# Head movements modulate visual responsiveness in the absence of gaze shifts

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Visuospatial attention is strongly associated with saccades. Given that gaze shifts are often accomplished by combined eye–head movements, attention may also be coupled to head movements. We showed that simply turning the head without shifting the gaze is sufficient to cause a transient unbalance in responding to a visual stimulus. Manual responses to a stimulus flashed shortly before the onset of a horizontal head movement were faster in congruent trials, when the head moved towards the stimulus, than in incongruent trials, when the head moved away from the stimulus. These effects are similar to those observed for saccades. We take this as evidence for a tight link between visuospatial attention and head movements, even when the gaze does not shift. *NeuroReport* 19:831–834 © 2008 Wolters Kluwer Health | Lippincott Williams & Wilkins.

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## Introduction

During the preparation of both saccades [1–6] and goal-directed arm movements [7,8], visuospatial attention is allocated to the target of the movement. The coupling with attention seems to be tighter for saccades than for arm movements because only in the latter case visuospatial attention can be withdrawn once the movement target has been tagged [9].

Gaze shifts are often accomplished by coordinated eye and head movements [10–14]. Moreover, head movements can inherit a number of saccadic properties and functions when ocular motility is lost [15,16]. Despite the synergistic relationship between eye and head movements, the coupling between visuospatial attention and head movements has not been investigated in detail. To the extent that the allocation of visuospatial attention facilitates sensory-motor processing at target location, it would seem logical to assume that visuospatial attention is associated to both the eye and head components of a gaze shift, not just to saccades [17]. If so, the simple act of rotating the head might be sufficient to bias the allocation of attention even in the absence of gaze shifts. Here we show that a head rotation unaccompanied by a gaze shift creates an unbalance in responding to a test visual stimulus presented ipsilaterally or contralaterally with respect to the endpoint of the head movement.

## Methods

### Participants and tasks

Ten participants (age: 20–45 years, six males) took part in the experiments. Eight participants were naif as to the purpose of the study. Informed consent was obtained following the guidelines of the local Ethical Committee.

Participants were seated at a distance of 57 cm from a computer screen in a dim room. In the first experiment they had to make a fast horizontal head rotation ('point your nose') to a peripheral target (diameter 2°) located 10° to the left or to the right of a central fixation cross, without shifting the gaze from central fixation. In the second experiment they had to make a saccade to the peripheral target without moving the head. In both cases the movement had to begin 1 s after the last of three warning tones (Fig. 1). The movement was always the same within a session (eye or head, to the right or to the left). The secondary task was to press the mouse left key upon detection of a visual stimulus (diameter 0.4°, duration 100 ms) flashed at 10° either to the left or to the right of the fixation point. In half of the trials the stimulus was on the same side of the target (congruent trials), in the other half it was on the opposite side (incongruent trials). Response time was computed from stimulus onset. The interval between the last tone and the stimulus presentation (stimulus onset asynchrony) could take six values (400–2400 ms, in 400 ms steps, Fig. 1). Thus, the asynchrony between the stimulus and movement onset (henceforth, stimulus to movement asynchrony) varied approximately between −1 s (stimulus leading movement onset) and +2 s (stimulus lagging movement onset).

A trial was excluded if (i) the movement was in the wrong direction; (ii) its amplitude was less than 5°; (iii) was shorter than 100 ms or longer than 1300 ms; (iv) participants made an erroneous saccade, or a microsaccade (<1°, 1.6% of the trials), when a head movement was required. Overall, 12% of the trials were excluded.

There were four sessions (head/eye movement, left/right direction). A session consisted of (2 stimulus side) × (6 stimulus onset asynchrony) × (4 repetition)=48 trials,
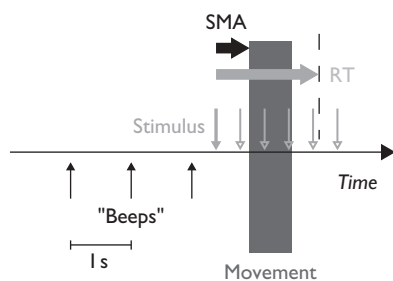
**Fig. I** Sequence of events in a single trial. All six stimulus onset asynchronies used in the experiment are represented, which define the timing of the visual test stimulus (light grey vertical arrows) relative to the warning tones (beeps). For clarity, only one response time (light grey horizontal arrow) and one stimulus to movement asynchrony (black horizontal arrow) are shown, which are relative to the first stimulus onset asynchrony. The vertical dashed line represents the manual response. The dark grey area represents the movement duration.

randomly alternated. The order of the four sessions was counterbalanced across participants. Experiments were preceded by a single familiarization session.

