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In the upright stance, posture is better controlled to perform precise visual tasks than laser pointing tasks

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Running title: Adjusted postural control in visual tasks

Abstract

Purpose. In the upright stance, young adults better stabilize their posture when they perform precise visual or pointing movements than when they stand quietly. We tested if postural stability could be improved further if precise and pointing tasks were combined. **Method**. Twenty-four healthy young adults (22±12 years) performed six tasks combining three visual tasks (precise search, unprecise free-viewing and fixation tasks) and two pointing tasks (pointing-on and pointing-off tasks with laser beam on and off, respectively). In the visual tasks, participants either searched to locate targets within an image (precise task), looked at the image with no goal (unprecise task) or fixated on a cross (fixation task). In the pointing-on tasks, participants pointed a laser beam onto a small circle (2°) located in the middle of a larger circle (21°) containing the image. **Result**. As expected, postural sway was reduced in the precise task in contrast to the fixation tasks. Contrary to expectations, both precise and pointing-on tasks did not add their stabilizing effects. Furthermore, the pointing-on task almost did not influence body movements. The participants rotated their eye and head more and their upper back less in the precise visual tasks than in the unprecise visual tasks. **Conclusion**. The participants used a stabilizing coordination to fully explore images with eye and head rotations while stabilizing their body to perform precise gaze shifts. Our findings suggest that posture stabilization is performed to facilitate success in precise visual tasks more so than to perform pointing-on tasks.

Keywords: Postural control; Reduced sway; Gaze shifts; Pointing; Young adults

Abbreviations: AP: Anteroposterior; COP: center of pressure; ML: mediolateral; SD: standard deviation; V: mean velocity

Introduction

In the upright stance, individuals continuously sway and the characteristics of their sway depend on the task constraints and goals (Horak 2006; Ivanenko and Gurfinkel 2018). Visual constraints influence postural sway both during passive conditions, such as when eyes are closed vs. open (Edwards 1946; Fujimoto and Ashida 2019) and during active visual tasks (Lee and Lishman 1975; Fujimoto and Ashida 2019). In active tasks, postural sway is reduced both during precise visual tasks (Stoffregen et al. 2007; Rougier and Garin 2007; Rodrigues et al. 2013) and during visuomotor tasks such as when participants point a laser beam towards spatial targets (Balasubramaniam and Turvey 2000; Balasubramaniam et al. 2000; Taube et al. 2008). Previously, it has been shown that postural sway is reduced in both anteroposterior (AP) and mediolateral (ML) directions in all published precise visual tasks (Bonnet and Baudry 2016). The results are more contrasted in studies with pointing the laser beam towards spatial targets, hereafter called pointing-on task (laser light on). Indeed, postural sway is decreased in the most specific direction to perform pointing-on tasks (Balasubramaniam and Turvey 2000; Balasubramaniam et al. 2000; Chen and Stoffregen 2012). However, postural sway was also found to increase in the direction non-specific to perform pointing-on tasks in these three studies (Balasubramaniam and Turvey 2000; Balasubramaniam et al. 2000; Chen and Stoffregen 2012) and also in the pointing-on task in Dos Anjos et al. (2016). Overall, except in Dos Anjos et al. (2016)[1], all these published results show that people need to stabilize their posture to succeed in precise visual tasks more than they need to stabilize their posture to succeed in pointing-on tasks. In fact, it is easier for individuals to precise gaze shifts and/or point a laser beam within a target if the standing posture is stable, (cf. Stoffregen et al. 1999; Mitra 2003; Bonnet and Baudry 2016). In the literature on postural control, the decrease and increase of postural sway are considered as showing better postural stability (Mitra 2003; Haddad et al. 2013) and postural instability (Bonnet et al. 2009; Johansson et al. 2017), respectively. However, the literature on that is still inconclusive (Hortobágyi et al. 2020).

To the best of our knowledge, no researchers have tested the combined effect of precise visual and pointing-on tasks together on postural control. We predicted that postural sway could be reduced even further, i.e. postural control improved even more, when precise visual and pointing-on tasks are performed simultaneously, especially if both tasks are challenging. Indeed, it is recognized that postural sway is reduced in challenging precise and/or pointing-on tasks than in easier precise and/or pointing-on tasks (Balasubramaniam et al. 2000; Chen and Stoffregen 2012; Bonnet and Baudry 2016).

