Optimization of postural control in precise gaze shifts and laser pointing

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Running head: postural control in visual and visuo-motor tasks

Abstract

Young adults are known to reduce their postural sway to perform precise visual search and laser pointing tasks. We tested if young adults could reduce even more postural and/or center of pressure sway to succeed in both tasks simultaneously. The methodology is novel because published pointing tasks usually require continuously looking at the pointed target and not exploring an image while pointing elsewhere at the same time. Twenty-five healthy young adults (23.2±2.5 years) performed six visual tasks. In the free-viewing task, participants randomly explored images with no goal. In two visual search tasks, participants searched to locate objects (easy search task) or graphical details (hard search task). Participants additionally pointed a laser beam into a central circle (2°) or pointed the laser turned off. Postural sway and center of pressure sway were reduced complementarily – in various variables – to perform the visual search and pointing tasks. Unexpectedly, the pointing task influenced more strongly postural sway and center of pressure sway than the search tasks. Overall, the participants adopted a functional strategy in stabilizing their posture to succeed in the pointing task and also to fully explore images. Therefore, it is possible to inverse the strength of effects found in the literature (usually stronger for the search task) in modulating the experimental methodology. In search tasks more than in free-viewing tasks, participants mostly rotated their eyes and head, and not their full body, to stabilize their posture. These results could have implications for shooting activities, video console games and rehabilitation most particularly.

Keywords: Postural control; Visual and pointing tasks; Interaction and priority; Ecological images on a large display; Young adults

Abbreviations: AP: Anteroposterior; COP: center of pressure; ML: mediolateral; SD: standard deviation; V: mean velocity; COP/body movements: COP and/or body (head, neck, lower back) movements

1. Introduction

In the upright stance, individuals sway at all time and the characteristics of their sway depend on multiple constraints such as the task performed (Ivanenko & Gurfinkel, 2018). It is well known that healthy young adults sway significantly less when they perform precise visual search tasks (Giveans, Yoshida, Bardy, Riley, & Stoffregen, 2011; Rodrigues et al., 2013; Rougier & Garin, 2007; Stoffregen, Hove, Bardy, Riley, & Bonnet, 2007) and pointing tasks (Balasubramaniam & Turvey, 2000; Balasubramaniam, Riley, & Turvey, 2000; Dos Anjos, Lemos, & Imbiriba, 2016) than when they perform the respective control tasks. Precise visual search tasks refer to tasks in which individuals have to place their gaze at precise locations. Pointing tasks refer to experimental tasks in which individuals have to point and keep a laser beam into a specific target.

The literature shows that the amplitude and velocity of postural sway are lowest in the most difficult visual search and pointing tasks (Bonnet & Baudry, 2016; Bonnet, Szaffarczyk, & Baudry, 2017; Chen & Stoffregen, 2012; Taube, Leukel, & Gollhofer, 2008). At a general level, postural control is more strongly adjusted to perform visual search tasks than pointing tasks. Indeed, postural sway is reduced in all directions in visual search tasks while it is mostly reduced in one axis[1] in pointing tasks (Balasubramaniam & Turvey, 2000; Balasubramaniam et al., 2000; Chen & Stoffregen, 2012). Despite the extensive literature regarding the adjustment of postural control to perform visual search and pointing tasks, we are aware of only one study combining both visual search and pointing tasks. In a recent study of our group, healthy young adults had to point a laser beam continuously in a central target while exploring a small image (visual angle: 21°) to locate targets. As expected, postural sway was more controlled to perform the visual search task than the pointing task. Postural sway was even only significantly reduced to perform the visual search task than the control free-viewing task (Bonnet, Dubrulle, & Singh, 2021). So far, we are not aware of any study combining visual search and pointing task when participants look at large images imposing them to turn their head and body. This situation is possible in day-to-day life, for example in pointing a finger toward a target and in looking at another person to discuss that target. At the theoretical level, this new experimental combination is interesting to increase the difficulty of the visual and pointing tasks and to test more strongly adaptation of postural control to succeed in both tasks simultaneously.

The present study was designed to study how young adults stabilize their postural sway to perform a combination of visual search and pointing tasks. Healthy young participants performed six tasks combining three visual tasks (an easy search task, a hard search task and an unprecise free-viewing task projected onto a large panoramic display) and two pointing tasks (pointing a laser toward a target with the laser beam either on or off). Our main hypothesis was that young adults would reduce their postural sway more in performing both visual search and pointing tasks together than in performing these tasks in isolated manners and more so at the head than at any other levels of the body. Our second hypothesis was that young adults would stabilize their posture more to perform visual search tasks than pointing tasks. Our third hypothesis was to find more significant findings in the mediolateral direction than in the anteroposterior direction because the images were larger laterally (120°) than vertically (22.5°).

[1] The mediolateral vs. anteroposterior axis is not mentioned here because it depends on how participants looked at the target, i.e. either with the target in front of them or in turning their head 90° (Balasubramaniam & Turvey, 2000; Balasubramaniam, Riley, & Turvey, 2000; Chen & Stoffregen, 2012).

2. Methods

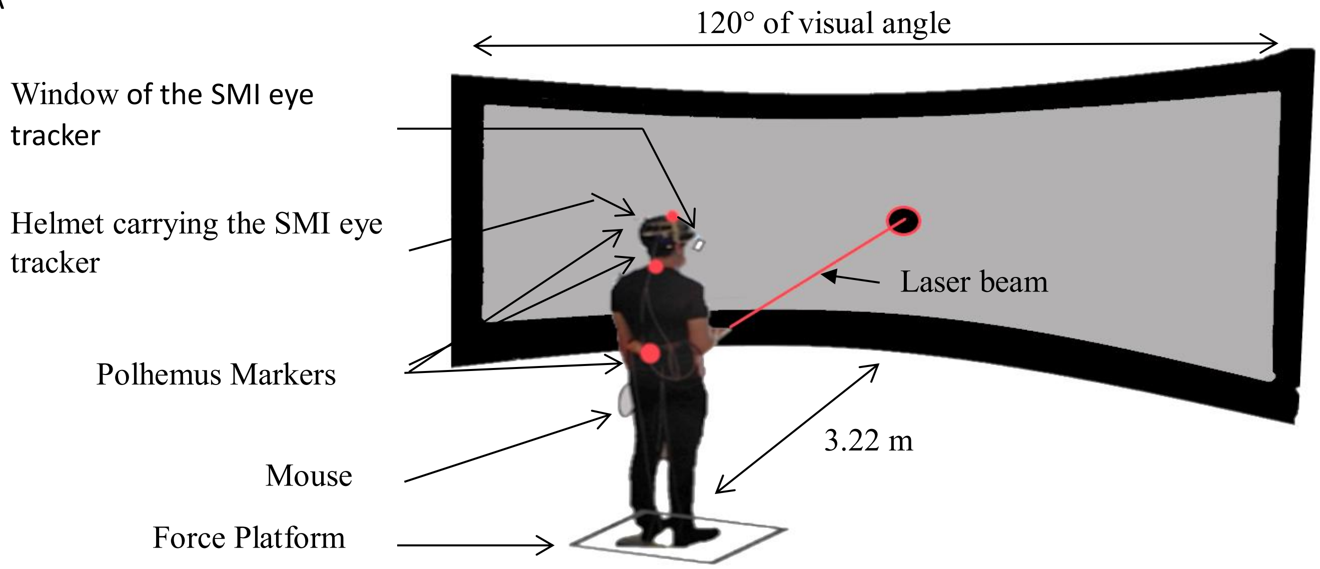
2.1. Participants

Twenty-five healthy young volunteers (14 males, 11 females) participated in this study. The mean age, bodyweight and height were 23.2±2.5 years, 65.0±11.1 kg and 171.1±7.9 m, respectively. The study was approved by the local ethical committee of Lille. The participants gave their written, informed consent prior to participation.