### Recording procedures
Eye movements were recorded by a head-mounted system (ASL 501, Applied Science Laboratories, Bedford, MA, USA; frame rate 120 Hz, low pass 30 Hz). Head position was measured indirectly from the compensatory eye movements. The delay of 9–10 ms introduced by the vestibuloocular reflex [18], was compensated by shifting the recording by one video frame. The onset and offset of head movements, which often were quite smooth, were estimated independently by two experimenters through visual inspection of position and velocity traces. The accepted value was the average of the two estimates, whose difference never exceeded two video frames. Eight percent of the trials contained artefacts and were excluded. Asynchronies between the recording system and the display were controlled by measuring the physical delays with a photocell.

### Data analysis
For statistical analyses, we used paired Student's *t*-test and univariate analyses of variance with participants as random factor. Movement side and stimulus side were treated as fixed factors, both independently, and after collapsing them into a single factor (congruence).

### Results
In the head-movement condition the average latency across participants between the third tone and movement onset was 978 ms ± 284 SD, with a movement duration of 649 ms ± 256 SD and an amplitude of 13.3° ± 5.2 SD. Neither stimulus nor movement side had a significant effect on head movement latency, duration and amplitude ($P > 0.2$ in all cases), except that leftward movements were slightly larger than rightward ones [13.9° ± 5.6 SD vs. 12.6° ± 4.7 SD; $F_{(1,9)} = 14.285$, $P = 0.004$].

Response times were independent of movement and stimulus side [$F_{(1,9)} = 1.459$, $P = 0.151$ and $F_{(1,9)} = 1.968$, $P = 0.190$]. For intermediate stimulus to movement asynchronies (−0.5 to 0.5 s), where stimulus–response intervals (Fig. 2a, light grey lines) and head movements (dark grey lines) overlapped extensively, response times were much longer than in trials in which the movement either ended

before the stimulus, or had not begun yet (616 ms ± 285 SD vs. 388 ms ± 153 SD; see also Fig. 3a). This large increase in response times was likely due to an interference between moving the head and responding to the visual stimulus at the same time (dual-task effect).

Importantly, response times depended on the congruence between stimulus and movement side [Fig. 3a; interaction congruence × bin: $F_{(13,110)} = 2.012$, $P = 0.026$], and were smaller in congruent than incongruent trials. The effect of congruence emerged for stimuli displayed before the onset of head movement, that is, during movement preparation. In the stimulus to movement asynchrony interval (−250, −50 ms) the mean response time difference across participants was 67 ms ± 88 SD [$t_{(9)} = 2.384$, $P = 0.020$], with an identical median value. We excluded trials with stimulus to movement asynchrony ≥ 50 ms because of possible mis-estimates of movement onset (see Methods). Thus, although
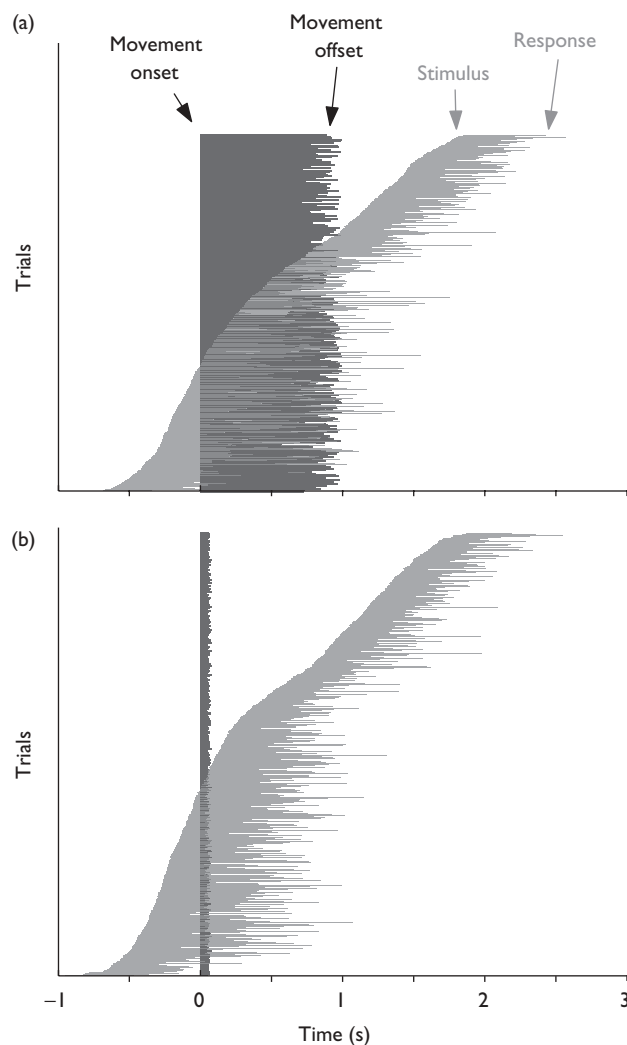