Our objective was to study how precise visual and pointing-on tasks interact and affect postural sway and gaze shifts. Twenty-four healthy young adults performed six tasks combining three visual tasks (precise, unprecise and fixation tasks) and two pointing tasks (-pointing-on and pointing-off tasks). We hypothesized that the precise visual and the pointing-on tasks would significantly reduce postural sway (Balasubramaniam et al. 2000; Bonnet and Baudry 2016) (Hypothesis 1). Combining these two previous tasks was expected to further reduce postural sway compared to both tasks performed separately (Hypothesis 2). We also expected to find stronger effects of gaze than pointing on postural control and gaze shifts (Hypothesis 3). In other words, we expected to find more significant effects with precise visual tasks than pointing-on tasks.

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[1] For information, Dos Anjos et al. (2016) complementary showed participants significantly reduced their COP sway when they performed a condition with internal feedback. In this condition with no laser beam, participants looked at their COP sway displayed in front of them and tried to keep them within a target during trials.

Methods

Participants

24 healthy young adults (12 males, 12 females) from the University of Lille participated in this study. Their mean age, bodyweight and height were 21.8 ± 1.8 years, 68.8 ± 11.9 kg and 170.8 ± 8.6 m, respectively. All the participants had a good or adequately corrected visual acuity. They all informed the investigators that they could see experimental images clearly. The study was performed in accordance with the tenets of the Declaration of Helsinki and was approved by our local ethical committee. The participants gave their written, informed consent to participation.

Apparatus

A dual-top force platform (AMTI, Watertown, MA, USA; Figure 1A) was used to record center of pressure (COP) displacement with a sampling frequency of 200 Hz. Two papers marked the position of the feet on the two platforms to standardize the feet width (14 cm) and angle (17°) in a normative way (McIlroy and Maki 1997). A Polhemus system (Polhemus Liberty 240/8-8 System, Colchester, VT; 240 Hz) was used to record head, upper back and lower back displacements with a sampling frequency of 240 Hz (Figure 1A). The markers were attached to a helmet (worn by the participants during the study), to the upper back (at the seventh cervical vertebrae) and at the lower back on a belt (given and worn by the participants during the study; Figure 1A). An eye tracker (SensoMotoric Instruments, Teltow, Germany; 50 Hz) was used to record gaze shifts (Figure 1A).

In each trial, the participants looked at a new image from a puzzle for children called “where is Waldo” in the USA (Collection Waldo by Martin Handford; Figure 1B). The images were projected into a large circle at the participant’s eye height (Figure 1A). The images in the precise visual task contained four Waldos (the same Waldo copied and pasted at four locations within the image) and the images in the unprecise visual task did not contain any Waldo. Tis puzzle for children was already used in our previous studies (Bonnet et al. 2017, 2019).

Insert Figure 1A and B about here

The force platform was located 3.32 m from the facing wall (Figure 1A), the large circle containing the image was 1.23 m large (visual angle: 21°) on that wall. This large circle contained a central small black circle of 2° useful for the pointing-on task (see below). A MATLAB script (MathWorks Inc., Natick, MA, USA) synchronized all devices (platform, Polhemus, eye tracker) with images projected onto the wall. In each task, the participants held a laser pointer (Legmaster LX 4) in their preferred hand and a computer mouse in the non-preferred hand. The participants had to keep the laser pointed in their preferred hand to perform the subtle visuo-motor pointing-on task and only had to click on the mouse – already in their hand – with the other non-preferred hand.

Tasks

Each participant performed eighteen trials each one lasting 33 sec. There were six tasks and three trials per tasks. The six tasks were the fixation, unprecise and precise visual tasks performed along with the pointing-on or pointing-off tasks. The six tasks were also called fixation-pointing-on, unprecise-pointing-on, precise-pointing-on, fixation-pointing-off, unprecise-pointing-off, precise-pointing-off for abbreviation . We used three trials per task to increase the study's statistical power.

In the precise visual task, the participants were instructed to search and find the location of as many Waldo personages as possible within the image. The participants had to click on the mouse each time they located and fixated a Waldo personage. At the end of the trial, we asked the participants how confident they were to have found Waldo when they had clicked on the mouse. They had to report a confidence score concerning their task performance (from 1 (low), to 5 (high)). In the unprecise visual task, the participants had to freely explore the image as they liked without searching for anything in particular. In the fixation task, the participants had to fixate a stationary black cross, located at the center of a small black circle of 2°, for the duration of the trial. In the fixation task, the images – that the participant could not explore – were the same images as in the unprecise visual task. The fixation task served as a basis to further understand the main effects of precise visual and pointing-on tasks. In fact, we needed a basic fixation task with no movement to get useful baseline data to verify if participants better stabilized their posture in the precise visual task (with results in the unprecise visual and fixation tasks being equal) or if they destabilized their posture in the unprecise visual task (with results in precise visual and fixation tasks being equal).