2.2. Apparatus

Three video-projectors (Optoma HD83, London, United Kingdom) were used to display the images onto a full panoramic display (radius: 2.04 m; high: 2 m; circumference: 12.8 m; Figure 1A). The participants could see the images with a left/right visual angle of 120° and an up/down angle of 22.5° (Figure 1A). On the center of each image, a black circle (2° of visual angle) was always present (Figure 1A). The images projected onto the display (one per trial) were virtual images inside or outside living homes such as a kitchen, a living-room, a garden, etc (Figure 1B).

A



B

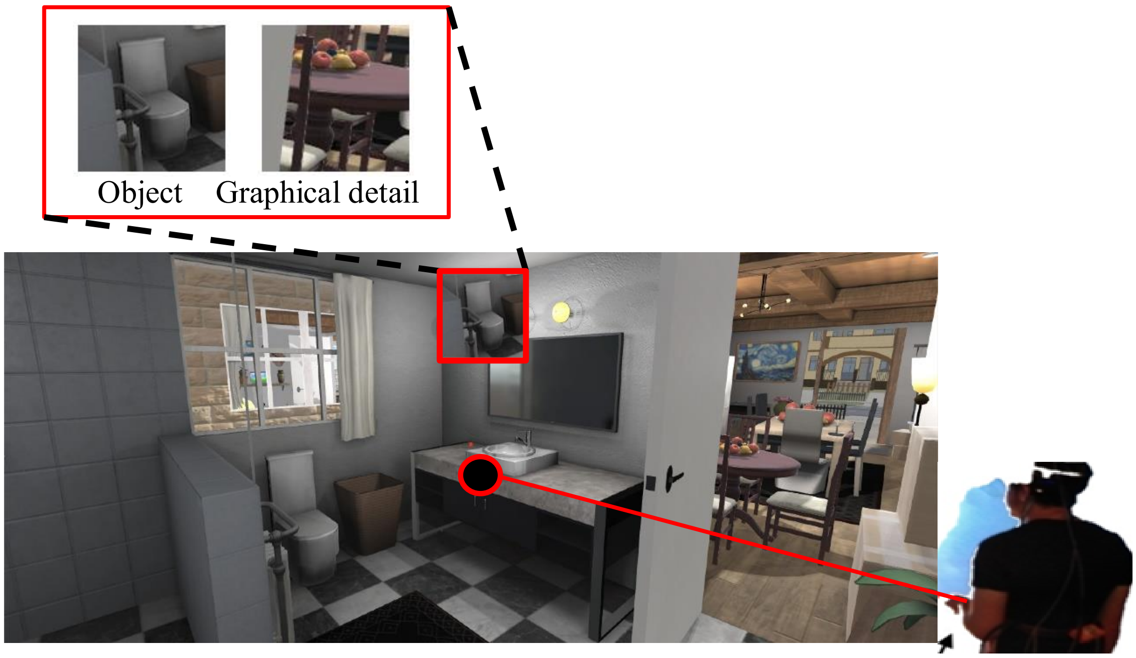


Figure 1. A. Representation of the experimental setting. The participant stood on a force platform in front of the panoramic display. On this display, an image was projected with a visual angle of 120°. The three Polhemus markers (showed in red) were attached to a helmet, to the neck (at the seventh cervical vertebrae) and to the lower back on a belt. An eye tracker was attached to the helmet to record the participants' eye movements. The participants hold a laser in one hand and pointed the laser beam into a small black circle (2°). In their other hand, the participants hold a mouse to click on it each time they found a target in the image. B. Representation of one image shown to the participants on the panoramic display. This Figure shows the red rectangle (at the top center of the image) in which a target – to be found within the image – was presented in both search tasks. In the easy search task, an entire target object had to be found in the hard search task, a target graphical detail of the image had to be found. Once the target was found, the participants clicked on the mouse and another target appeared in the red rectangle. In the free-viewing task, there was no red rectangle (and no object to be found). The laser beam was on in half of the trials. In the other half of the trials, the participants still maintained their forearm perpendicular to the body but the laser beam was off.

A force platform (dual-top AMTI, Watertown, MA, USA) was used to record center of pressure (COP) movement (Figure 1A) with a sampling frequency of 200 Hz. A magnetic tracking system (Polhemus Liberty 240/8-8 System, Colchester, VT, USA) was used to record lower back (on a belt), neck (at the 7th cervical vertebrae) and head (on a helmet) movements (Figure 1A) at 240 Hz. An eye tracking system (SensoMotoric Instruments, Teltow, Germany) was used to record eye movements (Figure 1A) at 50 Hz.

Throughout the experimental procedures, participants hold a laser pointer (laser pointer Legmaster LX 4) in one hand and a computer mouse in the other hand (Figure 1A). Their feet were located on normalized lines (17 cm, 14°, McIlroy & Maki, 1997). During the study, the participants were barefoot. The room light was turned off so that they could clearly see/explore the images to perform the visual tasks.

A MATLAB (MATLAB 7.10 software, The MathWorks, Natick, MA, USA) customized script recorded all these devices (force platform, Polhemus, eye tracker) synchronously.

2.3. Tasks and instructions

This study design involved three visual (free-viewing, easy searching and hard searching) and two pointing tasks (laser beam on or off). The term precise task referred to both visual search and pointing tasks. The free-viewing task was considered as an unprecise visual task, i.e. a control task of the two visual search tasks, as in our previous studies (Bonnet, Davin, & Baudry, 2019; Bonnet, Davin, Hoang, & Baudry, 2019; Bonnet, Szaffarczyk, et al., 2017). Three trials per visual task (with and without the pointing task) were performed, each trial lasting 48 sec, for a total of 18 trials. The order of each task was randomly chosen but the three trials per task were performed one after another. Two rest periods of 5 min were set, i.e., after completing six and twelve trials.

In all trials, the participants were instructed to keep the computer mouse in their hand and in contact to their upper leg to be able to click on the button without moving their arm. In addition, the participants had to hold a laser pointer with their forearm perpendicular to the body and the laser pointed forward (Figure 1A and 1B).

