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Benefits associated with the standing position during visual search tasks

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Running head: A case for the standing position

Abstract

The literature on postural control highlights that task performance should be worse in challenging dual tasks than in a single task because the brain has limited attentional resources. Instead, in the context of visual tasks, we assumed that i) performance in a visual search task should be better when standing than when sitting and ii) when standing, postural control should be better when searching than performing the control task. 32 and 16 young adults participated in studies 1 and 2, respectively. They performed three visual tasks (searching to locate targets, free-viewing and fixating a stationary cross) displayed in small images (visual angle: 22°) either when standing or when sitting. Task performance, eye, head, upper back, lower back and center of pressure displacements were recorded. In both studies, task performance in searching was as good (and clearly not worse) when standing as when sitting. Sway magnitude was smaller during the search task (vs. other tasks) when standing but not when sitting. Hence, only when standing, postural control was adapted to perform the challenging search task. When exploring images, and especially so in the search task, participants rotated their head instead of their eyes as if they used an eye-centered strategy. Remarkably in Study 2, head rotation was greater when sitting than when standing. Overall, we consider that variability in postural control was not detrimental but instead useful to facilitate visual task performance. When sitting, this variability may be lacking, thus requiring compensatory movements.

Keywords: Sitting position; Standing position; Task performance; Postural sway; Selectivity of attention; Young adults

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

Competing Interests: Authors are required to disclose financial

Introduction

In the standing position, individuals have to control their balance because they sway at all time (Winter 1995; Ivanenko and Gurfinkel 2018). In the literature, postural control is usually considered as the primary task of the brain as individuals need to avoid falling (Woollacott and Shumway-Cook 2002; Swan et al. 2004). Once individuals are able to maintain balance, they can perform and succeed in other tasks such as cognitive tasks (silently counting, exploring images, talking to someone) – usually called secondary tasks (Woollacott and Shumway-Cook 2002; Swan et al. 2007; Petrigna et al. 2020). In classical dual task theories (Schneider and Shiffrin 1977; Shiffrin and Schneider 1977; Navon and Miller 1987; Schneider and Chein 2003), investigators expect that task performance (e.g. rate of success in the task performed) should be worse, at least never better, in dual tasks than in single tasks. Accordingly, in the literature on postural control, it has been shown that the maintenance of postural control requires attentional resources (Lajoie et al. 1993, 1996; Vuillerme et al. 2002, 2006; Vuillerme and Nougier 2004; Roerdink et al. 2011; Remaud et al. 2012; Kang et al. 2021). Less attentional resources are therefore available to perform the other task. Therefore, the assumption is that either task performance (success, failure) at a secondary task or postural control or both task performance and postural control should be worse when standing than when sitting (Woollacott and Shumway-Cook 2002; Huxhold et al. 2006; Bloem et al. 2006; Remaud et al. 2012; Serra-Anó et al. 2015; Bergouignan et al. 2016). Equivalent levels of task performance when standing and when sitting are clearly unexpected, except if the secondary task is easy to perform. Only one cognitive model assumes that task performance could be better in a dual task than in a single task, this is the U-shaped nonlinear interaction model (e.g. Huxhold et al. 2006; Lacour et al. 2008). However, better task performance in this model is only possible if the dual task is very easy (Bonnet and Baudry 2016). To the best of our knowledge, this -shaped nonlinear interaction model would also assume better task performance when sitting than when standing for any task.

In the present manuscript, we took another standpoint. We considered that postural control and postural sway are not problematic for task performance even if postural control requires some attentional resources. Instead, in healthy young adults, our claim was that postural sway in quiet stance – with no external perturbation – is relevant for task performance, and especially for success in visual tasks. We agree with previous reports that too much sway variability is inappropriate for task performance (Fraizer and Mitra 2008). Fraizer and Mitra (2008) showed in their review that cognitive task performance is negatively affected when the maintenance of balance is mechanically or visually perturbed and also when postural control is challenged in reducing the base of support (e.g. narrow stance, heel-to-toe stance). However, we suggest that too little variability may also be inappropriate to reach optimal task performance. Indeed, in their fifth study, Mark et al. (1990) showed that young adults could not perceive well and could not improve their task performance in affordance perception when they could not sway at all. In this study, participants looked at a "seatpan" (a horizontal piece of wood) that was moved up or down by the experimenter. Participants had to judge the height from the floor at which they could sit (or not) on the "seatpan". Participants stood on a 10-cm-high block, which they could not see. The results showed that participants' judgment improved from trial to trial when they stood quietly without support but not when they stood against the wall and could not sway. Therefore, the simple fact of swaying in the standing position helped people to better perceive their affordance to sit on the seatpan.

More generally, a body of evidence shows that variability in displacement is essential for improving task performance and even for achieving motor learning (for a review, see Sánchez et al., 2017). Investigators have shown that moving an object strapped to a hand or a foot can provide useful clues to its length - even when the object cannot be seen (Turvey 1996; Hajnal et al. 2007). Even simply standing and swaying as usual allows young participants to accurately judge the length of unseen rods placed in their back at their shoulder (Palatinus et al. 2013, 2014) and to accurately judge the possibility to stand on a slant ramp (Hajnal et al. 2018, 2022). These studies (Palatinus et al. 2013, 2014; Hajnal et al. 2018, 2022) all showed that postural sway and/or sway variability is relevant to perceive affordances and we sustain this point of view. Consistent with our general claim, some studies have shown that task performance in modified Stroop task can be better performed when standing than when sitting (Rosenbaum et al. 2017; Smith et al. 2019). Overall, the low sway variability when sitting (Vette et al. 2010; Grangeon et al. 2015; Serra-Anó et al. 2015) may impair task performance in a visual search task.

