiorespiratory coupling: Common rhythms in cardiac, sympathetic, and respiratory activities. *Progress in Brain Research, 209*, 191-205. https://doi.org/10.1016/B978-0-444-63274-6.00010-2

Felisatti, A., & Fischer, M. H. (Eds.). (2024). *Experimental methods in embodied cognition: How cognitive psychologists approach embodiment*. Routledge.

Flexman, J. E., Demaree, R. G., & Simpson, D. D. (1974). Respiratory phase and visual signal detection. *Perception & Psychophysics, 16*(2), 337-339. https://doi.org/10.3758/BF03203952

Fodor, J. A. (1983). *The modularity of mind*. MIT Press.

Haouzi, P., & Bell, H. J. (2009). Control of breathing and volitional respiratory rhythm in humans. *Journal of Applied Physiology, 106*(3), 904-910. https://doi.org/10.1152/japplphysiol.90675.2008

Harrison, S. J., Bianchi, S., Heinzle, J., Stephan, K. E., Iglesias, S., & Kasper, L. (2021). A Hilbert-based method for processing respiratory timeseries. *NeuroImage, 230*, 117787. https://doi.org/10.1016/j.neuroimage.2021.117787

Harting, C., Hehemann, L., Stetza, L., & Kayser, C. (2025). Respiration shapes response speed and accuracy with a systematic time lag. *Proceedings of the Royal Society B: Biological Sciences, 292*(2044), 20242566. https://doi.org/10.1098/rspb.2024.2566

Heck, D. H., Correia, B. L., Fox, M. B., Liu, Y., Allen, M., & Varga, S. (2022). Recent insights into respiratory modulation of brain activity offer new perspectives on cognition and emotion. *Biological Psychology, 170*, 108316. https://doi.org/10.1016/j.biopsycho.2022.108316

Hildebrandt, G., & Engel, P. (1963). Der Einfluß des Atemrhythmus auf die Reaktionszeit. *Pflügers Archiv - European Journal of Physiology, 278*(2), 113-129. https://doi.org/10.1007/BF00362684

Johannknecht, M., & Kayser, C. (2022). The influence of the respiratory cycle on reaction times in sensory-cognitive paradigms. *Scientific Reports, 12*(1), Article 2586. https://doi.org/10.1038/s41598-022-06364-8

Kayser, C., Hehemann, L., & Stetza, L. (2026). The alignment of respiration to sensory-motor events is shaped by expected effort. *iScience, 29*(3), 115046. https://doi.org/10.1016/j.isci.2026.115046

Kluger, D. S., Balestrieri, E., Busch, N. A., & Gross, J. (2021). Respiration aligns perception with neural excitability. *eLife, 10*, e70907. https://doi.org/10.7554/eLife.70907

Kluger, D. S., Gross, J., & Keitel, C. (2024). A dynamic link between respiration and arousal. *The Journal of Neuroscience, 44*(47), e1173242024. https://doi.org/10.1523/JNEUROSCI.1173-24.2024

Kraft, A., Sommer, W. H., Schmidt, S., & Brandt, S. A. (2011). Dynamic upper and lower visual field preferences within the human dorsal frontoparietal attention network. *Human Brain Mapping, 32*(7), 1036-1049. https://doi.org/10.1002/hbm.21087

Lakoff, G., & Johnson, M. (1980). *Metaphors we live by*. University of Chicago Press.

Levine, M. W., & McAnany, J. J. (2005). The relative capabilities of the upper and lower visual hemifields. *Vision Research, 45*(21), 2820-2830. https://doi.org/10.1016/j.visres.2005.04.001

Lenth, R. V., & Piaskowski, J. (2026). *emmeans: Estimated marginal means, aka least-squares means* (Version 2.0.2) [Computer software]. https://doi.org/10.32614/CRAN.package.emmeans

Melnychuk, M. C., Robertson, I. H., Plini, E. R. G., & Dockree, P. M. (2021). A bridge between the breath and the brain: Synchronization of respiration, a pupillometric marker of the locus coeruleus, and an EEG marker of attentional control state. *Brain Sciences, 11*(10), Article 1324. https://doi.org/10.3390/brainsci11101324

Meteyard, L., Cuadrado, S. R., Bahrami, B., & Vigliocco, G. (2012). Coming of age: A review of embodiment and the neuroscience of semantics. *Cortex, 48*(7), 788-804. https://doi.org/10.1016/j.cortex.2010.11.002

Molle, L., Coste, A., Benoit, C.-E., Derosiere, G., Janaqi, S., Perrey, S., & Dupeyron, A. (2023). Inhalation boosts perceptual awareness and decision speed. *Journal of Neurophysiology, 130*(3), 516-523. https://doi.org/10.1152/jn.00492.2022

Morey, R. D., & Rouder, J. N. (2018). *BayesFactor: Computation of Bayes factors for common designs* (Version 0.9.12-4.2) [Computer software]. https://doi.org/10.32614/CRAN.package.BayesFactor

Nakamura, N. H., Fukunaga, M., & Oku, Y. (2018). Respiratory modulation of cognitive performance during the retrieval process. *PLOS ONE, 13*(9), Article e0204021. https://doi.org/10.1371/journal.pone.0204021

Oku, Y. (2022). Temporal variations in the pattern of breathing: Techniques, sources, and applications to translational sciences. *The Journal of Physiological Sciences, 72*, 22. https://doi.org/10.1186/s12576-022-00847-z

