



# Influence of postural constraints on eye and head latency during voluntary rotations

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## ABSTRACT

Redirecting gaze towards new targets often requires not only eye movements, but also synergistic rotations of the head, trunk and feet. This study investigates the influence of postural constraints on eye and head latency during voluntary refixations in the horizontal plane in 14 normal subjects. Three postural conditions were presented, (1) sitting in a chair using only eye and head movements, (2) standing without feet movements and (3) standing with feet movement. Head–eye reorientations towards eccentric un-predictable locations were performed towards  $\pm 45^\circ$  and  $\pm 90^\circ$  targets and back towards a central, spatially predictable target. Results showed that postural constraints affected eye latency but only when subjects knew the future location of the target (recentering “return” trials). Specifically, relatively longer eye latencies were observed when subjects had to turn their feet back towards the predictable central target. These findings suggest that the additional CNS processing required to reduce degrees of freedom during predictive motion introduces delays to the eye movement in order to efficiently assemble the components of a new motor synergy.

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## 1. Introduction

Large voluntary gaze reorientations are common in everyday life often requiring combined rotations of the eye, head and trunk towards the intended target (Land, Mennie, & Rusted, 1999). In many situations, i.e. when reaching distant targets, foot rotations are also involved (whole-body rotations). How such postural constraints influences movement timing, in particular eye latencies is not known.

When a seated observer foveates a target only with eyes movement (i.e. head fixed), eye latencies are approximately 200–250 ms for  $40^\circ$  horizontal eccentricity (Fuller, 1996; Isotalo, Lasker, & Zee, 2005). During saccades also involving head movements, head latency is longer than eye latency because of the larger mass of the head and biomechanical properties of the neck muscles (Zangemeister & Stark, 1981, 1982b). In addition, head and eye latencies during gaze shifts depend on target amplitude and predictability (Goldring et al., 1996; Guitton & Volle, 1987; Zangemeister & Stark, 1982a), target timing (Moschner & Zangemeister, 1993) and subjects' instructions and alertness (Zangemeister & Stark, 1982a).

In parallel, several studies dealt with eye–head coordination during various postural scenarios (for a review, Land, 2006). During straight ahead walking, eye movements are launched forward of the actual foot steps to explore the terrain for future footfalls (Patla, Adkin, & Ballard, 1999). When the walking direction

changes, body rotation is preceded by eye saccades toward the future walking direction initiated concomitantly with head movement (Hollands, Patla, & Vickers, 2002). Hollands, Zivara, and Bronstein (2004) first investigated the synergic organization of eye and whole-body using a ‘turning on the spot’ paradigm towards targets in yaw. More recently, Anastasopoulos et al. (2009) used this paradigm and asked subject to align their whole-body toward targets positioned on a circular array ( $45^\circ$ ,  $90^\circ$ ,  $135^\circ$  and  $180^\circ$  either right or left). These authors described a typical sequence of eye-to-foot movement onset, independently of target location predictability or amplitude. Surprisingly, however, relatively long eye latencies were reported in these whole-body gaze reorientation studies (400 ms for  $45^\circ$  target eccentricity).

The question therefore arises as to whether postural set (e.g. standing vs. seating) modulates eye and body movement initiation during gaze reorientations. Accordingly, we investigate eye and head movement latencies during gaze shifts both when sitting and when upright, with and without foot movements. We hypothesize that the addition of body segments involved in gaze reorientation can yield delays in movement onsets in order to assemble an efficient motor synergy.

## 2. Materials and methods

### 2.1. Participants

Fourteen healthy subjects (6 males and 8 females;  $25.7 \pm 4.0$  years, mean  $\pm 1$  SD) participated in this experiment.

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They had normal vision and no neurological or musculoskeletal disorders. The study was approved by the Imperial College River-side Ethics Committee.