In the two studies described below, our objective was to investigate task performance (success, failure, rate of success) when standing and when sitting and to test relations between task performance and postural sway. In the first study, we tested the primary hypothesis, i.e. whereby task performance is better when standing than when sitting. An alternative primary hypothesis was that the same level of task performance could be achieved when sitting and when standing if seated participants increased their postural sway in moving more their upper body part to perform the visual search task. In other words, individuals could gain useful information and optimize task performance by moving their body leftwards, rightwards, forwards and backwards more when sitting than when standing. To the best of our knowledge, this alternative hypothesis has never been tested. Our second hypothesis was that when standing, postural control would be better when performing the search task than the control task. To test our hypotheses, healthy, young adults performed an extremely challenging visual search task (see below).

Methods of study 1

Participants

Thirty-two healthy young adults (16 females/16 males; age: 20.8±1.1 years; bodyweight 65.1±10.7 kg; height: 1.76±0.1 m) from the University of Lille participated in this study. The study was performed in accordance with the tenets of the Declaration of Helsinki. The study was approved by the local ethical committee of Lille. Participants gave their written, informed consent to participation.

We used Rosenbaum et al. (2017)'s study to compute the sample size. Based on their most difficult task in Study 1, Gpower estimated that the sample size should be 15 (chosen alpha: 0.05; effect size: 0.8; power: 0.9). We chose to have a much larger sample size to have a higher power.

Apparatus

A dual-top force platform (AMTI, Watertown, MA, USA; 120 Hz) was used to record center of pressure (COP) linear displacement. A paper sheet was attached on each platform to demark the standardized position of the feet (14 cm between both foot heels and 17° between both feet; cf. McIlroy & Maki, 1997). A magnetic motion tracking system (Polhemus Liberty 240/8-8 System, Colchester, VT; 200 Hz) was used to record head, upper back and lower back linear and angular displacements. It is worthy to mention that when sitting, individuals "move their body" instead of swaying. However, for simplicity of understanding, we used the term "postural sway" to discuss how the body spontaneously moves when standing and when sitting. A head-mounted eye tracker (SensoMotoric Instruments, Teltow, Germany; 50 Hz) was used to record eye angular displacements. A video projector (Optoma HD83, London, United Kingdom) was used to project experimental images (one per trial) on a wall in a circle (subtending a visual angle of 22°; circle diameter: 121 cm). The images were projected at eye-height in each trial.

MATLAB 7.10 software (The MathWorks, Natick, MA, USA) was used to synchronize all devices at the time the image was projected onto the wall. The custom script also calibrated all devices, randomly chose images to be displayed in each task and randomly chose tasks order per participant.

Experimental images came from a puzzle for Children called "where is Waldo" (Collection Waldo by Martin Handford; Figure 1). The little personage Waldo was present in half of images in all tasks. The puzzle is known to be extremely difficult because Waldo is well hidden in images. Experimental images were projected at 3.11 m from participants to avoid the proximity and structure in images (forms, colors, texture) to influence COP and/or postural sway (Bonnet et al. 2010) – hereinafter referred to as COP/postural sway.

Insert Figure 1 about here

Tasks and instructions

Participants performed three visual tasks (search, control free-viewing and fixation) in both standing and seated positions for a total of six tasks. There were two trials per tasks and each trial lasted 40 sec. Each visual task was performed in block, combining both standing and seated positions in the same block.

The order of these three blocks was randomly chosen. Half of participants, i.e. 16 participants, performed all blocks with the standing position first and seated position afterwards and the other half of participants performed these positions in the reversed order. The images per task were chosen randomly in each task.

Participants began each trial in looking at a black cross (subtending a visual angle of 2°) placed at the center of the circle containing an experimental image. In the fixation task, the black cross stayed at the center of the circle throughout the trial. In both search and control free-viewing tasks, the black cross disappeared after 7.5 sec. In the free-viewing task, once the cross disappeared, participants were instructed to look at the image and be interested in the content of it. In the visual search task, participants were instructed to locate where Waldo in the image was. Once they were sure to have found Waldo, they had to look at it for 2-3 sec and then look largely outside of the circle to stop the trial. They needed to be confident to have found Waldo before moving their eyes out of the circle. If they could not find it, they had to search for it until the end of the trial. After each trial in which participants supposedly found Waldo, the question of confidence about the finding was asked with 5 being the highest score and 1 the lowest score. This score was used to indirectly estimate how difficult the task to find Waldo was. Also, it served as an estimate to verify that participants performed the task as requested. In the fixation task, the black cross stayed 40 sec and participants had to look at it throughout the trial. In this fixation task, an image surrounded the black cross but participants should not look at it, as they had to perform the fixation task. This basic task was intended to provide baseline data to better understand the sense of a significant difference in eye and COP/postural displacements between searching and free-viewing. In other words, we used the basic task to know if participants swayed more or less than baseline in one condition vs. the other (which would be equal to baseline).

In the standing position, participants were told to relax and keep their arms and hands by the side of the body. In the seated position, participants were seated on a stool located on the force platform. They were instructed to keep their hands above their thighs and to place their feet on a stool's barre located just above the force platform surface. In both standing and seated positions, participants were requested to avoid any voluntary displacements (e.g., no hand displacement, no switch of bodyweight from one leg to the other when standing).