When the laser beam was on, i.e. in the pointing-on task, the participants had to point and keep the laser beam as best as possible within the central small black circle of 2° for the duration of the trial. When the laser beam was off, i.e. in the pointing-off task, the participants only had to keep their arm and laser pointer in approximately the same position as when the laser beam was on with no other requirement. In our definition, the pointing-off task was not considered as an act of pointing but instead as a control task.

Our methodology is novel and different from previous approaches. In the precise-pointing-on and unprecise-pointing-on tasks, the participants could not fixate on the laser beam at all time as in published manuscripts (Balasubramaniam and Turvey 2000; Balasubramaniam et al. 2000; Fukushima et al. 2008; Taube et al. 2008; Chen and Stoffregen 2012; Dos Anjos et al. 2016). Instead, they needed to look at it only briefly to fully explore images during the trials.

In each trial, the participants were told to relax. The upper part of the arm holding the laser was held by the side of the body with the elbow flexed 90° and with the forearm perpendicular to the body (Figure 1A), as in other studies (Balasubramaniam and Turvey 2000; Balasubramaniam et al. 2000; Chen and Stoffregen 2012). The participants were asked to rotate their wrist and/or upper arm to move the laser beam. At the beginning of each trial, the participants had to fixate a stationary black cross (2° large) for three seconds. The black cross did not disappear in the fixation tasks but it disappeared after 3 sec in the precise and unprecise visual tasks.

At the methodological level, the fact that the precise visual and pointing-on tasks were challenging was a strength in our project. Indeed, postural sway is more reduced in a challenging than in a non-challenging precise and/or pointing-on task (Balasubramaniam et al. 2000; Chen and Stoffregen 2012; Bonnet and Baudry 2016). Postural sway is still reduced, and even strongly, when participants merely strongly search for hdden targets, even if they do not locate them (Bonnet et al. 2017, 2019).

Procedure

Once they arrived in the experimental room, the participants signed the informed consent forms. They were then given instructions for the various tasks. To explain the task, we showed them an image of Waldo. Then, we invited them to take their shoes off and we installed the Polhemus markers on the head, the upper back, and lower back levels (Figure 1A). They stood upright on the platform and the light was turned off so that the participants could clearly see the images. The order of the tasks was randomized across participants as well as the images in each trial. Overall, all images were visualized an equal number of time in each task in using the same procedure as in Bonnet et al. (2019). To aid relaxation, participants were instructed to sit down and rest after nine trials (midway through the study).

Dependent variables

We analyzed the standard deviation (SD) and mean velocity (V) of COP and body (lower back, upper back and head) linear movement in the AP and ML directions. These variables are classically used in the literature on postural control (Palmieri et al. 2002; Paillard and Noé 2015), both in visual (Bonnet et al. 2019) and visuo-motor tasks (Dos Anjos et al. 2016). The angular body movement in the pitch (up-down) and yaw (left-right) directions as well as gaze shifts in the up-down and left-right directions were also analyzed. These analyses in angular movement served to know if participants also stabilized their body in rotating less their head and/or body parts. Less body rotations could then provide explanation to know why the participants exhibited less (linear) COP and/or body movements. For simplicity of writing, the general term COP/body movements is used to refer to COP and/or body movements. We reported these various and subtle movements because the participants performed subtle visual and visuo-motor tasks that could affect their head and/or lower body parts differently.

The performance in the pointing-on task was analyzed using the video from the eye-tracker. For each trial with the laser beam on, the number of times the laser beam i) touched and ii) escaped out of the black circle were analyzed. The performance at the precise visual task was analyzed by counting the number of times Waldo was accurately and inaccurately (errors in finding Waldo) found. We also averaged their confidence score.

Preparation of data

The first 3 sec of each trial were not considered for analyses. Data of the force platform and of the Polhemus systems were resampled at 50 Hz. Data of the eye tracker were not fully available because of blinks and pupil dilation. As the beam was turned off, pupil dilation sometimes could be too large, thus causing the eye tracker to lose the pupil position. For analyses, we only used trials in which less than 20% of the eye-tracking data were missing. For analyses, the mean of the three trials per task for each variable was used.