## 2.2. Apparatus and methods

Participants sat or stood in darkness at the center of a circular array (radius 1.2 m) of 5 LEDs located at 45° intervals at eye level. At each trial onset, subjects were required to fixate the central LED (0° target) and align the head (and also the trunk and feet when they were standing) toward this initial location. After a delay of 5 s, the central target was extinguished thus indicating that another LED, either left (−90°, −45°) or right (+45°, +90°) in the horizontal plane, had been lit. Subjects had to look at this second LED ('outbound' trials) by turning the eyes and other body segment(s), depending on postural condition (see below). After another interval of 5 s, this second LED was turned off while the central LED was turned on thus cueing subjects to return back to the initial position ('return' trials). Note that 90° targets when executing outbound trials were inferred as they are initially non-visible – e.g. subjects turn in the wrong direction in approximately 50% of trials (Anastasopoulos et al., 2009).

Three postural conditions were tested: (a) Seated subjects, placed in a high-chair without arm-rest in the center of the circular array, were required to reorient towards the eccentric or central target and fixate it ('sitting' condition; Fig. 1a). During these trials, trunk movement was partly restricted by the backrest and gaze shifts were achieved mainly by means of eye and head displacement. (b) Standing subjects with arms hanging along side (alongside) the body were required to rotate toward the target and fixate it without moving their feet ('standing' condition; Fig. 1b). (c) Standing subjects were instructed to turn and align the eyes, head, trunk and feet with the target ('whole-body rotation' condition; Anastasopoulos et al., 2009; Hollands, Zivara, & Bronstein, 2004; Fig. 1c).

In all conditions, subjects were instructed to rotate towards the intended location as soon as targets on–offset. Subjects were instructed to perform the rotations consistently in all postural conditions. For each condition, subjects executed 4 blocs of 10 outbound and return trials each. Conditions changed after a bloc was completed in a random order. As a whole, an equal number of eccentric targets (−90°, −45°, +45°, +90°) was presented such that each one appeared 10 times for each postural condition. On the account of possible practice effects a 'training' bloc was executed before each new postural condition (Zeevi & Peli, 1979).

The head, upper trunk and feet horizontal rotations (yaw plane) were recorded with a Polhemus Fastrak motion analysis system (Polhemus, Colchester, VT; 30 Hz; latency 4 ms, accuracy 0.15° RMS). Markers were placed on a tightly adjusted helmet, on the C7 spinous process and dorsally on each foot. Horizontal eye-in-head rotations were recorded using bi-temporal DC electro-oculography (EOG; flat response 90 Hz) with skin surface electrodes placed at the outer canthi of each eye. The on–off LED signals, EOG and body position markers were sampled at 240 Hz and stored for off-line analysis. EOG was calibrated at the beginning and end of the experiment by asking subjects to fixate visual targets at 0° and ±45° while the head was held stationary.

## 2.3. Data processing

Head, upper trunk and feet data were low-pass filtered by a second order Butterworth filter (cut-off 10 Hz). Movement latencies of all segments were calculated from the time derivative when the signal characterizing segment velocity reached 15 deg s<sup>−1</sup> (Fuller, 1996; Moschner & Zangemeister, 1993) and visually adjusted using unfiltered position data according to Teasdale et al. (1993). Ninety degree outbound trials (initially non-visible) were excluded from

the analyses when subjects wrongly predicted and turned in the incorrect direction. These data exclusions did not affect the data set distribution, remaining normally distributed and comparable across conditions.

Analysis of variance (ANOVAs) with repeated-measures and post hoc tests (Tukey's HSD) were conducted on the mean latencies. Postural condition (sitting, standing and whole-body rotation), target predictability (outbound and return) and amplitude (45° and 90°) were the within-subject repeated factors. We chose 45° and 90° amplitude in order to facilitate latency comparisons with our previous studies where long saccadic latencies were observed (Anastasopoulos et al., 2009; Hollands, Zivara, & Bronstein, 2004) and to investigate the effect of initial target amplitude/visibility and predictability. Initial ANOVAs conducted separately on 45° and 90° targets indicated that partial head turns to 90° due to biomechanical constraints did not interfere with the variables of interest (eye and head latencies). Significance was set at  $p < .05$  for all analyses. Between-subject variability is given as ±1 SD. The sampling rates used dictated that latency differences were only included in the statistical analysis if they were >33 ms for all body segments and >4 ms for the eye.