Procedure

Before starting the study, the instructor explained the tasks but without saying that they would see images of the Waldo game and without saying that they would have to search for Waldo in some trials. The instructor only instructed participants to search for Waldo before beginning the block of the two search tasks (and therefore sometimes well after the first recordings). This procedure was used to avoid biasing spontaneous gaze shifts (Noton and Stark, 1971) that could occur in forbidding participants to search for Waldo in the free-viewing task. Overall, the study was not tiring because participants switched from the standing position to the seated position about every two minutes to perform two short trials of 40 sec in each condition. Before the first trial, participants took their shoes off and the light was turned off.

Preparation and choice of the dependent variables

The first 7.5 sec of data in each trial (COP, head, upper back, lower back, eye displacements) were not analyzed. Some data of the eye tracker were not available because the eye tracker recorded "0-value" each time participants blinked or had too large pupil dilation (caused by the light turned off). Trials with more than 20% of "0-value" were not considered for analysis. The trials in which Waldo was found were removed before performing statistical analyses for eye and COP/postural displacements. Indeed, the trials had stopped before the end (once Waldo was found) and there were not as many data in these trials as in other trials.

For head, upper back, lower back and COP linear displacements, the range (R), standard deviation (SD) and mean velocity (V) on the mediolateral (ML) and anteroposterior (AP) axes were calculated. For lower back, upper back, head as well as eye angular displacements, the R, SD and V were calculated in the yaw (left/right) and pitch (up/down) directions.

The distinction between linear and angular displacements is important at the theoretical and practical levels. Head, upper back, lower back and COP *linear* displacements corresponded to postural (head, upper back, lower back) sway and/or COP sway to discuss more or less sway, as conventionally cited in the literature reports. Eye, head, upper back, lower back and COP *angular* displacements corresponded to eye and body rotations to perform the task, i.e. how eye and body coordinated their displacements to perform the task. Rotations of the head and/or body, in complement to eye rotations could be found in our study as the images were greater than 15° (Proudlock and Gottlob 2007).

The performance to find Waldo was analyzed in counting the number of correct (Waldo found) and incorrect findings (another personage found).

Statistical analyses

Box plots were used to identify the presence of extreme outliers (more than two SD outside the quartiles) for each variable in each trial. Each outlier was cancelled, as recommended by (Tabachnick B. & Fidell, 2006, pp. 76-77, 92, 100). Normality and homogeneity of variance were assessed with Wilk-Shapiro test and Mauchly test, respectively. Two-ways analyses of variance (ANOVAs, with visual tasks and positions as independent variables) were performed on the various dependent variables ($p<0.01$). These ANOVAs were performed either with the three visual tasks for COP/postural linear and angular displacements or only with the free-viewing and search tasks for dependent variables related to eye movements. Post-hoc Newman-Keuls were used to better understand main effects of visual tasks and also visual task by position interaction effects. In this later situation, six contrasts were performed to specifically assess main effects of visual tasks separately in both seated and standing positions ($p<0.01$). All analyses were performed with Statistica 10 software (Statsoft Inc., Tulsa, OK, USA).

Results of study 1

Performance in the search task

A total of 128 search task trials were performed and Waldo was found only in 17 of them (11 correct and 6 incorrect findings). Hence, Waldo was found correctly 17.2% of the time[1]. There was no difference in finding Waldo between the seated (5 correct and 3 incorrect findings) and standing (6 correct and 3 incorrect findings) positions. Overall, participants correctly found Waldo 15.63% of the time seated and 18.75% of the time standing. The chi-square to compare the number of correct/incorrect answers when sitting vs. when standing was not significant ($\chi^2(1)=0.86$, $p>0.05$). The confidence score to have found Waldo correctly was 3.81±1.19 seated and 3.88±1.27 standing.

ANOVAs for linear and angular displacements of the body

The main effects of position were significant in all ANOVAs with linear and angular variables ($F_s(1,32)>10.87$, $p<0.01$, $\eta^2>0.23$) except in three ones, i.e. for COP V_{AP}, lower back V_{AP} and lower back V_{yaw}, *ns*. The significant ANOVAs showed that young adults exhibited significantly larger displacements (COP, lower back, upper back, head in the AP, ML, yaw and pitch directions) when standing than when sitting.

For COP/postural linear displacements, there were a greater occurrence of significant visual task by position interaction effects than significant main effects of task. Table 1 shows that participants moved their COP/body in the same manner in free-viewing and searching than in fixation when sitting. In contrast, in the standing position, all contrasts in Table 1 showed that participants swayed significantly less in searching than fixation. Moreover, more than 50% of the contrasts showed that participants swayed significantly less in free-viewing than fixation (Table 1).

For body angular displacements, there were no significant visual task × position interaction effects, *ns*. The two significant main effects of task in Table 2 showed that participants rotated their head significantly more in searching than in fixation in both yaw and pitch directions. Participants also rotated their head more in searching than in free-viewing for SD_{yaw} (Table 2). Overall therefore, participants

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[1] Waldo was present only in half of the trials and thus in 64 trials.

rotated their head more in searching than in both other tasks but still swayed less in searching than in both other tasks.

Insert Tables 1 and 2 about here

Selection, choices and analyses for eye movements

Overall, 87.33% of the eye movement time-series contained more than 80% of valid data. The percentage of valid data was higher in the remaining 295 files as it reached 94.43±5.33%.

In all ANOVAs performed, only one main effect of task was significant, i.e. for the variability of eye movements in the left/right direction larger in searching (8.16°±0.45°) than free-viewing (7.39°±0.47°) ($F(2,62)=13.10$, $p<0.01$, $\eta^2=0.31$). No main effects of position and no visual task × position interaction effects were significant, *ns*.