Statistical analyses

Wilk-Shapiro tests verified the normality of the data and Mauchly tests verified the homogeneity of variance for within factors. When the normality and homogeneity of variance were satisfied, two-way analyses of variance (ANOVAs) and post-hoc Newman-Keuls were performed on the various dependent variables to test Hypotheses 1, 2 and 3. We tested Hypothesis 1 (reduction of COP/body movements in precise visual and pointing-on tasks) in analyzing main effects of precise visual and pointing-on tasks. We tested Hypothesis 2 (addition of precise visual and pointing-on effects) in analyzing gaze by pointing interaction effects and also contrasts between i) the precise-pointing-on task vs. precise-pointing-off task and between ii) the precise-pointing-on task and unprecise-pointing-on task. To test Hypothesis 3 (stronger effect of precise visual than pointing-on on postural control), we looked at the number and size of significant main effects of precise visual and pointing-on tasks in the ANOVAs and we contrasted the results between i) the precise-pointing-off task vs. unprecise-pointing-off task (testing the effects of the precise visual task) and between ii) the fixation-pointing-on task vs.

the fixation-pointing-off (testing the effects of pointing-on). The *p*-value was set at $p<0.01$ for multiple comparisons.

Results

Selection and choices before analyses

432 trials were performed. Overall, 88.9 % of the trials (384/432) contained more than 80 % of gaze shifts data (i.e. less than 20% missing eye-tracking data due to blinks and pupil dilation). In the 384 trials that were accepted, on average ~2.6% of the data were missing.

ANOVAs

The results of the ANOVAs and post-hoc Newman-Keuls are shown in Tables 2 and 3. In terms of linear movement and in reference to Hypothesis 1, 2 and 3, participants swayed significantly less and slower in the precise visual tasks than in both unprecise and fixation tasks (Table 1). The ANOVAs did not show any significant effect in the pointing-on task (no main effect, no interaction effect). However, the ANOVAs showed significant main effect of pointing-on for upper back V_{yaw} ($F(1,22)=10.29, p<0.01$, Figure 2).

In terms of angular movement, the magnitude of head rotation was larger during the precise visual task than the fixation task (Table 1). In contrast, upper back rotation was significantly slower in the precise visual task than the fixation task (Table 1).

In terms of gaze shifts and in reference to Hypothesis 3, Table 2 shows that the participants made larger gaze shifts in up/down and left/right directions in precise than unprecise visual tasks. The amplitude of gaze shifts was also larger when the participants pointed the laser beam onto the target than when the laser beam was off (Table 2).

Insert Tables 1 and 2 and Figure 2 about here

Complementary analyses

All the ANOVAs between the two fixation tasks were not significant. In contrasts, post-hoc Newman-Keuls contrasts between the precise-pointing-off and unprecise-pointing-off tasks showed that the participants exhibited significantly slower head V_{ML}, upper back V_{ML}, lower back V_{ML} and upper back V_{yaw} but larger head SD_{yaw} ($p<0.01$) in the precise-pointing-off task.

Performance at the Waldo and pointing-on tasks

The number of times Waldo was accurately found was not significantly different in the precise-pointing-on task (1.25±1.14) and in the precise-pointing-off task (0.76±0.82). Also, the number of wrong clicks on the mouse was not significantly different between the precise-pointing-on task (0.08±0.15) and the precise-pointing-off task (0.21±0.22).

The laser beam left the black circle 0.3±0.6, 0.1±0.3 and 0.8±1.0 times on average in the fixation, unprecise and precise visual tasks, respectively.

Discussion

Our objective was to test the gaze by pointing interaction effects on postural control and visual exploration in healthy young adults. The results supported our hypothesis that a precise visual task would have stronger effects on these variables than a pointing-on task. In fact, the pointing-on task had minimal effect on all our dependent variables. Overall, it seems that participants could reduce their postural sway in performing a precise visual task with relative ease, but were not able to reduce postural sway further when two stabilizing tasks were performed together.