Gaze shift tasks. In both search tasks, the participants had to locate as many targets – within the image – as possible throughout the trial. In the easy search task, the targets were full objects, e.g. a coffee machine, a pen, a table. In the hard search task, the targets were only graphical details such as the corner of a coffee machine, a part of the floor. Twenty targets could be found in each task. The image of one target was displayed within a red rectangle[2] (Figure 1B) at the top center of the image. The participants were instructed to locate the target, to click on the mouse when looking at this target found and to continue the search task. The click on the mouse recorded this event for later analysis and changed the target visible into the red rectangle (Figure 1B). In the search task, the participants were asked to make as fewer mistakes as possible in locating the targets and to find as many targets as possible. At the end of each trial in the search task, the participants had to suggest a confidence score for each object found (1 being the lowest score and 5 the highest score). In the free-viewing task, the participants had to freely explore the image content. The free-viewing was considered as the control task of both search tasks.

Pointing tasks. When the laser beam was on[3], the participants were instructed to keep it constantly within the small central black circle for the duration of the trial. When the laser beam was off, the participants had to keep their arm with the laser in the same way as when the laser beam was on. The former and later task were called “pointing task” and “no-pointing task”, respectively. The no-pointing task was considered as the control task of the pointing task.

For all visual and pointing tasks, in the 3 first seconds the participants were instructed to stare at a white cross (2° of visual angle) centered in the black circle. After these 3 first seconds, the white cross automatically disappeared and the participants then could perform the requested visual task. In all tasks, the participants were instructed to relax and to freely turn their eyes and body as they liked to look at the image.

As it should be clear, in all tasks with the laser beam on, the participants could check the location of the laser beam as many times as they liked but they could not look at this beam continuously. This procedure is novel in science as published studies required the participants to look at the laser beam to keep it within a target (Balasubramaniam & Turvey, 2000; Balasubramaniam et al., 2000; Chen & Stoffregen, 2012; Dos Anjos et al., 2016; Morrison & Keogh, 2001). It should be noted that our results with the use of the laser beam may not be comparable to these previous studies as the participants did not look at the beam continuously.

2.4. Preparation of the data

Prior to any analysis, the first 3 sec of each data were excluded as the participants fixated the cross at the beginning of each trial. Data from the force platform and Polhemus systems were resampled at 50 Hz, at the same frequency as eye tracker’s data. In contrast to data from the force platform and Polhemus, data from the eye tracker were not fully available. In fact, the eye tracker recorded 0-values for missing data, e.g. during blinks. As in previous studies (Bonnet, Davin, & Baudry, 2019), we analyzed only trials with more than 80% of useful data, i.e. with fewer than 20% of missing values.

2.5. Dependent variables

For analyses to test our hypotheses we used classical variables of COP and/or body (lower back, neck, head) linear movements: standard deviation (SD) and mean velocity (V) on the anteroposterior (AP) and mediolateral (ML) axes (Paillard & Noé, 2015).

[2] This rectangle was red to be clearly visible and immediately detectable.

[3] A scratch was used to keep the laser beam turned on. Hence, the participants did not have to push onto any button.

As the participants rotated their head and body segments as they liked to explore the large panoramic display (120°), we had to report their body angular movements for complementary purposes. Indeed, we had to inform whether larger and/or faster body rotations could eventually lead to larger and/or faster COP/postural sway. To test similarity in body rotations in all tasks, we used the SD and V variables but this time in the yaw (left/right) and pitch (up/down) directions. We computed dependent variables in AP, ML, yaw and pitch directions and not global variables such as general path length and ellipse area to provide information about postural control in both axes. It is indeed known that postural control mechanisms are different to control ML postural sway and AP postural sway (Bonnet, Cherraf, Szaffarczyk, & Rougier, 2014; D. A. Winter, Prince, Frank, Powell, & Zabjek, 1996).

As the participants moved their eyes everywhere as they liked to explore the large panoramic display, we also had to report their (angular) eye movements for complementary purposes. To this end, we used two sorts of variable to study i) spatio-temporal characteristics of time-series in using SD and V and ii) characteristics of fixation. Analyses of spatio-temporal characteristics of eye movements served to describe the pattern of eye movement. Analyses of the characteristics of fixation served to investigate if the participants looked more carefully at further objects, in terms of SD, in one task than in another. To analyse characteristics of fixation, all characteristics of saccade were excluded before calculating the SD of fixation. We already used both types of eye movement variables in previous studies (Bonnet, Davin, & Baudry, 2019; Bonnet, Davin, Hoang, et al., 2019; Bonnet, Szaffarczyk, et al., 2017).

As the participants had to perform visual search and pointing tasks, their performance had to be recorded. We reported these performances to show that the participants indeed performed the task as requested and to show the difficulty of the tasks performed. For the visual search tasks, we calculated the number of targets found. The performance was separated into correct and incorrect findings when the participants clicked on the computer mouse in looking at the correct and incorrect target. For the pointing task, the recorded videos of the eye-tracker were used to count how many times the laser beam i) touched the external line of the black circle and ii) completely went out of the black circle.

2.6. Statistical analyses

Before analyses, we checked the existence of outliers. We defined outliers as extreme values (more than 2 SD outside the quartiles). We were especially concerned about outliers because the participants were free to look at the large panoramic display and some participants could have performed the tasks very differently than others. We analyzed outliers in the spreadsheets showing the dependent variables per individuals (horizontal lines) and in the tasks and trials (vertical lines). If an outlier could be detected, we deleted these outliers, as recommended by (Tabachnik & Fidell, 2006, pp. 76-77, 92, 100).

Before analyses, we also verified normality with the Shapiro-Wilk test and homogeneity of variance with the Mauchly sphericity test. When data did not respect these conditions, analyses were not performed. Two-way analyses of variance (ANOVAs), with visual search tasks and pointing tasks as factors, were performed on the various dependent variables. Post-hoc Newman-Keuls tests were performed to know which visual task differed when main effects of search were found. To test our main hypothesis, we specifically search for the existence of visual task by pointing interaction effects in the ANOVAs. To test our secondary hypothesis, we searched for stronger effect sizes and a greater number of significant main effects of visual search than of pointing in the ANOVAs. In all analyses, we did not test in which task (search vs. pointing) the participants exhibited significantly lower COP/postural sway but in which of these tasks, the participants changed their COP/postural sway the most (from the control task to the experimental task). The *p*-value was set at $p<0.01$. This alpha level was adjusted based on the test of several hypotheses and not on the number of ANOVAs, as suggested by (Rubin, 2017). Partial eta squared was used to quantify the effect size in Tables 1, 2 and 3.

3. Results

3.1. Selection and choices before analyses

Overall, 83.3% of eye tracker trials had more than 80% of useful data. Once the files with more than 20% of missing 0-values were deleted, the remaining eye tracker files contained on average 90±8.1% of existing data.

Concerning outliers, for the spreadsheets of COP/body variables, four values were deleted. In the final spreadsheets for the time-series and fixation characteristics of eye movement, seven and five values were deleted, respectively. These missing values explain the lower degrees of freedom in ANOVAs showed in Tables 1, 2 and 3.

3.2. Task performance in both pointing and searching

The task performances were analysed to verify if the participants performed the task as requested and to provide complementary information.