Discussion of study 1

We found that participants performed the search task as well when standing and when sitting although this search task was extremely challenging. Moreover, postural control was better when performing the search task than the two other control tasks. Both results are unexpected based on the main model of limitation of attentional resources. They are also unexpected based on the U-shaped nonlinear interaction model as, again, our search task was extremely challenging (cf. Bonnet and Baudry 2016 for more detailed explanation).

We did not validate our main hypothesis that task performance could be better when standing than when sitting. Also, the alternative hypothesis was not validated as participants did not rotate their body segments more when standing than when sitting. Still indirectly yet, participants rotated their head more in searching than in both other tasks when standing. Moreover, they did not rotate their body less when sitting than when standing although they were more stable when sitting than when standing.

Transition to Study 2

One shortcoming of Study 1 is that there were not enough changes in task performance with only one Waldo per trial, and only in half of the trial, to find significant difference in task performance between the seated and standing positions. Moreover, the most important trials – when Waldo was found – were removed from the analyses (see Methods). For these reasons, Study 2 replicated Study 1 in including four Waldos in each image per search task. We discuss all results of Studies 1 and 2 together in the general discussion.

Methods of study 2

16 healthy students (8 females/8 males; age: 20.3±1.4 years; bodyweight 65.5±9.8 kg; height: 170.6±8.9 m) from the University of Lille were included in Study 2. This Study 2 was similar to Study 1 except for five aspects. Firstly, before coming to the study, participants knew they would try to search Waldo in some trials. Secondly, four same Waldos were copied and pasted in the full image in each trial in the search task. This procedure allowed us to better discriminate task performance to find Waldo (not just found vs. not found, but how many times they were found). Third, participants performed the same six tasks as in Study 1 but there were three trials per tasks and each trial lasted 43 sec. Fourth, participants held a mouse in their hand and click on a specific button each time they had located one Waldo. Fifth, the black cross was projected in the middle of the circle only for the 3 first sec in each trial.

Results of study 2

Performance in the search task

Waldo was searched in 384 trials and found 170 times (157 correct and 13 incorrect findings). Hence, Waldo was found correctly 40.9% of the time. There were some differences in finding Waldo when sitting

(88 correct and 8 incorrect findings) and when standing (69 correct and 5 incorrect findings). Overall, participants correctly found Waldo 45.83% of the time when sitting and 35.94% of the time when standing but the ratio correct findings/total findings was lower when sitting (91.67%) than when standing (93.24%). The chi-square to compare the number of correct/incorrect answers when sitting vs. when standing was not significant ($\chi^2(1)=0.70$, $p>0.05$). The confidence score to have found Waldo correctly was 4.54±0.85 when sitting and 4.37±1.03 when standing.

At the end of the free-viewing block of trials, participants were asked whether they had searched for it or for anything else during both free-viewing tasks. Participants explained that they did not search for anything, as instructed in this second study.

ANOVAs for linear and angular displacements of the body

The main effects of position were significant in all ANOVAs with linear and angular variables ($F_s(1,15)>12.39$, $p<0.01$, $\eta^2>0.31$) except eight ones, i.e. for COP V_{AP}, head SD_{ML}, lower back SD_{ML}, head SD_{yaw}, upper back SD_{yaw}, lower back SD_{yaw}, lower back V_{yaw} and lower back V_{pitch}, *ns*. The significant ANOVAs showed that young adults exhibited significantly greater linear and angular displacements when standing than when sitting. Overall, for the main effects of position, the results were similar to Study 1.

The significant visual task × position interaction effects and main effects of visual tasks showed that, participants moved in the same manner in the three visual tasks when sitting (*ns* between contrasts at all time, Table 3). These results also showed that participants moved differently in free-viewing and/or searching than in fixation when standing (Table 3). Participants swayed significantly less and slower in searching than fixation. Additionally, participants swayed with lower amplitude but they also swayed faster in free-viewing than fixation condition (Table 3). Overall, the results were a little bit different than in Study 1 with less significant visual task × position interaction effects but more main effects of visual task.

For body angular displacements, two contrasts were significant when sitting (Table 4), i.e. for head SD_{yaw} and head SD_{pitch}. These results concerned the amplitude of head displacement and showed that the seated participants rotated their head larger in searching that fixation in both yaw and pitch directions (Table 4). Also, when sitting, participants rotated their head more in free-viewing that fixation only in the pitch direction (Table 4). In the standing position, participants rotated their head larger in free-viewing that in both other tasks in the pitch direction. In Table 4, two other contrasts were significant and concerned the velocity of head and upper back displacements (Table 4). Both results showed that head V_{yaw} and upper back V_{yaw} were significantly slower in searching than in both free-viewing and fixation when standing and not when sitting. The result was stronger for head V_{yaw} than upper back V_{yaw} because the visual task × position interaction effect was significant only for head V_{yaw} (Table 4). Overall therefore, the results in body angular displacements were different than in Study 1: i) participants rotated their head more when sitting than when standing, more so in searching than in free-viewing; ii) when standing, participants did not rotate their head more in searching than in free-viewing but rotated it slower.

Insert Tables 3 and 4 about here

Selection, choices and analyses for eye movements

Overall, 92.78% of the eye movement time-series contained more than 80% of valid data. The remaining 254 files contained 95.27±4.69% of valid data.

In all ANOVAs performed, only one main effect of position was found significant. This effect showed faster up/down eye movements standing (2.81±1.22) than seated (2.54±1.18) ($V_{up/down,}$ $F(1,15)>10.45$, $p<0.01$, $\eta^2>0.30$). No main effects of visual task and no visual task × position interaction effects were significant, *ns*.