**Fig. 2** Temporal relationship between movement execution (dark grey) and stimulus–response interval (light grey). (a) Head movements. (b) Saccades. Each row represents a trial. Trials are aligned on movement onset, and are ordered by stimulus to movement asynchrony. In a few trials both the visual stimulus and the manual response occur before movement onset (bottom rows), whereas in other trials they occur after the movement has terminated (top rows). In most trials there is at least a partial overlap between head movement and stimulus–response interval.
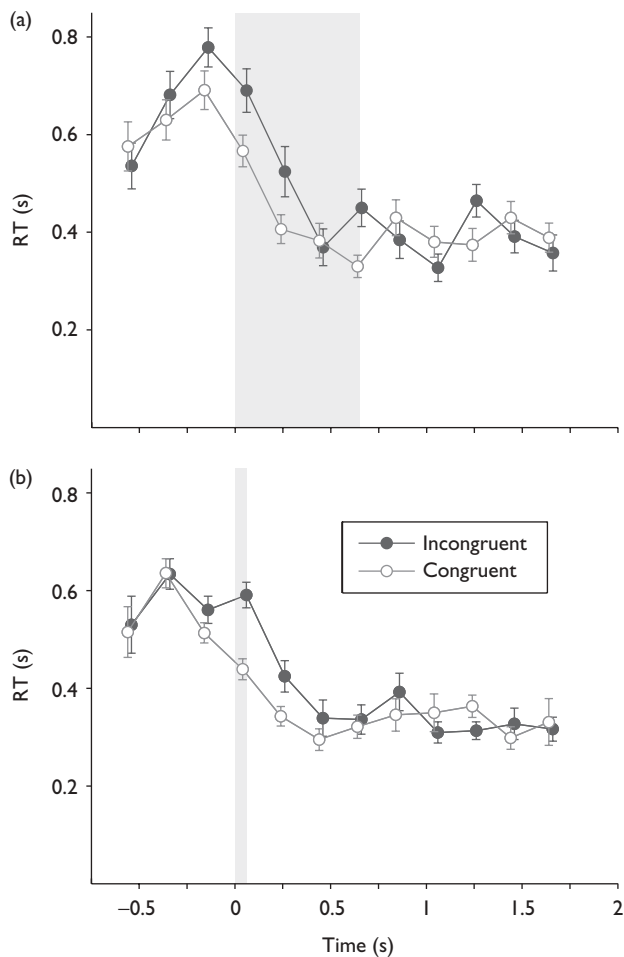
**Fig. 3** Response times in congruent and incongruent trials, binned in 200 ms stimulus to movement asynchrony intervals. (a) Head movements. (b) Saccades. Data are aligned on movement onset, whose mean duration is indicated by the grey area. Bars represent SEM.

the gaze always remained in the central position, responding to a brief visual stimulus displayed shortly before an ipsilateral head rotation was faster than when the rotation was directed contralaterally.