For the pointing task, the ANOVAs did not show any significant difference in the number of times the laser beam touched the external line of the black circle ($F(2,48)=0.41$, $p>0.05$) or went out of this target circle ($F(2,48)=1.09$, $p>0.05$). The laser beam touched this line 1.06±0.97, 0.97±0.75 and 1.22±0.92 times and went out of the circle 0.35±0.62, 0.19±0.31 and 0.20±0.36 times in free-viewing, easy searching and hard searching, respectively. Overall therefore, the participants were quite accurate in keeping the laser beam within the black circle in the three visual tasks.

For the number of target correctly found in both easy and hard visual search tasks, the 2×2 repeated measure ANOVA showed a main effect of visual searching ($F(1,24)=91.06$, $p<0.01$) but no main effect of pointing ($F(1,24)=2.65$, $p>0.05$) or visual searching by pointing interaction effect ($F(1,24)=0.91$, $p>0.05$). The amount of targets correctly found was higher in easy searching (11.1±2.9) than in hard searching (6.7±2.3). For the number of targets incorrectly found, the 2×2 repeated measure ANOVA did not show any significant finding ($F_s(1,24) < 2.65$, $p>0.05$).

3.3. COP and body sways

The analyses in COP and body sways served to test our three hypotheses.

Concerning the main effects of visual searching, the results showed that the participants oscillated significantly less and slower in easy searching than in both free-viewing and hard searching in various dependent variables on the AP and ML axes (Table 1). The only exception to this rule concerns head V_{ML}. In fact, the ANOVA showed a significantly greater head V_{ML} in easy and hard searching than in free-viewing (Table 1). Additionally, there was a greater amount of significant differences between easy searching and free-viewing than between hard searching and free-viewing (5 vs 2; cf. Table 1). Concerning the main effects of pointing, all the significant main effects in Table 1 show that the participants moved their COP/body segments significantly lower and slower when the laser beam was on than off.

In relation to our second hypothesis, the results showed that young adults did not stabilize their posture more to perform visual search tasks than pointing tasks. Instead, Table 1 shows that the various main effects of pointing were stronger in average (effect size: 0.36±0.12; Table 1) than the various main effects of gaze (effect size: 0.22±0.04; Table 1).

Main ANOVAs did not show any significant visual searching by pointing interaction effects for any of the variables presented in Table 1 (p>0.01). In relation to our main hypothesis, these results showed that young adults did not reduce their COP/body sway more in performing both visual search and pointing tasks together than in performing these tasks in isolated manners.

Insert Table 1 about here

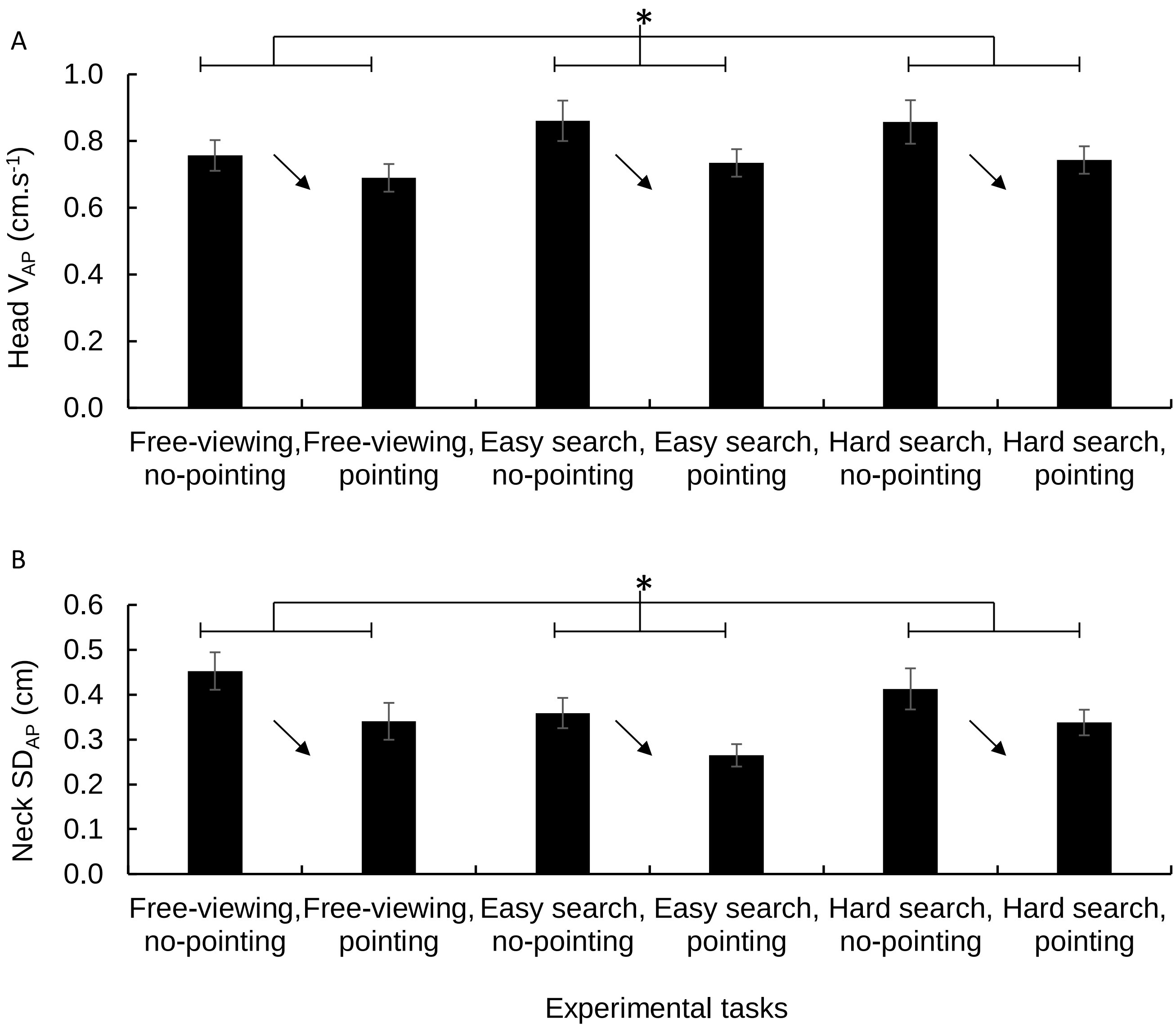


Figure 2. Main effects of visual search and of pointing in the ANOVAs for Head V_{AP} (Figure 2A) and Neck SD_{AP} (Figure 2B). Head V_{AP} concerns the mean velocity of head movement on the anteroposterior axis (in centimeter per second, or $cm.s^{-1}$). Neck SD_{AP} concerns the standard deviation of the neck movement on the anteroposterior axis (in centimeter, or

cm). The experimental tasks were the free-viewing task performed with the laser turned off (free-viewing, no-pointing), the free-viewing task performed simultaneously with the laser pointing task with the laser beam turned on (free-viewing, pointing), the easy search task performed with the laser turned off or on and the hard search task performed with the laser turned off or on. The three arrows going down show the significant main effect of pointing. The horizontal lines comparing the free-viewing, easy search and hard search tasks show the significant main effect of visual search. The error barres represent the standard errors of the mean. $p<0.01$.