General discussion

In the present study, we tested whether task performance could be higher when standing than when sitting (primary hypothesis). We also tested if task performance could be optimum in the standing position because there is relevant behavioral variability – not too low and not too high – to perform and succeed in the task (behavioral variability would be too low when sitting; secondary hypothesis). In Studies 1 and 2, the results showed that task performance was as good (and clearly not worse) when standing as when sitting. Consistent with our secondary hypothesis, participants in Study 2 turned their head more when sitting than when standing – supposedly to capture useful information that they could not obtain in the too stable seated position. In both studies and consistent with our third hypothesis, participants swayed less in searching than in free-viewing and/or fixation only when standing and not when sitting. In complement, the results of both Studies 1 and 2 showed that the eyes should be centered in the orbit to perform well in the search task. We explain that participants could perform this eye-centered strategy more easily when standing than when sitting because they swayed more when standing.

Optimization of performance in search tasks

The performance ratio (correct findings/total findings x 100) when sitting and when standing was respectively 62.5% and 66.67% in Study 1 and 91.67% and 93.24% in Study 2. These values did not differ significantly and so our primary hypothesis (better performance when standing than when sitting) was not validated. It is still important to note that task performance was as good when standing as when sitting in our extremely challenging visual task in Studies 1 and 2.

In the literature on postural control, many studies have shown that task performance is similar when standing and when sitting; these involved (i) visual modified stroop tasks (Caron et al. 2020; Straub et al. 2022), (ii) verbal and visuospatial tasks (Dault et al. 2001), (iii) cognitive and skill performance tasks (Rostami et al. 2020; Kang et al. 2021), (iv) Brooks spatial and verbal tasks (Ehrenfried et al. 2003), (v) mental rotating task (Budde et al. 2020) and (vi) auditory-manual tasks (Woollacott and Shumway-Cook 2002; Swan et al. 2004; Huxhold et al. 2006; Lacour et al. 2008; Boisgontier et al. 2013; Stephan et al. 2018; Bayot et al. 2018). Also in the literature on human factors engineering many published studies have shown that the standing position did not deteriorate task performance relative to the seated position in various tasks such as typing, computer mouse use, work-related tasks, memory tasks, reading comprehension, mathematics tasks, creativity etc. (see for reviews and further details, see Karakolis & Callaghan, 2014; Sui et al., 2019). For example, standing did not alter performance in visual tasks such as X-ray baggage screening (Drury et al. 2008) or identifying and correcting misspelled words within a text (Commissaris et al. 2014). Furthermore, standing does not alter performance in perceptual tasks such as information processing or short-term memory (Russell et al. 2016). All these results are clearly not in line with the model of limited attention resources.

Changes in body rotation when standing vs. when sitting

As we did not find an expected better task performance when standing than when sitting, we tested our secondary hypothesis that participants would exhibit more behavioral variability in the search task – and here would engage more body rotation when sitting than when standing – to compensate for too low variability in the sitting position. We only found this effect in study 2 in which participants rotated their head more often when sitting than when standing (Table 4). These results are further discussed after explaining changes in postural sway in the three visual tasks.

Changes in postural sway when standing vs. when sitting

In studies 1 and 2, when participants stood, they swayed significantly less in the search task than in the free-viewing task (Tables 1 and 3). These results thus validated our third hypothesis. In Study 2 as in Study 1, post-hoc tests showed that the significant effects were only caused by a change in COP and postural sway in the standing position and not in the seated position. Therefore, participants reduced their postural sway when standing to optimize task performance in visual search tasks. However, in studies 1 and 2, participants did not change their postural sway in any visual task when sitting (Table 1 and 3). In other words, there was no need for participants to reduce postural sway even further when sitting to optimize task performance. To the best of our knowledge, the contrasted finding that individuals do not reduce their postural sway when sitting but need to do so when standing is novel.

In studies 1 and 2, the reduction of postural sway to perform the search task in the standing position was strong in relation to published reports (Stoffregen et al. 2007; Rougier and Garin 2007; Giveans et al. 2011; Bonnet and Baudry 2016). Indeed, participants still swayed significantly less in the search task than in both other tasks although they rotated their head significantly more than in the free-viewing and/or fixation tasks (Table 2 and 4). We are aware of only one previous study showing a similar finding in a study performed on a large display (Bonnet et al. 2019). It thus means that when standing, participants strongly strengthened their postural control to perform the search task.

An eye-centered strategy as an optimal strategy to succeed in the search task

In Study 1, the results showed that participants preferred rotating their head instead of their eyes to explore the images, in both standing and seated positions and significantly more so in the search task than in the free-viewing task (Tables 2). In Study 2, i) participants rotated their head more (SD_{yaw} and SD_{pitch}) in searching than in fixating both when standing and when sitting (Table 4); ii) participants' eyes did not move differently in both searching vs. free-viewing and in both seated vs. standing positions, except for one single result in study 1 (cf Results section). This eye-head coordination is remarkable as participants needed to sway less in searching than in free-viewing and fixating but still preferred to rotate their heavy head than their light eyes. In adopting such a behavior, participants risked to increase their postural sway while they needed and indeed swayed less in searching than in free-viewing and fixating. Moreover, the eyes can move without any effort but not the head (Land 2004; Franchak et al. 2021). So why did participants need to rotate their head and not their eyes to optimize their task performance to locate Waldos?