## 3. Results

Overall, the eyes began to move first, followed by the head and the trunk. During whole-body rotations, however, the head often started to move in the direction of the central target earlier than the eye. Compared to sitting and standing conditions, eye latency was longer during whole-body rotations. In the latter case, foot rotation started long after the movement onset of all other segments (Fig. 1c). Also, both eye and head latencies were generally shorter during return as compared to outbound trials. Since feet and trunk were not involved in all conditions, only eye and head latency variations can be compared.

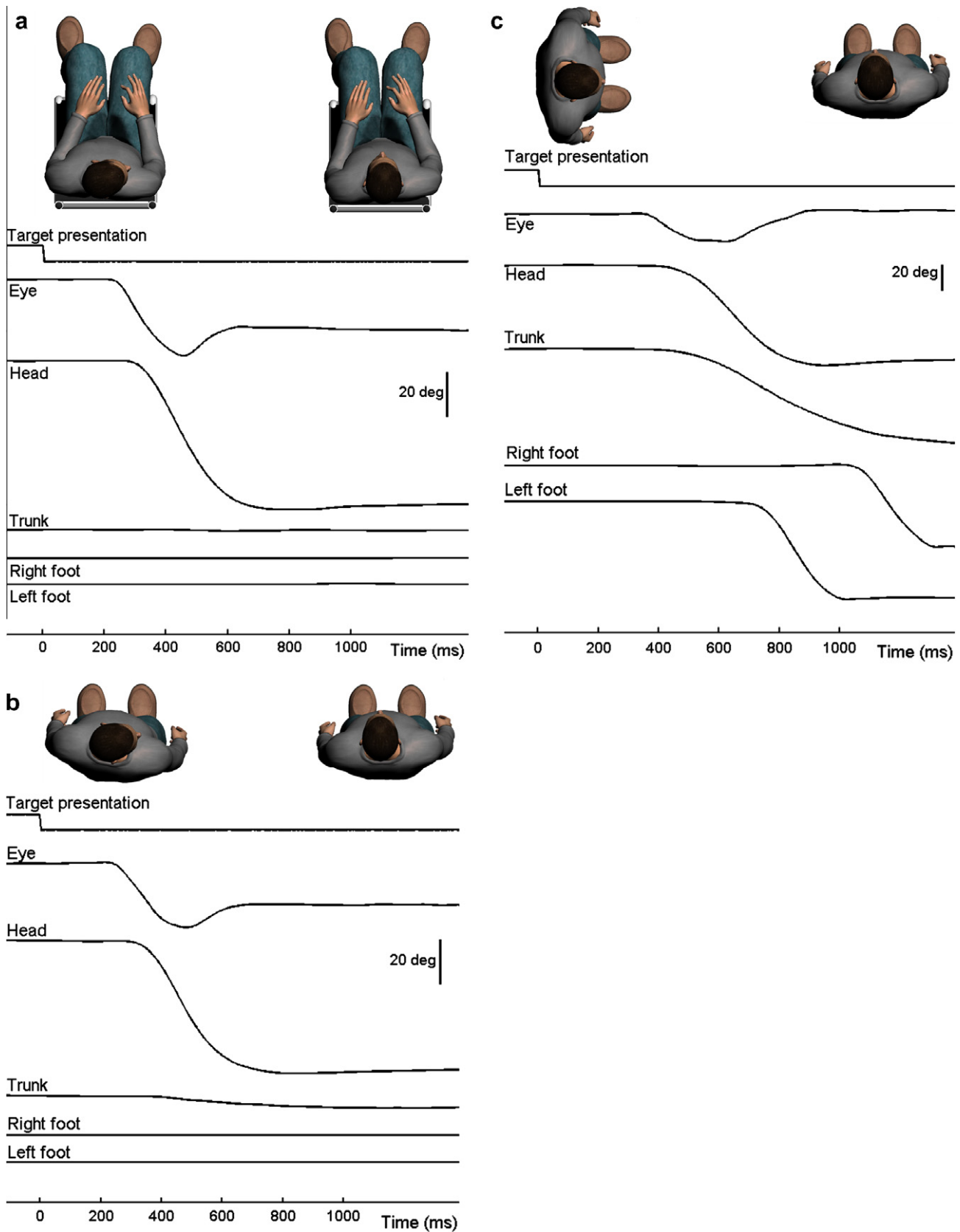
### 3.1. Eye latency

The effects of postural constraints, target location predictability and eccentricity on eye latency were statistically evaluated by a  $3 \times 2 \times 2$  repeated measures ANOVA with postural condition, target predictability and amplitude as main factors (Fig. 2). Eye latency was significantly longer in outbound as compared to return trials ( $318 \pm 88$  ms and  $262 \pm 71$  ms respectively,  $F_{(1,13)} = 86.8$ ;  $p < .001$ ). In addition, a significant effect of postural condition was found ( $F_{(2,26)} = 13.0$ ;  $p < .001$ ) with a longer eye latency for whole-body rotation as compared to sitting and standing conditions ( $305 \pm 84$  ms vs.  $282 \pm 80$  ms,  $p < .001$  and  $283 \pm 82$  ms,  $p < .001$ ; respectively). The interaction between postural condition and target predictability was significant ( $F_{(2,26)} = 13.4$ ;  $p < .001$ ), with eye latency longer when returning to the central target but only during the whole-body rotation condition (Fig 2). Eye latencies were not different across postural conditions in outbound trials.

Eye latencies towards initially non-visible 90° targets were longer as compared to targets of 45° eccentricity ( $317 \pm 91$  ms vs.  $262 \pm 67$  ms,  $F_{(1,13)} = 51.1$ ;  $p < .001$ ). Furthermore, the interaction target amplitude  $\times$  predictability was statistically significant ( $F_{(2,26)} = 22.4$ ;  $p < .001$ ); eye latency was even longer when the target was not predictable and initially non-visible ( $353 \pm 94$  ms;  $p < .001$  for comparisons between outbound 90° and all other targets).

### 3.2. Head latency

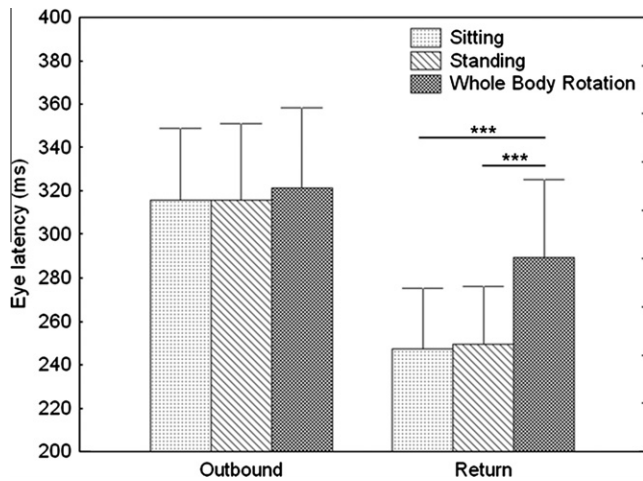
Head latency was usually longer than eye latency ( $348 \pm 106$  ms). A similar statistical analysis was performed on head



**Fig. 1.** Representative leftward gaze shifts towards the central target starting from a 90° eccentric target position (return trials) during sitting (a), standing (b) and whole-body rotation (c) conditions (target presentation at 0 ms). On top of each panel, body segments position is illustrated before (left) and after (right) the rotation.

latency according to postural condition, target predictability and amplitude as within-subject factors. Head latency was longer during outbound trials ( $403 \pm 124$  ms vs.  $306 \pm 65$  ms for return trials,