3.4. Body angular movements

We studied body angular movements for control purposes. For body angular movements, the main effects of visual searching showed that the participants rotated their head, and only their head, significantly more and faster in hard searching than in both free-viewing and easy searching and also sometimes in easy searching than in free-viewing (Table 2). These results were found in both yaw and pitch directions. Furthermore, all the significant main effects of pointing showed that the participants rotated their body parts significantly less when the laser beam was on than off (Table 2). As for COP/body linear movements, there were no significant visual search by pointing task interaction effects for any of the body angular movements presented in Table 2 ($p>0.01$).

Overall, the results in section 3.3. and 3.4. show that the participants turned more their head in searching than in free-viewing but still exhibited less COP/postural sway in searching than in free-viewing. They also showed that the participants turned less their head in pointing than no-pointing and exhibited less COP/postural sway in pointing than no-pointing.

Insert Table 2 about here

3.5. Eye movements

We reported how the participants moved their eyes to check compliance with instructions and/or to explain where the participants looked at they were free to move their eyes as they liked. In the study, the eyes performed fixations further in the up/down direction in hard searching than in free-viewing and easy searching (Table 3). The eyes also moved further in the left/right direction in hard searching than in free-viewing (Table 3). Eye movements were faster in hard searching than in free-viewing in both up/down and left/right directions (Table 3). In complement, the eyes went faster in both up/down and left/right directions in easy searching than in free-viewing (Table 3).

When the laser beam was on in the pointing tasks, the participants did not move back and forth often to check if the laser beam was well located in the black central circle (Figure 4). Indeed, they directed their central vision to the laser beam only less than 6 times per trial in the free-viewing task and only less than 2.5 times in both search tasks (Figure 4). The ANOVA testing a main effect of task was significant ($F(2,32)=9.53$, $p<0.01$). Post-hoc analyses showed that the participants looked significantly less at the laser beam in both search tasks than in the free-viewing task ($p<0.01$).

Insert Table 3 about here

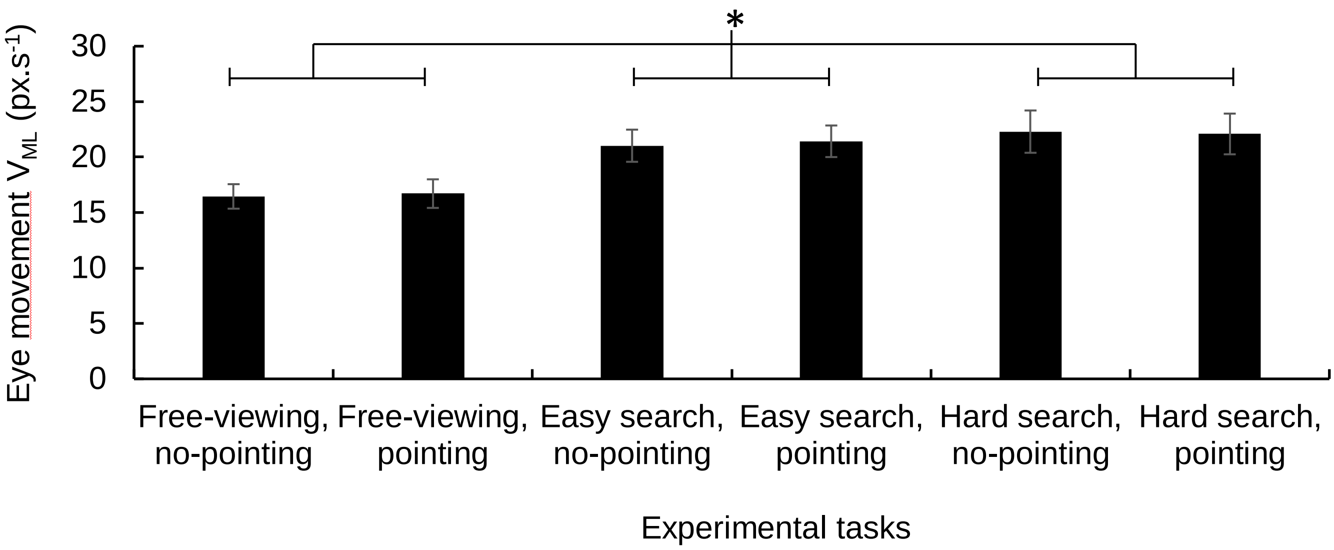


Figure 3. Main effect of visual search in the ANOVA for eye movement in the left-right direction (VLR, in pixels per second, or px.s^{-1}). The experimental tasks were the free-viewing task performed with the laser turned off (free-viewing, no-pointing), the free-viewing task performed simultaneously with the laser pointing task with the laser beam turned on (free-viewing, pointing), the easy search task performed with the laser turned off or on and the hard search task performed with the laser turned off or on. The horizontal lines comparing the free-viewing, easy search and hard search tasks show the significant main effect of visual search. The error barres represent the standard errors of the mean. $p<0.01$.

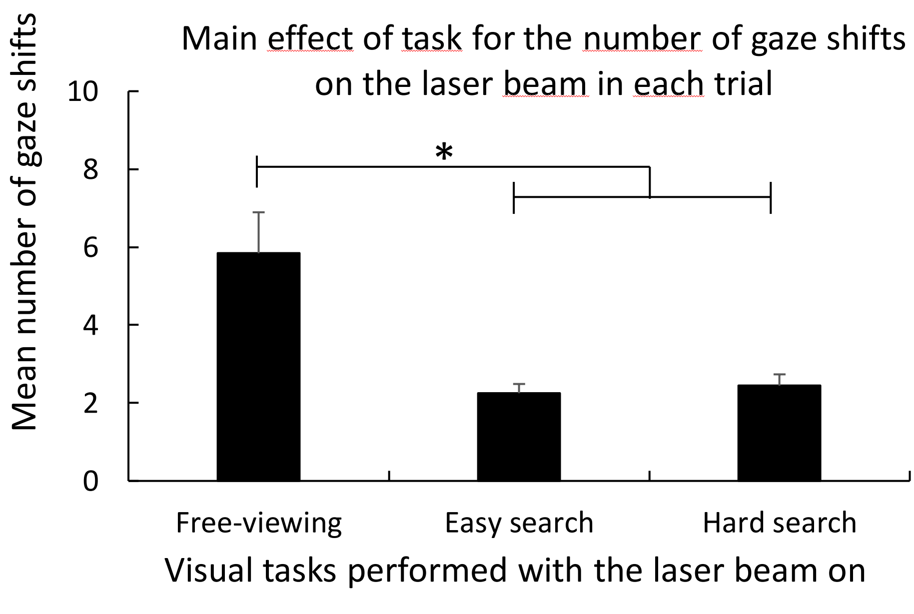


Figure 4. Main effect of the number of gaze shifts on the laser beam per trial in the ANOVA. The experimental tasks were the free-viewing task, the easy search task and the hard search task all performed with the laser beam on and pointed toward the black circle in front of the participants. The error barres represent the standard errors of the mean. $p<0.01$.