A posteriori, we assume that participants may have turned their head instead of their eyes to improve their visual perception and anticipate the forthcoming saccade (Proudlock and Gottlob 2007). They may have tried to maintain their pupil at the center of the orbit to continuously perceive and detect targets in the best manner. Indeed, when the eyes are centered in the orbit, they are best positioned to perceive details because the density of cones is greatest around the fovea (Proudlock and Gottlob 2007). Furthermore, this primary eye position facilitates the acquisition of future visual targets with gaze shifts (Proudlock and Gottlob 2007). To the best of our knowledge, this eye-centered hypothesis has not been discussed in the literature on vision. Vision investigators usually expect participants to move their eyes (rather than their head) to gaze at the target because saccades are extremely rapid (Proudlock and Gottlob 2007). For exception, one recent study showed that young adults increase both head and eye rotations, and especially increased head rotations, in a search and retrieval task than in a free-viewing task while walking in the street (study 2 in Franchak et al. 2021). However, these investigators did not discuss our conceptual eye-centered hypothesis as such. Overall, our results replicated and complemented Franchak et al.'s (2021) study only when standing and exploring small and dense images. It must be borne in mind that our experimental design promoted an eye-centered strategy as participants freely explored very small and complex images. In this context, small gaze shifts could be performed in rotating the head and not in moving the eyes.

The validity of models found in the literature on postural control

Our results are clearly not in line with the classical view that performing a dual-task (maintaining the standing position and performing a visual search task) should lead to worse postural control and/or worse task performance than in the control single task (either standing quietly or sitting and performing the search task). As our task was extremely difficult and as participants had to maintain their balance when they stood, investigators in dual-task theories would have claimed to find worse task performance and/or worse postural control, surely never better results. Our two studies showed i) better postural control when performing the search task than the control free-viewing task and/or fixation task and ii) equal task performance – at least not worse – when performing the search task when standing than when sitting. Moreover, our study 2 showed that young adults needed to rotate their head and therefore engage this functional behavioral variability to succeed in the visual search task. When sitting, participants did not only move their eyes but instead engaged head rotation to center their eyes in their orbit to optimize their task performance. Our results are not explainable with the dual-task theories (Schneider and Shiffrin 1977; Shiffrin and Schneider 1977; Navon and Miller 1987; Woollacott and Shumway-Cook 2002; Schneider and Chein 2003; Lacour et al. 2008; Bayot et al. 2018; Petrigna et al. 2019).

Our results are also not in line with the U-shaped nonlinear interaction model although investigators sustaining this model assume that a dual task can be performed with more automatic processes than a single task (Huxhold et al. 2006; Lacour et al. 2008). In fact, by definition with its U-shaped form, this model can only sustain better task performance when the dual task is very easy but it still assumes worse task performance when the dual task is hard (Bonnet and Baudry 2016; Bonnet et al. 2017). In our study, the search task was extremely hard with a high level of failure to find Waldo. In our study, this U-shaped nonlinear interaction model would have expected worse results when standing than when sitting. One problem with this model is that it is not adequate in terms of energy and evolution (natural selection), as we explained in Bonnet and Baudry (2016). Indeed, it assumes that postural control is more cognitively demanding, i.e. it is less automatic, when humans do not do anything in the standing position – in quiet stance – than when they perform a dual task (Bonnet and Baudry 2016). Why would the brain use a complicated non-automatic process to control posture when individuals do not do anything and not a simplified, less attentionally demanding and available automatic process? Usually, human functional system employs the principle of minimizing energy expenditure to perform any task (Riccio and Stoffregen 1988; Bonnet and Despretz 2012). The central nervous system is involved in minimizing energy expenditure to maintain postural control (Hur et al. 2019). Consistently, Houdijk et al. (2009) found significant correlations between the quantity of center of pressure sway and energy consumption measured with an open circuit respirometry system; the larger participants swayed, the more they expended energy to control their balance. Furthermore, Houdijk et al. (2015) showed that the metabolic cost could be an optimization criterion for the central nervous system to control balance. In other words, the brain should not use a complicated non-automatic and energy consuming process to control posture when individuals do not do anything. Cautiously, the U-shaped nonlinear interaction model is a well validated model, sustained by many studies (Huxhold et al. 2006; Palluel et al. 2010; Bucci et al. 2013; Legrand et al. 2013; Haid and Federolf 2019) and could therefore be relevant in many other experimental contexts than in our study.

Summary and limitations

The present research had some limitations. Firstly, the validity of our initial hypothesis was only tested in healthy young adults. We did not claim and did not test this hypothesis with older adults and/or patients with impairments in vision, posture and/or attention. Secondly, the validity of our initial hypotheses (better performance when standing) was only tested in visual tasks. We assume that visual tasks are best to test this hypothesis as the eyes need to move and researchers can record these motions and contrast them with body motions. Our hypothesis could still be tested and validated in other sensory interaction with the environment (e.g. auditory localization task) but with less powerful results as we would not be able to measure ‘movements of the ears’. Our hypothesis could be tested and validated in two motor tasks (e.g. standing and balancing a stick on a finger). Thirdly, the present studies were limited because we cannot know whether higher behavioral variability and/or better attention allowed participants to perform the challenging search task as well when standing and when sitting. In fact, some investigators already discussed that the level of alertness and arousal could be better when standing than when sitting (Ebara et al. 2008; Barra et al. 2015), especially if participants are tired (Caldwell et al. 2003). Future research should dissociate the beneficial effects of standing vs. swaying on task performance in testing relations between task performance and postural sway.