$F_{(1,13)} = 32.9$ ;  $p < .001$ ). It was also longer to initially non-visible targets of 90° eccentricity ( $391 \pm 129$  ms vs.  $320 \pm 68$  ms for 45° targets,  $F_{(1,13)} = 70.5$ ;  $p < .001$ ). The effect of postural condition



**Fig. 2.** Eye latency as a function of postural condition and target predictability. Latencies are increased by approximately 15% when returning to the central target during whole-body rotation as compared to the sitting and standing conditions. Errors bars denote 95% confidence intervals. \*\*\* $p < .001$ .

was non-significant ( $F_{(2,26)} = 1.6$ ;  $p = .23$ ) but the interaction postural condition  $\times$  target predictability which was just significant ( $F_{(2,26)} = 4.3$ ;  $p = .03$ ). However, this latter effect is questionable because the difference observed between latencies in these conditions (whole-body rotation: 318 ms vs. sitting: 296 ms) was below the time resolution afforded by the sampling frequency of our head-body recording device (i.e., 30 Hz, see Section 2) and will not be discussed further.

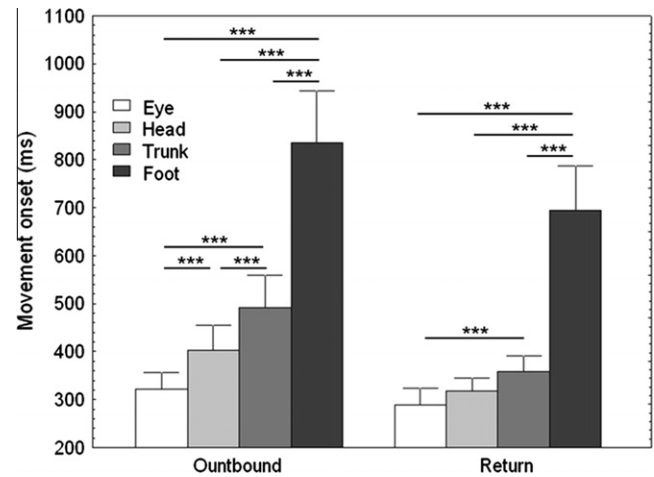
### 3.3. Relation between segments onset latencies

Intersegmental coordination patterns of movement onset during whole-body rotations were analyzed by  $4 \times 2 \times 2$  repeated-measures ANOVA with body segment, target predictability and amplitude as main factors. All these factors were significant ( $F_{(3,39)} = 227.7$ ;  $p < .001$ ;  $F_{(1,13)} = 49.0$ ;  $p < .001$ ; and  $F_{(1,13)} = 84.8$ ;  $p < .001$ , respectively). A typical sequence of movement onset was thus observed from the eyes to the feet (comparisons between all segments were significant at  $p < .001$  except head vs. eye and head vs. trunk). Furthermore, the interaction between body segment  $\times$  target predictability was significant ( $F_{(3,39)} = 15.31$ ;  $p < .001$ ). This result indicated that body segment latencies overlapped more during return trials (Fig. 3), as previously reported (Anastasopoulos et al., 2009). Besides, the interaction between segment  $\times$  target amplitude was also significant ( $F_{(3,39)} = 5.0$ ;  $p < .01$ ), thus suggesting a longer latency when the target was not predictable and initially non-visible ( $647 \pm 63$  ms;  $p < .001$  for comparisons between outbound  $90^\circ$  and all other targets).

## 4. Discussion

The present experiment investigated eye and head latencies when subjects performed voluntary rotations to targets during different postural constraints (sitting, standing and whole-body rotation). The main result was a significant influence of postural set on eye latency, but only when the subjects knew the location of the target (i.e., return or predictable trials). When subjects had to re-orient to this central target with a whole-body rotation, the eye movement was delayed with respect to other participating body segments (Fig. 2).