Stronger effects of precise visual task than pointing-on task on posture and vision

The results supported our hypothesis (Hypothesis 1) that the amplitude and velocity of COP/body linear movements would be significantly lower in the precise visual task than in the unprecise and fixation tasks (Table 1). This result is consistent with previous reports (Prado et al. 2007; Stoffregen et al. 2007; Rougier and Garin 2007; Bonnet and Baudry 2016) and showed that individuals stabilize their posture to facilitate precise gaze shifts on specific targets (Stoffregen et al. 1999; Mitra 2003; Bonnet and Baudry 2016). The novel aspect of our study is that this main effect was still present even when the participants performed an additional task (the pointing-on task) (Figure 1A). The participants may have exhibited significantly lower and slower COP/body linear movements because they exhibited significantly lower and slower angular movements in the precise visual task than in the unprecise and fixation tasks (Table 1). Therefore, overall, the participants reduced their body angular and linear movements to perform the precise visual tasks.

The precise visual task had very strong effects on postural control. Young adults swayed significantly less in the precise visual tasks than in both unprecise and basic fixation tasks although they turned their head significantly more in the precise visual tasks than in both other tasks (Table 1). Previous reports have shown significantly less sway in precise visual tasks than in fixation tasks when participants do not move their body (Stoffregen et al. 2006, 2007; Prado et al. 2007; Bonnet et al. 2017). It should be noted that young adults turned their upper back significantly less in precise visual than in the unprecise and fixation tasks (Table 1). Hence, in precise visual tasks, it seems likely that the participants stabilized their upper back in both angular and linear ways to facilitate larger head rotations (Table 1) and larger eyes movements (Table 3) to reach precise locations. Thus, the participants used an efficient stabilizing coordination, i.e. they stabilized their posture to be able to rotate their head further to succeed in precise visual tasks.

In contrast to other reports (Balasubramaniam and Turvey 2000; Balasubramaniam et al. 2000; Danna-Dos-Santos et al. 2015; Dos Anjos et al. 2016), we did not find any significant main effect of pointing-on in postural sway, i.e. in COP/body linear movements. A simple interpretation of these results is that the realization of two stabilizing tasks (precise visual and pointing-on tasks) impeached the stabilizing effect of the pointing-on task to exist. In the pointing-on task, we cannot suggest that the absence of significant reduction of COP/body (linear) sway was because of large gaze shifts to come back and forth to check the position of the laser beam. Indeed, the participants almost never looked at the pointing light in both precise and unprecise visual tasks.

Originally, we expected that precise visual tasks would have a stronger effect on COP/body and gaze shifts than the pointing-on task (Hypothesis 3). The results supported Hypothesis 3 because more significant effects were found in precise visual task than in the pointing-on task in COP/body linear and angular movements (11 vs. 1 main effects; cf. Table 1 and Results section) and in gaze shifts (2 vs. 1 main effects in Table 2). The pointing-on task had little, if any, effect on COP/body movements as also showed by the absence of significant difference between the fixation-pointing-on task and the fixation-pointing-off task (cf. Complementary analyses).

Gaze by pointing interaction effects on postural control and visual exploration

At the level of COP/body linear and angular movements, the results did not show any significant gaze by pointing interaction effects. This result did not support our second hypothesis (Hypothesis 2) that both factors could add their influence at the postural level. On the one hand, we could conclude that postural sway only can be reduced until a certain level to succeed in precise visual task and pointing-on tasks. Stoffregen et al. (2007) already showed that and proposed the existence of a "plateau" below which postural sway cannot be reduced further. In their study, healthy young adults performed four visual tasks, i.e. a fixation task and precise visual tasks in which participants had to gaze target appearing left and right at 0.5, 0.8 and 1.1 Hz at 11° of visual angle. Their results showed that postural sway was significantly reduced in the three precise visual tasks (in comparison to the basic fixation task) but was not further reduced in the 0.8 and 1.1 Hz tasks in contrast to the 0.5 Hz task. Our results therefore are consistent with Stoffregen et al.'s (2007) hypothesis of a plateau because our precise visual task was very difficult (see Results for performance) and supposedly harder to perform than Stoffregen et al.'s (2007) task. On the other hand, the absence of significant gaze by pointing interaction effects could also be due to the fact that our participants mainly used their peripheral vision to verify the laser beam in the unprecise- and precise-pointing-on visual tasks performed. If true, our results would suggest that postural sway is reduced only when targets are fixated. This effect is expected at the theoretical level (Stoffregen et al. 1999, 2006) but, it was never verified with central vs. peripheral vision. In turn, the participants succeeded quite well in pointing the laser beam onto the small circle in using their peripheral vision. Therefore, peripheral vision was effective to well succeed in the pointing-on task but it seemed ineffective to reduce postural sway.