The key message of the present studies is that the standing position and the associated postural sway should be seen as positive and not as negative factors - at least for healthy adults in situations with no perturbation. Postural variability could be beneficial for performance in visual search tasks. The present study was the first to test this hypothesis and to generate supporting evidence in Study 2. Overall, we suggest that for healthy, young adults, postural sway in the standing position should be viewed as (i) “free” access to the information[2] required for success in a visual search task, and (ii) a way of enriching visual stimulation compared to a restrained condition (such as the seated position). In our view, postural sway is a form of exploratory activity that can facilitate, instead of deteriorate, task performance in visual tasks. Other investigators already confirmed this statement in affordance studies, i.e. when participants had to decide whether they could perform/succeed in an activity or not (e.g. Mark et al. 1990; Palatinus et al. 2013, 2014; Doyon et al. 2021; Hajnal et al. 2022). In healthy, young adults, the increased head rotation observed in both studies in both the standing and sitting positions should be considered as a sign of the functional eye-head coordination for attaining the information required for success and not as a sign of limited or divided attentional resources. In fact, the results showed a new type of eye-head strategy (the eye-centered hypothesis) in Studies 1 and 2 using small and extremely dense images. Overall, postural sway in the standing position may facilitate – rather than impair – perception, action, attention, and even cognition.

Declaration

Conflict of interest

None

Acknowledgment
None

Data availability statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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[2] This expression means that postural sway moves the eyes in space with no effort as individuals do not decide to sway or do not sway by will. Hence, postural sway allows the eyes to explore the visual environment without constraining individuals to intentionally move their eyes and/or rotate their head to do so. When standing, this free exploration is tiny but it still occurs at all time.

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Table 1. Significant main effects of visual tasks (fixation, free-viewing, search) and visual task by position interaction effects for linear movement of the center of pressure (COP), head, upper back and lower back movements in the two-way ANOVAs. In the three visual tasks, the participants either performed a fixation task or explored images of the puzzle for Children called “where is Waldo”, either with no specific goal (free-viewing task) or in trying to locate Waldo. The participants performed these three tasks either in the seated or upright position. The table shows the name of the variables (columns) and the mean±standard deviation of each variable in each task, results of the ANOVA (lines). Important is to recall that the main effects of position were not shown as they were significant in almost all analyses (cf. text). Post-hoc Newman-Keuls were performed and significant contrasts are shown by (*), (+) and (-). (*) shows a significant difference between the search tasks and the fixation tasks. (+) shows a significant difference between the search tasks and the free-viewing tasks. (-) shows a significant difference between the free-viewing tasks and the fixation tasks. The *p*-value was set at $p<0.01$.

Linear COP/body (head, upper back, lower back) variables	Fixation seated	Free-viewing seated	Search seated	Fixation upright	Free-viewing upright	Search upright	Main effect of visual	Task by position interaction effect
COP SD_{AP} (cm)	0.37±0.03	0.34±0.01	0.36±0.02	1.27±0.10 (*,-)	1.12±0.09 (-)	1.00±0.06 (*)	$F(2,62)=5.52$, $\eta^2= 0.13$	$F(2,62)=6.56$, $\eta^2=0.15$
Head SD_{AP} (cm)	0.07±0.01	0.09±0.01	0.09±0.01	0.36±0.03 (*)	0.35±0.03	0.28±0.02 (*)	*ns*	$F(2,62)=5.61$, $\eta^2=0.15$
Head SD_{ML} (cm)	0.07±0.01	0.09±0.01	0.09±0.01	0.33±0.03 (*)	0.31±0.02	0.31±0.02 (*)	*ns*	$F(2,62)=6.16$, $\eta^2=0.17$
Upper back SD_{AP} (cm)	0.06±0.01	0.07±0.01	0.07±0.01	0.36±0.03 (*,-)	0.35±0.04 (-)	0.34±0.04 (*)	*ns*	$F(2,62)=6.23$, $\eta^2=0.16$
Upper back SD_{ML} (cm)	0.06±0.01	0.07±0.01	0.07±0.01	0.39±0.04 (*)	0.38±0.04	0.33±0.03 (*)	*ns*	$F(2,62)=6.55$, $\eta^2=0.17$
Lower back SD_{AP} (cm)	0.02±0.00	0.02±0.00	0.02±0.00	0.26±0.02 (*,-)	0.23±0.02 (-)	0.24±0.03 (*)	$F(2,62)=5.46$, $\eta^2= 0.15$	$F(2,62)=5.51$, $\eta^2=0.15$
Lower back SD_{ML} (cm)	0.01±0.00	0.01±0.00	0.01±0.00	0.28±0.03 (*,-)	0.24±0.02 (-)	0.21±0.02 (*)	$F(2,62)=8.53$, $\eta^2= 0.20$	$F(2,62)=9.50$, $\eta^2=0.22$

Note. The dependent variables were the range standard deviation (SD) and mean velocity (V). For SD and V, the variables are shown on the anteroposterior (AP) and mediolateral (ML) axes.

Table 2. Significant main effects of visual tasks (fixation, free-viewing, search) for angular movement of the head, upper back and lower back movements in the two-way ANOVAs. The definition of the tasks and columns is described in the legend of Table 1. The main effects of position were not shown as they were significant in almost all analyses (cf. text). Hence, the mean±SD of the variables in the three visual tasks showed averages in both seated and upright positions. Post-hoc Newman-Keuls were performed and significant contrasts are shown by (*), (+) and (-) as in Table 1.