4. Discussion

When the visual search and pointing tasks were performed simultaneously, the results showed that they did not add their stabilizing effects on postural control. However, they involved complementary variables 80% of the time. As in the literature reports, COP/body sway was reduced in search tasks compared to free-viewing and in pointing the laser beam on compared to its control laser off task. Unexpectedly, the pointing task had the strongest stabilizing effect on postural control. In fact, the young participants reduced their COP/body sway to easily succeed in the pointing task to be able to well explore images in the free-viewing and visual search tasks.

4.1. Visual search and pointing tasks influenced COP/body sway in a complementary way

In relation to our main hypothesis, there was no interaction effect involving both visual search and pointing tasks for any tested variable of COP/body sway (Table 1; Figure 2A and 2B). Hence, young adults did not stabilize their posture better in performing both visual search and pointing task simultaneously than in performing them in isolated manners. Therefore, these results invalidated our main hypothesis. To explain these unexpected results, one could refer to Stoffregen, Bardy, Bonnet, Hove and Oullier's (2007) main argument. These investigators suggested that postural sway can be reduced in gaze shift tasks than in control tasks until a certain limit, or plateau, below which it cannot be reduced further. In this previous study (Stoffregen, Bardy, et al., 2007), young participants significantly reduced their COP sway in performing three gaze shift tasks (0.5 Hz, 0.8 Hz, 1.1 Hz at 11° of visual angle) in contrast to a basic fixation task. However, participants could not reduce COP sway further in the harder tasks (0.8 Hz or 1.1 Hz) than in the easier task (0.5 Hz). Our results extend Stoffregen et al.'s (Stoffregen, Bardy, et al., 2007) conclusion in showing the existence of this plateau when performing two challenging tasks with various difficulties and with large visual explorations.

Remarkably, 80% of the time, when one variable showed a significant main effect of visual task, it did not show a main effect of pointing or vice versa (Table 1). Therefore, when one task could not stabilize posture at some levels, the other task did so. In other words, instead of stabilizing their posture better in performing both tasks together (as we originally expected), the participants stabilized their posture in different ways in performing both tasks together. These complementary effects can be found in Table 1. For example, the participants' COP sway was significantly lower to perform visual search tasks than the free-viewing control task for both COP SD_{ML} and COP SD_{AP} but not for COP V_{ML} (Table 1). However, the participants' COP sway was lower to perform the pointing task vs. no-pointing task for COP V_{ML} but not for COP SD_{ML} and COP SD_{AP}. The other results for head, neck and lower back also show the same trend in Table 1 for this complementary effect of the main effects of searching and pointing. To the best of our knowledge, the suggestion of complementary effects of two stabilizing tasks is novel, not suggested earlier in any studies analyzing the effects of visual tasks on postural control (Legrand, Barra, Senot, & Doré-Mazars, 2015; Prado, Stoffregen, & Duarte, 2007; Rodrigues et al., 2013; Rougier & Garin, 2007; Stoffregen, Pagulayan, Bardy, & Hettinger, 2000). Therefore, tasks with specific aims may constrain differently postural control functioning, leading to seek different organizational strategies to succeed in the task.

In relation to our third hypothesis, Tables 1, 2 and 3 show approximately an equal quantity of significant results is both directions (AP vs. ML for sway; yaw vs. right for rotation; up/down vs. left/right for eye movement). This trend in the results was not expected as the visual angle was more extended left/right (120°) than up/down (22.5°) to explore all images on the panoramic display. Our results showed that postural control was equally challenged in both AP and ML directions. One way to explain these results is that the participants did not turn their eye and head quickly from one side of the panoramic display to the other. Instead, they explored the images slowly everywhere, as noticed by the experimenter in looking at all participants performing the various tasks during experimental trials. In the present study, the participants were free to move as they liked and did move slowly probably to avoid any postural destabilization in the ML direction.

4.2. The pointing task was the most influential task for postural control

In relation to our second hypothesis, we tested if the stabilization of postural control could be higher in visual search tasks than in pointing tasks. Unexpectedly, our results showed that young adults adjusted postural control more in the pointing task than in the visual search task. Indeed, for COP/body sways, the various main effects of pointing were stronger in average than the various main effects of gaze (Table 1). These results were unexpected firstly because the participants only briefly looked at the position of the laser beam throughout the trials. Secondly, the literature reports showed that the reduction of COP/body sway is strong (in both AP and ML axes) and systematic in visual search tasks than in control visual tasks (Bonnet & Baudry, 2016). In contrast, COP/body sway was found to be lower in pointing tasks on one specific axis but higher on the orthogonal axis[1] in three studies (Balasubramaniam & Turvey, 2000; Balasubramaniam et al., 2000; Chen & Stoffregen, 2012). Similarly, Dos Anjos et al. (2016) also showed that COP and ankle sway was lower in the pointing task when participants performed the task with internal feedback but COP and ankle sway was also higher with external feedback. Thirdly, these results contrasted with previous ones found recently (Bonnet et al., 2021). In this study, healthy young adults also performed both visual search and pointing tasks together but this time with images projected onto a small visual display (visual angle: 21°). In this aforementioned study, the participants did not reduce their postural sway to perform the pointing task; they only significantly reduced their postural sway to perform the visual search task. Fourthly, the results were also unexpected because they did not concern more especially head movement but equally all levels of the body (COP, lower back, neck and head; Table 1). This overall unexpected finding is explained in section 4.4.

4.3. COP/body sway to perform the tasks in isolated manners

In relation to the literature, previous studies repeatedly showed that COP/body sways are significantly lower in visual search tasks vs. their control tasksand in pointing tasks vs. their control tasks (Balasubramaniam & Turvey, 2000; Chen & Stoffregen, 2012; Dos Anjos et al., 2016; Giveans et al., 2011; Rodrigues et al., 2013; Rougier & Garin, 2007; Stoffregen, Bardy, et al., 2007; Taube et al., 2008). Significant differences observed in our study were consistent with these previous findings both for the pointing task and for the visual search tasks. For the visual search tasks, there is only one exception to this rule, i.e. faster head movements on the ML axis in both easy and hard searching than in free-viewing. This result is explained by faster head rotations in the yaw direction in both easy and hard searching than in free-viewing most likely due to the temporal pressure to find as many targets as possible (Table 2; Figure 3). Overall, our results in both pointing and search tasks extend the literature reports in showing that significant effects still exist for both visual search and pointing tasks even if both tasks are performed together. Additionally, our results complement the existing knowledge in showing that the stabilizing effect in visual search tasks still exists even if large ecological images are explored (images of room house) instead of small cartoon images (Bonnet, Davin, & Baudry, 2019; Bonnet, Szaffarczyk, et al., 2017) or black targets projected onto a white background (Giveans et al., 2011; Rodrigues et al., 2013; Rougier & Garin, 2007; Stoffregen, Bardy, et al., 2007).