Target predictability is known to modulate eye-head coordination during whole-body rotation (Anastasopoulos et al., 2009) as



**Fig. 3.** Movement onset of the eye, head, trunk and foot (average of both feet) for the whole-body rotation condition as a function of target predictability. Post hoc tests did not reveal any significant difference between head latency and eye or trunk latency for return trials, indicating that body segment latencies were more overlapped ('en bloc') as previously reported (Anastasopoulos et al., 2009).

well as in seated posture (Moschner & Zangemeister, 1993). When subjects know the future target location, gaze movement onset is earlier than toward targets of unknown locations. In the present experiment, we also found reduced eye latencies in trials toward predictable targets (return trials) whatever the postural constraints. Interestingly however, this reduction was less pronounced when the subjects had to move the feet toward the target (whole-body rotation vs. sitting and standing). The likely explanation is that when subjects can plan their rotation in advance (return trials), an additional oculomotor delay is introduced in order to optimize the coordination between eye and body segments and the anticipatory postural adjustments (APA) required before the onset of the voluntary rotation (Aruin & Latash, 1995; Massion, 1984). According to this interpretation, assembling the motor synergy and the APA would take longer during whole-body rotations because the number of involved segments is higher compared to rotations without feet movement. In agreement, the effects of postural constraints were only observed for predictable targets, when anticipatory mechanisms could be specifically defined and set relative to the task complexity. The greater eye movement delay observed during return whole-body rotation trials could be due to the processing required to reduce the degrees of freedom in the task, so that a more efficient rotation can be executed. According to Bernstein (1967), a goal could be reached by an infinite combination of joints and muscle coordination. Synergies (i.e., coordinated actions of muscles and joints toward a common goal) are thus assembled to reduce the controlled degrees of freedom. This hypothesis has been recently confirmed using a similar paradigm by Sklavos, Anastasopoulos, and Bronstein (2010), who showed that motor synergies are optimized during whole-body rotations, thus allowing simplification of the movement control with a higher level of efficiency.

As expected, eye latency was shorter than head latency, hence supporting the top-down rotational sequence observed in several studies (Anastasopoulos et al., 2009; Grasso et al., 1996; Hollands, Patla, & Vickers, 2002; Hollands, Zivara, & Bronstein, 2004). Moreover, our data showed that whereas postural condition influenced eye latency (whatever the target predictability or amplitude), it did not affect head latency. One could argue that the delay between eye and head during whole-body rotation might be shorter than when sitting or standing. As a consequence, this may yield a more 'en bloc' organization, optimal to rapidly align the body toward the target (Anastasopoulos et al., 2009). However, sampling frequency



limitations in the current study impose caution on this conclusion as subtle head latency differences may have been missed.

Even if we also observed a clear sequence of body segment rotation when the subject had to align his entire body to the target, movements onset of the different segments were previously described as longer than in the present study despite the same postural constraints (Anastasopoulos et al., 2009; Hollands, Zivara, & Bronstein, 2004; for 45° outbound target, eye latency: 450 ms, head latency: 550 ms, trunk latency: 650 ms, feet latency: 1200 ms). This difference might result from the distinct instructions given to subjects. Indeed, in the former studies, subjects were required to fixate the visual target with less strict instructions as the authors wanted to investigate the natural pattern and velocities of the whole body turning synergy. This was supported by data from Zangemeister and Stark (1982a) who showed that eye latency was shorter when the seated subjects were instructed to turn head and eyes toward a target as fast as possible compared to rotation at natural velocity.

## 5. Conclusion

Overall, our study showed that postural constraints affect the temporal organization of eye–head coordination. These effects occur when the future location of the target is known (i.e. under spatially predictable conditions). When the orientation toward a target involves feet movements during whole-body rotations, eye movement onset is delayed. This finding suggests different motor pre-programming depending on the level of postural constraints. We speculate that the observed delay in motion onset reflects the higher processing demands needed for organizing a complex motor synergy and its associated anticipatory postural adjustments.

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