The reduction of response times in congruent trials, compared with incongruent trials, cannot reflect a response bias, because the response was totally unrelated to congruence. Likewise, it cannot be attributed to an effect of congruence on head movement, which could have influenced the response time if manual responses were synchronized with the head movement. In fact, neither latency nor duration of the head movements were significantly affected by congruence in the stimulus to movement asynchrony interval $-250$ to $-50$ ms [$t(9)=-0.11$, $P=0.54$, and $t(9)=0.19$, $P=0.42$, respectively]. Moreover, in all but one participant the trial-by-trial correlation between response time and either movement latency or movement duration did not reach significance.

The pattern of results in the saccade condition was similar to that in the head movement condition (Figs 2b and 3b). First, in both congruent and incongruent trials response times were longer when the stimulus was presented either shortly before or shortly after the saccade. Second, in the presaccadic stimulus to movement asynchrony window

between $-250$ and $-50$ ms there was a response time advantage for congruent trials over incongruent ones of $59\,\text{ms}\pm87$ SD [$t(9)=2.125$, $P=0.031$], which was not significantly different from that found in the first experiment [$t(9)=0.177$, $P=0.863$].

## Discussion

The main result of our study is that a horizontal rotation of the head while the gaze remained on a central fixation point shortened response times to ipsilateral test stimuli displayed shortly before movement onset, as compared with contralateral stimuli. The prime candidate to mediate this congruence effect is visuospatial attention. This is in keeping with the well-known association between saccades and attention, probed with both response times [1,8,19], and stimulus recognition paradigms [2–4]. Although the time course of the allocation of attention depends on the experimental conditions [5], it is generally admitted that attention is deployed before saccadic onset in the direction of the movement. As we found a similar effect of congruence for both eye and head movements, it is plausible that also head movements are preceded by a similar shift of visuospatial attention, even if the gaze does not move.

Insofar as head movements and saccades often cooperate to shift the gaze [12], it seems logical that visuospatial attention is associated to both motor components. Another possibility is that the intention to move the head triggers a saccadic plan even if observers were instructed not to perform such a movement. If so, the shift of attention may simply reflect the automatically programmed, but suppressed, saccade [20]. Two reasons to downplay this alternative explanation exist. First, in head movement trials there were no microsaccades, which could be symptomatic of a saccade-related shift of visuospatial attention [21]. Second, visuospatial attention in antisaccade tasks is allocated to the target of the antisaccade, not to the target of unrecognized, erroneous or suppressed prosaccades [22,23]. This suggests that suppressing a saccade suppresses also the attention shift that would otherwise be associated with it. Thus, the most parsimonious explanation for the observed reduction of the response times in congruent trials is indeed that commands to move the head, like oculomotor commands, are sufficient to generate a shift of the attentional focus.

As the same head movement was performed throughout an experimental session, it is safe to assume that the movement was overlearned. Yet, this did not prevent attention from being deployed just before movement onset, even towards the end of the session. The robustness of the effect stands in contrast with the results for reaching hand movements, where endogenous attention can be withdrawn once the movement target has been tagged [8,9]. Thus, the relationship of visuospatial attention with head movements seems to be more similar to that with saccades than that with arm reaching movements. It should be said, however, that our task was not too difficult, despite the effort to keep the gaze in central position to avoid undesired gaze shifts. Therefore, more demanding tasks in which attention deployment is explicitly manipulated [5] are required to further assess the strength of the association between head movements and visuospatial attention.

The fact that a response time advantage for congruent trials emerged at negative stimulus to movement asynchrony

suggests that visuospatial attention began to shift before movement onset [5]. However, this does not exclude that, due to integration times, movement-related signals (i.e. visual reafference, proprioception, vestibular signals) generated by movements occurring soon after the flashed stimulus, can influence 'retroactively' its saliency (see Ref. [24]). Unfortunately, in our experiments there were too few trials in which the response was given before movement onset (22 trials) to be able to assess the interaction between premotor and movement-related signals. Note that the difficulty would have persisted even if we had designed a perceptual recognition task, rather than a simple response time task, because the response would have again be given after the eye or head movement. The point might be clarified in a further study by probing attention in a go/no go task, where motor intention and execution are dissociated.

Our results indicate that an unintentional deployment of attention can occur when moving the head without shifting the gaze, as it may happen while driving a car or in sport. The study may also be a clue that, similarly to attention disorders caused by oculomotor palsy [25], chronic disturbances of head motility (e.g. cervical dystonia or persistent neck pain) could cause a tonic unbalance of visuospatial attention.