At the level of gaze shifts, the results also did not show any significant gaze by pointing interaction effects (cf. Table 2). Overall, pointing the laser beam onto the small black circle did not reduce visual exploration, probably because the images were small and could be explored fully without moving the gaze, thus the eyes, too far away from the central black circle.

Summary, limitations and perspectives

The present study improves our understanding of the adaptation of postural control to perform various visual tasks. It also enriches the experimental methodology in proposing a novel approach to combine both precise visual tasks and pointing-on tasks. This methodology could be seen as a limitation, as the participants almost never looked at the pointing location. However, it is also a strength as both tasks could be combined in this manner. In day-to-day life, it sometimes happens that both precise visual task and pointing-on tasks are combined, as in passing a basketball to a player without looking for him.

Our study showed that young adults stabilized linear and angular movements at the lower level of their body to facilitate larger gaze shifts on specific targets in the precise visual task. This stabilizing coordination was successful and robust because it existed even when the participants performed an additional pointing-on task. One limitation of our study was that the size of the pointing target was larger (2°) than in most previous laser pointing studies (< 1.3° in Balasubramaniam et al. (2000), < 0.78° in Balasubramaniam and Turvey (2000), 0.68° in Dos Anjos et al. (2016), < 0.42° in Morrison and Keogh (2001). However, we recall that the participants did not perform only the pointing-on task but also had to be able to look at the image in both precise visual tasks. Other investigators still showed significant effect of the pointing-on task on postural sway when the target size was larger than 2° (Chen and Stoffregen 2012) or when they had to move the laser beam (Taube et al. 2008). In the future, researchers should study gaze by pointing interaction effects on postural control with images projected in more ecological settings with larger visual angles. They should also test if postural sway can also be reduced in visual and visuo-motor tasks in older adults and/or in patients with

Parkinson’s Disease to succeed in these tasks. We could find that older adults increase their postural sway to compensate for by an impairment (e.g. a visual impairment; Bonnet et al. 2010). Older adults and patients with Parkinson’s Disease could also increase joint stiffness or muscle coactivation (Horak et al. 1992; Nagai et al. 2011) because of excessive constraints in both visual and visuo-motor tasks.

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Conflict of interest

There is no conflict of interest.

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Figure captions

Figure 1. A. Representation of the experimental setting. The participant stood on a force platform in front of a wall. On this wall, an image was projected into a circle. The three Polhemus markers were attached to a helmet, to the upper back (at the seventh cervical vertebrae) and at the lower back on a belt. An eye tracker was attached to the helmet to record the participant’s gaze shifts. B. Two figures shown to the participants during the study. The image was projected into a circle 21° large. In the precise visual, unprecise visual and fixation tasks, the participants also had to point a laser beam into the small black circle (2°) in the center of the large circle containing the image.

Figure 2. Significant main effect of pointing for the mean velocity of the upper back rotation in the yaw direction (Upper back V_{yaw}). The participants either pointed a laser beam into a central black circle (2°) for the duration of the trial (pointing-on task) or pointed the laser pointer turned off in the same direction (pointing-off task). Error bars represent the standard error of the mean. $p<0.01$.

Table 1. Significant main effects of gaze in the ANOVAs with two factors (gaze and pointing). Main effects concern center of pressure (COP) and/or body (head, upper back, lower back) movements. Non-significant ANOVAs are also shown for the COP/body linear dependent variables