4.4. Eye movements and postural control to perform the tasks

Eye movements were not different in pointing vs. no-pointing (cf. Results section). Therefore, in all free-viewing and search tasks, the participants were able to explore images similarly (as largely and as fast) when they had to maintain the laser beam into the small black circle than when the laser beam was off. This complementary result is important as it indirectly shows that the participants did not go back and forth to verify if the laser beam was still well maintained within the black circle. Indeed, if participants were moving their eyes back and forth, they would not be able to explore images extensively. Consistently our data in eye movements showed that the participants only rarely looked at the laser beam. In fact, Figure 4 shows that the participants only looked – in average – less than 6 times per trial the laser beam in the three tasks. Moreover, they even looked at it less in both search tasks (less than 2.5 times per trial) than in the free-viewing task (Figure 4). However, they still succeeded very well at the laser pointing task, i.e. they succeeded as well during all tasks. Complementarily, the participants succeeded to find targets within images as well when they pointed the laser beam into the black circle than when the laser was off.

In considering the results discussed in the last paragraph, our results in eye and body linear movements showed that i) postural control was strongly adjusted in the pointing task even if ii) the participants almost never looked at the position of the laser beam and iii) still succeeded well in the pointing task. For all these reasons, we suggest that the participants better controlled their posture to succeed in the pointing task – here supposedly the primary task – to fully focus their attention on the gaze shift tasks performed – here supposedly the secondary task. This interpretation well explain why we found that postural control could be better adjusted in pointing than in searching although we expected the opposite effect. These results are in line with a goal-directed organization/adaptation of postural control to succeed in combined visual and visuo-motor tasks.

At least two mechanisms could have allowed the participants to succeed in the pointing task almost without looking directly at the laser beam. First, the participants could have succeeded in the laser pointing task in using their proprioception provided by their muscle spindles to control and keep their arm position constant throughout the trial (Tsay, Allen, & Proske, 2016). In controlling the position of their arm, they controlled the position of the laser in their hand and could be confident that the laser beam was projected within the black circle. Second, the participants could have used their peripheral vision to intermittently verify that the laser beam stayed within the black central circle while exploring graphical details of experimental images. Accordingly, Klostermann, Vater, Kredel and Hossner (2019) explained that the use of peripheral vision helps to make several tasks at once. In using gaze anchor, the participants could decide where to perform new gazes shifts toward new elements of the display and at the same time check in peripheral vision the position of the laser beam (Klostermann et al., 2019). Sometimes, at rare occasions as we showed in our results section, they could have used the visual pivot – to move back and forth to check the position of the laser beam – (Klostermann et al., 2019) to unsure good task performance.

4.5. Limitations

A first limitation of the present study is the relatively large quantity of variables used at all levels of the body to test our hypotheses. However, we needed to use many variables to analyze which of the gaze shift and pointing tasks had the greatest effect on COP/body sways and in controlling for eye/body coordination. A second limitation is that we did not separate results in COP sway vs. head, neck and lower back sway as we wanted to provide a general view of postural control to perform the various visual tasks. We still need to emphasize that COP sway vs. postural sway do not mean the same thing, the displacement of the COP is considered as the controller and the displacements of the body are considered as the controlled variables. For more information in this respect, see Winter and colleagues' manuscripts (Winter, 1995; Winter et al., 1996) as well as our work (Bonnet, Morio, Szaffarczyk, & Rougier, 2014). A third limitation is that the laser pointing task was not comparable as published reports as the participants did not look at the laser beam continuously. However, important is to mention that the main effect of pointing was stronger than the main effect of searching. Therefore, the search task did not bias the results but instead required the participants to adapt their postural control in an original way that we explained in the previous paragraph. We thus showed an interesting novel finding.

4.6. Final remarks

In summary, our take home message is that young adults stabilized their postural control i) to easily succeed in the pointing task and ii) therefore to allow them to pay attention to the other visual search visual tasks performed. The participants stabilized their COP/body sways in complementary ways to perform both visual search and pointing tasks but did not stabilize their posture better when they performed both tasks together than separately. Also, the results validated that young adults need to control their postural sway to succeed in visual search and pointing tasks even when they look at large displays. At the practical level, these results are relevant for athletic games, i.e. when shooting targets with rifles (Era, Konttinen, Mehto, Saarela, & Lyytinen, 1996; Mononen, Konttinen, Viitasalo, & Era, 2007). They are also interesting at the clinical level because the implementation of combined tasks, in our case visual search and pointing tasks, could be a solution for rehabilitation (Liebherr, Schubert, Schiebener, Kersten, & Haas, 2016). Future studies should test if older adults and patients with motor disability (e.g., patients with Parkinson's Disease) are able to stabilize their COP/body sways to succeed in the pointing task to pay full attention to the gaze shift tasks performed. Patients with Parkinson's Disease may not be able to do so because they can use wrong strategies (Bloem, Grimbergen, Dijk, & Munneke, 2006) and may not be able to adapt their postural control to the task performed (Bonnet, Delval, & Defebvre, 2015; Bonnet, Delval, Szaffarczyk, & Defebvre, 2017).

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Conflict of interest

None

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Linear COP/body (head, neck, lower back) variables	Free-viewing task	Easy search task	Hard search task	Main effect of visual task	Laser beam off	Laser beam on	Main effect of pointing task
COP SD_{ML} (cm)	0.23±0.13 (+)	0.18±0.07 (+,*)	0.20±0.08 (*)	F(2,46)=6.11, η^2= 0.21	0.22±0.10	0.18±0.09	*ns*
COP SD_{AP} (cm)	0.43±0.17	0.37±0.11	0.38±0.11	F(2,46)=6.48, η^2=0.22	0.39±0.13	0.40±0.13	*ns*
COP V_{ML} (cm.s^{-1})	3.40±0.75	3.26±0.66	3.27±0.64	*ns*	3.40±0.69	3.21±0.66	F(1,23)=7.93, η^2=0.26
Head V_{ML} (cm.s^{-1})	1.18±0.24 (+,*)	1.24±0.22 (+)	1.26±0.22 (*)	F(2,48)=7.75, η^2=0.20	1.26±0.24	1.19±0.21	*ns*
Head V_{AP} (cm.s^{-1})	0.72±0.21	0.80±0.24	0.80±0.26	F(2,48)=5.74, η^2=0.19	0.82±0.27	0.72±0.19	F(1,24)=22.15, η^2=0.48
Neck SD_{AP} (cm)	0.40±0.17 (+)	0.31±0.13 (+,*)	0.38±0.16 (*)	F(2,48)=9.62, η^2=0.29	0.41±0.19	0.31±0.14	F(1,24)=7.89, η^2=0.25
Neck V_{AP} (cm.s^{-1})	0.30±0.11	0.29±0.08	0.31±0.10	*ns*	0.34±0.13	0.26±0.07	F(1,24)=24.24, η^2=0.50
Lower back SD_{ML} (cm)	0.51±0.20 (+,*)	0.43±0.13 (+)	0.44±0.14 (*)	F(2,48)=5.41, η^2=0.18	0.45±0.15	0.47±0.16	*ns*
Lower back V_{ML} (cm.s^{-1})	0.51±0.10 (+)	0.47±0.07 (+)	0.48±0.07	F(2,48)=7.52, η^2=0.25	0.50±0.09	0.47±0.07	*ns*
Lower back V_{AP} (cm.s^{-1})	0.22±0.10	0.20±0.06	0.22±0.09	*ns*	0.25±0.12	0.18±0.06	F(1,24)=11.11, η^2=0.32