## Conclusion

Making a horizontal head rotation unaccompanied by a gaze shift affected response times to a visual stimulus flashed shortly before movement onset. We argued that this effect is introduced by a transient unbalance of visuospatial attention that increases response times to stimuli contralateral to the direction of the impending head movement, as compared with ipsilateral stimuli.

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## References

1. Shepherd M, Findlay JM, Hockey RJ. The relationship between eye movements and spatial attention. *Q J Exp Psychol A* 1986; **38**:475–491.
2. Hoffman JE, Subramaniam B. The role of visual attention in saccadic eye movements. *Percept Psychophys* 1995; **57**:787–795.
3. Kowler E, Anderson E, Dosher B, Blaser E. The role of attention in the programming of saccades. *Vision Res* 1995; **35**:1897–1916.
4. Deubel H, Schneider WX. Saccade target selection and object recognition: evidence for a common attentional mechanism. *Vision Res* 1996; **36**: 1827–1837.
5. Deubel H. The time course of presaccadic attention shifts. *Psychol Res* (in press).
6. De'Sperati C, Deubel H. Mental extrapolation of motion modulates responsiveness to visual stimuli. *Vision Res* 2006; **46**:2593–2601.
7. Deubel H. Selective dorsal and ventral processing: evidence for a common attentional mechanism in reaching and perception. *Vis Cogn* 1998; **5**:81–107.
8. Sheliga BM, Craighero L, Riggio L, Rizzolatti G. Effects of spatial attention on directional manual and ocular responses. *Exp Brain Res* 1997; **114**:339–351.
9. Deubel H, Schneider W. Delayed saccades, but not delayed manual aiming movements, require visual attention shifts. *Ann N Y Acad Sci* 2003; **1004**:1–8.
10. Roucoux A, Crommelinck M. Control of head movement during visual orientation. In: Peterson B, Richmond F, editors. *Control of head movement*. Oxford: Oxford University Press; 1988.
11. Peterson B, Richmond F. *Control of head movement*. Oxford: Oxford University Press; 1988.
12. Stahl JS. Amplitude of human head movements associated with horizontal saccades. *Exp Brain Res* 1999; **126**:41–54.
13. Guitton D, Douglas RM, Volle M. Eye-head coordination in cats. *J Neurophysiol* 1984; **52**:1030–1050.
14. Pelz J, Hayhoe M, Loeber R. The coordination of eye, head, and hand movements in a natural task. *Exp Brain Res* 2001; **139**:266–277.
15. Gilchrist ID, Brown V, Findlay JM. Saccades without eye movements. *Nature* 1997; **390**:130–131.
16. Gaymard B, Siegler I, Rivaud-Pechoux S, Israel I, Pierrot-Desilligny C, Berthoz A. A common mechanism for the control of eye and head movements in humans. *Ann Neurol* 2000; **47**:819–822.
17. Craighero L, Nascimben M, Fadiga L. Eye position affects orienting of visuospatial attention. *Curr Biol* 2004; **14**:331–333.
18. Collewijn H, Smeets JB. Early components of the human vestibulo-ocular response to head rotation: latency and gain. *J Neurophysiol* 2000; **84**: 376–389.
19. Posner MI. Orienting of attention. *Q J Exp Psychol* 1980; **32**:3–25.
20. Sheliga BM, Riggio L, Rizzolatti G. Spatial attention and eye movements. *Exp Brain Res* 1995; **105**:261–275.
21. Engbert R, Kliegl R. Microsaccades uncover the orientation of covert attention. *Vision Res* 2003; **43**:1035–1045.
22. Mokler A, Deubel H. Unattended saccades can be executed without presaccadic attention shifts. *Perception* 2000; **29**:54.
23. Mokler A, Fischer B. The recognition and correction of involuntary prosaccades in an antisaccade task. *Exp Brain Res* 1999; **125**:511–516.
24. Pola J. A model of the mechanism for the perceived location of a single flash and two successive flashes presented around the time of a saccade. *Vision Res* 2007; **47**:2798–2813.
25. Craighero L, Carta A, Fadiga L. Peripheral oculomotor palsy affects orienting of visuospatial attention. *Neuroreport* 2001; **12**:3283–3286.