Peirce, J. W., Gray, J. R., Simpson, S., MacAskill, M. R., Höchenberger, R., Sogo, H., Kastman, E., & Lindeløv, J. K. (2019). PsychoPy2: Experiments in behavior made easy. *Behavior Research Methods, 51*(1), 195-203. https://doi.org/10.3758/s13428-018-01193-y

Perl, O., Ravia, A., Rubinson, M., Eisen, A., Soroka, T., Mor, N., Secundo, L., & Sobel, N. (2019). Human non-olfactory cognition phase-locked with inhalation. *Nature Human Behaviour, 3*(5), 501-512. https://doi.org/10.1038/s41562-019-0556-z

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*(1), 3-25. https://doi.org/10.1080/00335558008248231

Power, J. D., Lynch, C. J., Dubin, M. J., Silver, B. M., Martin, A., & Jones, R. M. (2020). Characteristics of respiratory measures in young adults scanned at rest, including systematic changes and “missed” deep breaths. *NeuroImage, 204*, 116234. https://doi.org/10.1016/j.neuroimage.2019.116234

Previc, F. H. (1990). Functional specialization in the lower and upper visual fields in humans: Its ecological origins and neurophysiological implications. *Behavioral and Brain Sciences, 13*(3), 519-542. https://doi.org/10.1017/S0140525X00080018

Previc, F. H., Declerck, C., & de Brabander, B. (2005). Why your "head is in the clouds" during thinking: The relationship between cognition and upper space. *Acta Psychologica*, *118*(1-2), 7–24. https://doi.org/10.1016/j.actpsy.2004.10.012

Pylyshyn, Z. W. (1980). Computation and cognition: Issues in the foundations of cognitive science. *Behavioral and Brain Sciences, 3*(1), 111-132. https://doi.org/10.1017/S0140525X00002053

Richards, B., Holle, H., Skarratt, P. A., & Lindsay, S. (2026). *Breathing route does not affect visual search: A pre-registered replication and extension* [Manuscript submitted for publication]. School of Psychology and Social Work, University of Hull.

Rouder, J. N., Speckman, P. L., Sun, D., Morey, R. D., & Iverson, G. (2009). Bayesian *t* tests for accepting and rejecting the null hypothesis. *Psychonomic Bulletin & Review, 16*(2), 225-237. https://doi.org/10.3758/PBR.16.2.225

Saltafossi, M., Zaccaro, A., Kluger, D. S., Perrucci, M. G., Ferri, F., & Costantini, M. (2025). Respiration facilitates behavior during multisensory integration. *Psychophysiology, 62*(9), e70145. https://doi.org/10.1111/psyp.70145

Seydell-Greenwald, A., Pu, S. F., Ferrara, K., Chambers, C. E., Newport, E. L., & Landau, B. (2019). Revisiting the landmark task as a tool for studying hemispheric specialization: What's really right? *Neuropsychologia, 127*, 57-65. https://doi.org/10.1016/j.neuropsychologia.2019.01.022

Shulman, G. L., Pope, D. L. W., Astafiev, S. V., McAvoy, M. P., Snyder, A. Z., & Corbetta, M. (2010). Right hemisphere dominance during spatial selective attention and target detection occurs outside the dorsal frontoparietal network. *Journal of Neuroscience, 30*(10), 3640-3651. https://doi.org/10.1523/JNEUROSCI.4085-09.2010

Singmann, H., Bolker, B., Westfall, J., Aust, F., & Ben-Shachar, M. S. (2025). *afex: Analysis of factorial experiments* (Version 1.5-1) [Computer software]. https://doi.org/10.32614/CRAN.package.afex

Skog, E. E., Issar, D., Grigg, M., Nelson, S. E., Kainerstorfer, J. M., & Smith, M. A. (2026). From breath to behavior: Respiratory features predict visual detection performance [Preprint]. *bioRxiv*. https://doi.org/10.64898/2026.03.18.712638

Stetza, L., Hehemann, L., & Kayser, C. (2025). Evidence that respiratory phase may modulate task-related neural representations of visual stimuli. *The Journal of Neuroscience, 45*(21), e2236242025. https://doi.org/10.1523/JNEUROSCI.2236-24.2025

Tort, A. B. L., Brankačk, J., & Draguhn, A. (2018). Respiration-entrained brain rhythms are global but often overlooked. *Trends in Neurosciences, 41*(4), 186-197. https://doi.org/10.1016/j.tins.2018.01.007

Tort, A. B. L., Laplagne, D. A., Draguhn, A., & Gonzalez, J. (2025). Global coordination of brain activity by the breathing cycle. *Nature Reviews Neuroscience, 26*(6), 333-353. https://doi.org/10.1038/s41583-025-00920-7

Vinogradova, O. L., Borovik, A. S., Zhedyaev, R. Y., & Tarasova, O. S. (2024). Respiratory sinus arrhythmia: Physiological mechanisms and relationship with systemic blood pressure fluctuations. *Human Physiology, 50*(3), 276-284. https://doi.org/10.1134/S0362119724700749

Yoshimura, N., Yonemitsu, F., Marmolejo-Ramos, F., Ariga, A., & Yamada, Y. (2019). Task difficulty modulates the disrupting effects of oral respiration on visual search performance. *Journal of Cognition, 2*(1), Article 21. https://doi.org/10.5334/joc.77

Zelano, C., Jiang, H., Zhou, G., Arora, N., Schuele, S., Rosenow, J., & Gottfried, J. A. (2016). Nasal respiration entrains human limbic oscillations and modulates cognitive function. *Journal of Neuroscience, 36*(49), 12448-12467. https://doi.org/10.1523/JNEUROSCI.2586-16.2016