Table 1. Significant main effects of visual task (free-viewing, easy search, hard search) and main effect of pointing task (laser beam off; Laser beam on) for linear movement of the center of pressure (COP), head, neck and lower back movements in the two-way ANOVAs. Dependent variables that did not show any significant effect of visual task are not shown. In the three visual tasks, the participants i) explored images of rooms of houses, either ii) with no specific goal (free-viewing task) or iii) in trying to locate targets (either full objects in the easy search task or graphical details in the hard search task). They performed these visual tasks either in pointing a laser beam into a small black circle located at the center of the image (laser beam on) or in pointing the same laser turned off approximately in the same direction (laser beam off). The table shows the name of the variables, the mean±standard deviation in each task, results of the ANOVA and the effect size with partial eta squared (η^2). (*) shows that the variable in the hard search task is significantly different than in the other(s) task(s) (post-hoc Newman-Keuls test). (+) shows that the variable in the easy search task is significantly different than in the free-viewing task (post-hoc Newman-Keuls test). The dependent variables were the standard deviation (SD) and mean velocity (V) shown on the anteroposterior (AP) and mediolateral (ML) axes. As an example, COP SD_{ML} refers to the SD of the COP movement on the ML axis. The variables are expressed in centimeters (cm) and centimeters per second (cm.s^{-1}). There was no significant interaction effect, *ns*. The *p*-value was set at p<0.01.

Angular body (head, neck, lower back) variables	Free-viewing task	Easy search task	Hard search task	Main effect of visual task	Laser beam off	Laser beam on	Main effect of pointing task
Head SD_{yaw} (°)	1.52±0.79 (*)	1.71±0.68 (*)	1.98±0.77 (*)	$F(2,48)=9.36$, $\eta^2=0.28$	1.77±0.65	1.71±0.77	*ns*
Head V_{yaw} (°.s^{-1})	1.52±0.60 (+,*)	1.79±0.56 (+)	1.79±0.48 (*)	$F(2,48)=10.54$, $\eta^2=0.31$	1.77±0.54	1.63±0.52	*ns*
Head V_{pitch} (°.s^{-1})	4.41±2.74 (+,*)	7.40±2.66 (+)	7.55±3.03 (*)	$F(2,48)=50.39$, $\eta^2=0.68$	6.95±2.80	5.96±2.61	$F(1,24)=13.78$, $\eta^2=0.36$
Neck SD_{pitch} (°)	0.84±0.47	0.77±0.43	0.81±0.47	*ns*	0.96±0.48	0.65±0.35	$F(1,23)=29.69$, $\eta^2=0.56$
Neck V_{yaw} (°.s^{-1})	0.88±0.19	0.90±0.19	0.91±0.22	*ns*	0.93±0.21	0.86±0.18	$F(1,24)=12.90$, $\eta^2=0.35$
Neck V_{pitch} (°)	0.91±0.36	0.98±0.36	1.01±0.44	*ns*	1.08±0.45	0.85±0.30	$F(1,24)=25.51$, $\eta^2=0.52$
Lower back SD_{pitch} (°)	0.60±0.44	0.48±0.34	0.46±0.28	*ns*	0.75±0.60	0.31±0.16	$F(1,23)=16.85$, $\eta^2=0.42$
Lower back V_{pitch} (°.s^{-1})	0.65±0.22	0.65±0.22	0.64±0.19	*ns*	0.73±0.25	0.57±0.21	$F(1,23)=9.32$, $\eta^2=0.29$

Table 2. Significant main effects of visual task (free-viewing, easy search, hard search) and main effect of pointing task (laser beam off; Laser beam on) for angular movement of the head, neck and lower back movements in the two-way ANOVAs. Dependent variables that did not show any significant effect of visual task are not shown. The definition of the tasks is described in the legend of Table 1. The table shows the name of the variables, the mean±standard deviation in each task, results of the ANOVA and the effect size with partial eta squared (η^2). (*) shows that the variable in the hard search task is significantly different than in the other(s) task(s) (post-hoc Newman-Keuls test). (+) shows that the variable in the easy search task is significantly different than in the free-viewing task (post-hoc Newman-Keuls test). The dependent variables were the standard deviation (SD) and mean velocity (V) shown in the yaw (left/right) and pitch (up/down) directions. As an example, Head SD_{yaw} refers to the SD of the head movement in the yaw (left/right) direction. The variables are expressed in degrees (°) and degrees per second (°.s^{-1}).There was no significant interaction effect, *ns*. The *p*-value was set at $p<0.01$.

Angular eye movement variables	Free-viewing task	Easy search task	Hard search task	Main effect of visual task
Fixation $SD_{up/down}$ (px)	53.27 ± 9.14 (*)	56.11 ± 6.80 (*)	61.34 ± 8.40 (*)	$F(2,46)=12.94$, $\eta^2=0.26$
Time-series $SD_{left/right}$ (px)	112.45 ± 18.49 (*)	118.92 ± 18.15	127.09 ± 23.96 (*)	$F(2,48)=11.29$, $\eta^2=0.32$
Time-series $V_{left/right}$ ($px.s^{-1}$)	16.47 ± 5.72 (+,*)	21.26 ± 6.79 (+)	22.47 ± 9.43 (*)	$F(2,48)= 20.10$, $\eta^2=0.46$
Time-series $V_{up/down}$ ($px.s^{-1}$)	18.84 ± 5.68 (+,*)	23.55 ± 8.39 (+)	24.71 ± 10.41 (*)	$F(2,48)=13.86$, $\eta^2=0.37$

Table 3. Significant main effects of visual task (free-viewing, easy search, hard search) for eye movement in the two-way ANOVAs. Dependent variables that did not show any significant effect of visual task are not shown. The table shows the name of the variables, the mean±standard deviation in each task, results of the ANOVA and the effect size with partial eta squared (η^2). The definition of the tasks is described in the legend of Table 1. (*) shows that the variable in the hard search task is significantly different than in the other(s) task(s) (post-hoc Newman-Keuls test). (+) shows that the variable in the easy search task is significantly different than in the free-viewing task (post-hoc Newman-Keuls test). The dependent variables were the standard deviation (SD), and mean velocity (V) shown in the left/right and up/down directions. As an example, Fixation $SD_{up/down}$ refers to the SD of the location of various fixations throughout the trial in the up/down direction. Time-series $SD_{left/right}$ refers to the SD of (continuous) eye movement in the left/right direction throughout the trial. The variables are expressed in pixel (px) and pixel per second ($px.s^{-1}$).There was no significant main effect of pointing task and no significant interaction effect, *ns*. The *p*-value was set at $p<0.01$.