COP/body linear dependent variables	Fixation tasks	Free-viewing tasks	Precise search tasks	Main effects of Gaze
Head SD_{ML} (cm)	0.98±0.21 (*)	0.92±0.16	0.87±0.11 (*)	$F(2,44)=7.20$, $p<0.01$
Head V_{ML} (cm.s^{-1})	2.14±0.17	2.16±0.16 (+)	2.12±0.17 (+)	$F(2,44)=9.45$, $p<0.01$
Upper back SD_{ML} (cm)	0.77±0.18 (*)	0.71±0.13	0.66±0.09 (*)	$F(2,44)=9.04$, $p<0.01$
Upper back V_{ML} (cm.s^{-1})	1.49±0.13	1.51±0.13 (+)	1.47±0.12 (+)	$F(2,44)=8.54$, $p<0.01$
Lower back SD_{ML} (cm)	0.60±0.16 (*)	0.54±0.11	0.50±0.07 (*)	$F(2,44)=8.31$, $p<0.01$
Lower back V_{ML} (cm.s^{-1})	1.16±0.14 (*)	1.16±0.13 (+)	1.13±0.13 (*,+)	$F(2,44)=7.39$, $p<0.01$
COP SD_{ML} (cm)	0.13±0.04 (*)	0.11±0.03	0.11±0.03 (*)	$F(2,44)=5.85$, $p<0.01$
Head SD_{AP} (cm)	0.26±0.07	0.26±0.07	0.27±0.09	*ns*
Head V_{AP} (cm.s^{-1})	0.64±0.12	0.64±0.12	0.62±0.12	*ns*
Upper back SD_{AP} (cm)	0.20±0.06	0.17±0.05	0.17±0.06	*ns*
Upper back V_{AP} (cm.s^{-1})	0.26±0.05	0.26±0.05	0.25±0.05	*ns*
Lower back SD_{AP} (cm)	0.15±0.06	0.13±0.04	0.13±0.04	*ns*
Lower back V_{AP} (cm.s^{-1})	0.20±0.07	0.21±0.08	0.19±0.06	*ns*
COP V_{ML} (cm)	3.22±0.56	3.25±0.55	3.20±0.57	*ns*
COP SD_{AP} (cm.s^{-1})	0.38±0.12	0.33±0.11	0.33±0.11	*ns*
COP V_{AP} (cm.s^{-1})	5.81±0.97	5.89±0.94	5.78±0.98	*ns*
Body angular dependent variables	Fixation tasks	Free-viewing tasks	Precise search tasks	Main effect of Gaze
Head SD_{pitch} (°)	0.28±0.09 (*,×)	0.38±0.16 (×)	0.46±0.18 (*)	$F(2,44)=15.99$, $p<0.01$
Upper back V_{pitch} (°.s^{-1})	0.79±0.20 (*)	0.77±0.19	0.73±0.19 (*)	$F(2,44)=6.42$, $p<0.01$
Head SD_{yaw} (°)	0.45±0.16 (*)	0.53±0.17	0.57±0.17 (*)	$F(2,44)=5.76$, $p<0.01$

Upper back V_{yaw} (°.s^{-1})	1.72±0.23 (*)	1.70±0.22	1.67±0.22 (*)	$F(2,44)=6.63$, $p<0.01$

Note. The upper part of Table 1 illustrates linear COP and/or body (head, upper back, lower back) movements and the lower part illustrates angular body movements. The dependent variables were the standard deviation (SD) and mean velocity (V) in the anteroposterior (AP), mediolateral (ML), pitch (up-down) and yaw (left-right) directions. The variables are expressed in centimeters (cm), degrees (°), centimeters per second (cm.s^{-1}), degrees per second (°.s^{-1}). * shows a significant difference between the precise visual search tasks and the fixation tasks (post-hoc Newman-Keuls test). + shows a significant difference between the precise visual search tasks and the non-precise free-viewing tasks (post-hoc Newman-Keuls test). × shows a significant difference between the fixation tasks and the non-precise free-viewing tasks (post-hoc Newman-Keuls test). The p-value was set to $p<0.01$.

Table 2. Significant and non-significant main effects of gaze for eye movements in the ANOVAs with two factors (see Table 1 for the name of the conditions).

Eye movement variables	Free-viewing tasks	Precise search tasks	Pointing-off	Pointing-on	Main effect of gaze	Main effect of pointing	Gaze by pointing interaction effect
$SD_{up\text{-}down}$ (°)	1.01±0.13	1.09±0.16	1.07±0.14	1.03±0.15	$F(1,22)=19.74$, $p<0.01$	*ns*	*ns*
$SD_{left\text{-}right}$ (°)	0.83±0.12	0.92±0.12	0.91±0.12	0.85±0.12	$F(1,22)=28.71$, $p<0.01$	$F(1,22)=18.48$, $p<0.01$	*ns*
$V_{up\text{-}down}$ (°)	0.16±0.04	0.15±0.02	0.15±0.02	0.16±0.03	*ns*	*ns*	*ns*
$V_{left\text{-}right}$ (°)	0.12±0.03	0.11±0.02	0.12±0.02	0.12±0.03	*ns*	*ns*	*ns*

Note. The dependent variables illustrate eye (angular) movements. The dependent variable was the SD in the left-right and up-down directions. The variables are expressed in degrees (°).