Angular body (head, upper back, lower back) variables	Fixation tasks	Free-viewing tasks	Search tasks	Main effect of visual task
Head SD_{yaw} (°)	0.93±0.13 (*)	1.04±0.15 (+)	1.32±0.16 (*,+)	$F(2,62)=9.98$, $p<0.01$, $\eta^2=0.22$
Head SD_{pitch} ($°.s^{-1}$)	0.47±0.03 (*)	0.53±0.05	0.62±0.05 (*)	$F(2,62)=8.91$, $p<0.01$, $\eta^2=0.19$

Note. The dependent variables were the standard deviation (SD), mean velocity (V) and ellipse area. For SD and V, the variables are shown in the yaw (left/right) and pitch (up/down) directions.

Table 3. Significant main effects of visual tasks (fixation, free-viewing, search) and visual task by position interaction effects for linear movement of the center of pressure (COP), head, upper back and lower back movements in the two-way ANOVAs. In the three visual tasks, the participants either performed a fixation task or explored images of the puzzle for Children called “where is Waldo”, either with no specific goal (free-viewing task) or in trying to locate four Waldos. The participants performed these three tasks either in the seated or upright position. The table shows the name of the variables (columns) and the mean±standard deviation of each variable in each task, results of the ANOVA (lines). Important is to recall that the main effects of position were not shown as they were significant in almost all analyses (cf. text). Post-hoc Newman-Keuls were performed and significant contrasts are shown by (*), (+) and (-). (*) shows a significant difference between the search tasks and the fixation tasks. (+) shows a significant difference between the search tasks and the free-viewing tasks. (-) shows a significant difference between the free-viewing and the fixation tasks. The *p*-value was set at $p<0.01$.

Linear COP/body (head, upper back, lower back) variables	Fixation seated	Free-viewing seated	Search seated	Fixation upright	Free-viewing upright	Search upright	Main effect of visual	Task by position interaction effect
COP SD$_{AP}$ (cm)	0.09±0.00	0.09±0.00	0.10±0.01	0.51±0.04 (*,-)	0.40±0.02 (-)	0.40±0.02 (*)	$F(2,30)= 6.88$, $\eta^2=0.27$	$F(2,62)= 6.07$, $\eta^2=0.25$
Head SD$_{ML}$ (cm)	0.13±0.02	0.15±0.01	0.21±0.02	0.21±0.02	0.18±0.01	0.18±0.01	*ns*	$F(2,62)=6.42$, $\eta^2=0.26$
Head V$_{AP}$ (cm.s^{-1})	0.16±0.01	0.17±0.01	0.16±0.01	0.45±0.02 (-)	0.47±0.02 (-)	0.45±0.02	$F(2,30)=5.51$, $\eta^2=0.21$	*ns*
Lower back V$_{AP}$ (cm.s^{-1})	0.05±0.00	0.05±0.00	0.05±0.00	0.163±0.01 (*)	0.18±0.01 (+)	0.159±0.01 (*,+)	$F(2,30)=7.93$, $\eta^2=0.27$	*ns*

Note. The dependent variables were the range (R), standard deviation (SD) and mean velocity (V) shown on the anteroposterior (AP) and mediolateral (ML) axes.

Table 4. Significant main effects of visual tasks (fixation, free-viewing, search) and visual task by position interaction effects for angular movement of the head, upper back and lower back movements in the two-way ANOVAs. The definition of the tasks and columns is described in the legend of Table 1. The main effects of position were not shown as they were significant in almost all analyses (cf. text). Post-hoc Newman-Keuls were performed and significant contrasts are shown by (*), (+) and (-) as in Table 1.

Linear COP/body (head, upper back, lower back) variables	Fixation seated task	Free-viewing seated task	Search seated task	Fixation upright task	Free-viewing upright task	Search upright task	Main effect of visual task	Task by position interaction effect
Head SD_{yaw} (°)	0.52±0.06 (*)	0.66±0.07	0.90±0.09 (*)	0.61±0.06	0.76±0.07	0.87±0.10	*F*(2,30)=8.97, η^2=0.27	*ns*
Head SD_{pitch} (°)	0.25±0.02 (*,-)	0.32±0.03 (-)	0.32±0.02 (*)	0.35±0.03 (-)	0.48±0.04 (-,+)	0.40±0.02 (+)	*F*(2,30)= 8.01, η^2=0.27	*ns*
Head V_{yaw} ($°.s^{-1}$)	0.30±0.02	0.32±0.02	0.32±0.02	0.55±0.04 (*,-)	0.57±0.04 (-,+)	0.53±0.04 (*,+)	*F*(2,30)= 7.88, η^2=0.26	*F*(2,30)= 9.23, η^2=0.28
Upper back V_{yaw} ($°.s^{-1}$)	0.25±0.01	0.25±0.01	0.25±0.01	0.37±0.01 (*,-)	0.38±0.01 (-,+)	0.36±0.01 (*,+)	*F*(2,30)= 7.90, η^2=0.26	*ns*

Note. The dependent variables were the standard deviation (SD), mean velocity (V) and ellipse area. For SD and V, the variables are shown in the yaw (left/right) and pitch (up/down) directions.

Figure captions

Figure 1. Two images shown to participants. For the initial 7.5 sec (in Study 1), participants had to look at the black cross at the center of the image. The central cross (subtending a visual angle of 2°) is represented in Figure 1. In the fixation task, the black cross did not disappear and participants had to look at it for the duration of the trial (40 sec). In the search and control free-viewing tasks, the black cross disappeared after 7.5 sec and participants were free to look at the image (subtending a visual angle of 22°) as they liked. In the search task, they had to search where the personage Waldo was located in that image. In the control free-viewing task, participants simply had to look at the image with no specific goal.