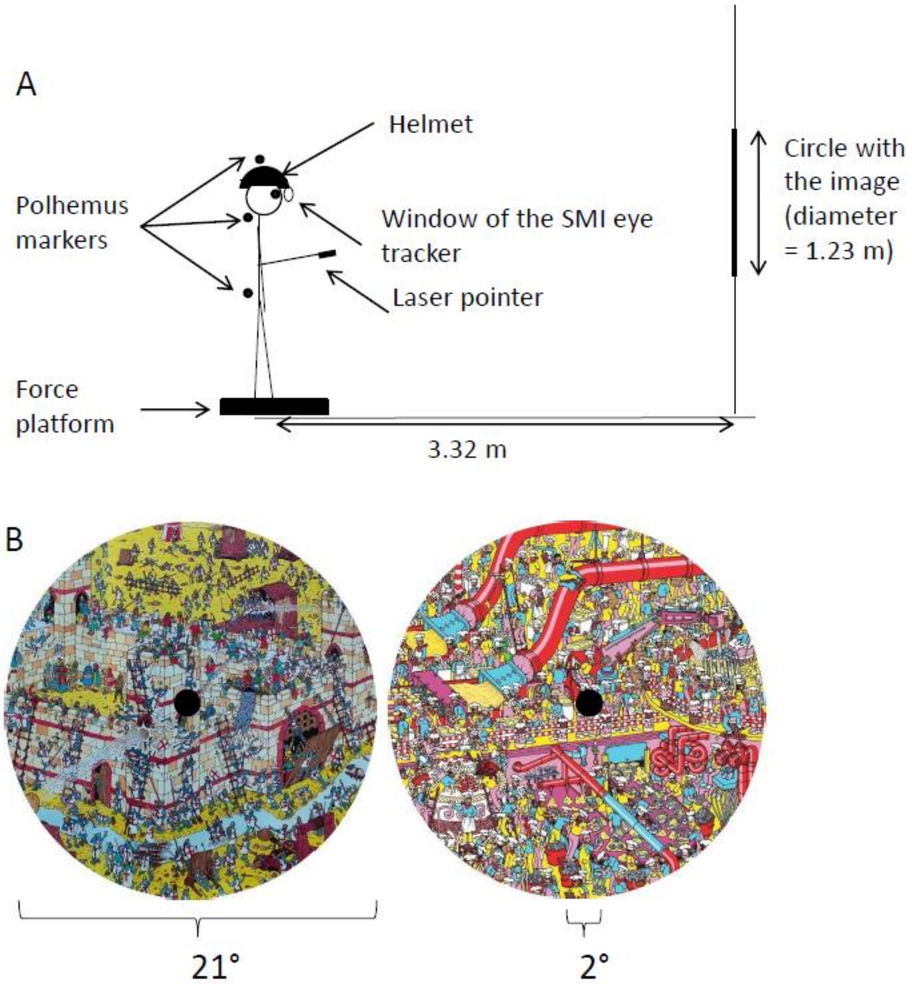
A
Helmet
Polhemus markers
Window of the SMI eye tracker
Laser pointer
Circle with the image (diameter = 1.23 m)
Force platform
3.32 m
B
21°
2°

Figure 1

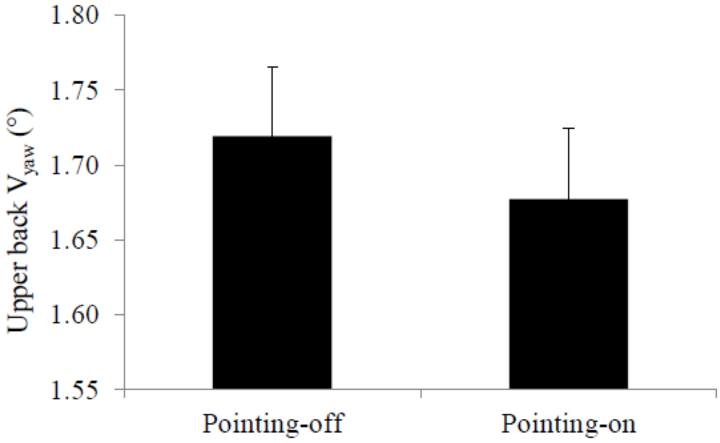
1.80
1.75
1.70
1.65
1.60
1.55
Upper back V_{yaw} (°)
Pointing-off
Pointing-on

Figure 2