Interaction between eye and body movements to perform visual tasks in upright stance

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Running head: postural control in precise visual tasks

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Abstract
Synergistic interactions between visual and postural behaviors were observed in a previous study during a precise visual task (search for a specific target in a picture) performed upright as steady as possible. The goal of the present study was to confirm and extend these novel findings in a more ecological condition with no steadiness requirement. Twelve healthy young adults performed two visual tasks, i.e. a precise task and a control task (free-viewing). Center of pressure, lower back, neck, head and eye movements were recorded during each task. The subjective cognitive workload was assessed after each task (NASA-TLX questionnaire). Pearson correlations and cross-correlations between eyes (time-series, characteristics of fixation) and center of pressure/body movements were used to test the synergistic model. As expected, significant negative Pearson correlations between eye and head-neck movement variables were only observed in searching. They indicated that larger precise gaze shifts were correlated with lower head and neck movements. One cross-correlation coefficient (between COP on the AP axis and eyes in the up/down direction) was also significantly higher, i.e. stronger, in searching than in free-viewing. These synergistic interactions likely required greater cognitive demand as indicated by the greater NASA-TLX score in searching. Moreover, the previous Pearson correlations were no longer significant after controlling for the NASA-TLX global score (thanks to partial correlations). This study provides new evidence of the existence of a synergistic process between visual and postural behaviors during visual search tasks.

1. Introduction

In ongoing life, individuals use their eyes to explore their environment, to interact with other individuals (…). When they stand upright, they sway continuously in a stochastic manner (Yamamoto et al., 2015). It could be asked how individuals can perform precise gaze shifts in such an unstable position.

Recently, we proposed a model of postural control (Bonnet & Baudry, 2016a) suggesting that the central nervous system (CNS) should control *relations* between eye movement on one hand and center of pressure (COP) and/or body movements on the other hand to succeed in precisely shifting gaze when standing upright. At the theoretical level, the synergistic model is concerned with the complementarities between eyes and center of pressure and/or body movements[1] (referred to as eye-COP/body movement further down). It tests if and how the visual and postural systems can work together. Noticeably, the synergistic model is not concerned with, or does not test, the coordination between eye and body movements (e.g. Anastasopoulos, Ziavra, Hollands, & Bronstein, 2009; Hollands, Ziavra, & Bronstein, 2004). It is also not concerned with muscular activities as it is usually the case in synergistic studies (e.g. Krishnamoorthy, Scholz, & Latash, 2007; Torres-Oviedo & Ting, 2010). Thus, the respective literature in both fields of research cannot be used to test the synergistic model.

In Bonnet and Baudry (2016a) and Bonnet et al. (2017), a first main prediction of the synergistic model is that young, healthy adults should exhibit significant and functional relations between eye and COP/body movements. Functional relations refer to relations that help to succeed in the task performed. Bonnet et al. (2017) suggested that functional relations should consist of negative Pearson correlations between eye and COP/body movement. Indeed, it definitely may be useful for individuals to better control – to reduce – their postural sway when trying to precisely reach a far target than a close one. Accordingly, the model assumes that the further away the target to reach is, the stronger postural control should become to succeed in precise gaze shifting. In this sense, negative Pearson eye-COP/body movement correlations are considered as stabilizing relations. A second main prediction of the synergistic model is that a triangular relation between eye, COP/body movement and cognition should exist (Bonnet & Baudry, 2016a). Indeed, precise visual tasks should require higher subjective cognitive involvement than imprecise tasks. Indeed, the brain should be responsible to link eye and COP/body movement to succeed in precisely shifting gazes. In imprecise visual tasks, there should be no need to increase the subjective cognitive involvement because relations between eye and COP/body movement are not required in these tasks[2]. Indeed, there is no specific target to reach and each saccade and fixation is thus successful.

So far, published studies compared postural sway in various visual tasks (for a review, cf. Bonnet & Baudry, 2016b), testing synergistic relations between motor variables (e.g. Krishnamoorthy, Latash, Scholz, Zatsiorsky, 2003; Latash, Levin, Scholz, & Schöner, 2010) or between eye movement variables (e.g. Proudlock & Gottlob, 2007) but not between eye and COP/body movements. Only Bonnet et al. (2017) tested the synergistic model. In this former study, 16 healthy, young adults performed a precise task in which they had to search to locate a target in an extremely dense image. They also performed an imprecise, control, task in which they simply looked at a similar image with no goal. They performed this study as stiff as possible. As expected, only significant negative eye-body movement relations were found in the precise task. These significant correlations specifically concerned the amplitude of head and neck movement, in terms of standard deviation and range, and not the velocity of movement. They also concerned the characteristics of fixation and not the characteristics of saccade.

[1] The term ‘synergy’ thus refers to the complementary work performed by the eye-COP/body movements to reach a target with the eyes. It only concerns these two kinds of movement, how they interact.

[2] For more details, see Bonnet et al. (2017).

Furthermore, participants needed to reduce the amplitude of their head and neck movements to be able to extend their precise fixations further. All the significant negative relations disappeared once the subjective cognitive involvement was controlled (evaluated by the National Aeronautics and Space Administration Task Load Index questionnaire; i.e. NASA-TLX; Hart & Staveland, 1988). Moreover, the NASA-TLX global score was significantly higher in searching than free-viewing (Bonnet et al., 2017). All these results thus validated the synergistic model.

The synergistic model is a recent model only validated once in Bonnet et al. (2017). Therefore, it needs more validation, confirmation, in other experimental conditions, with an updated methodology and analyses. In the present study, we tested healthy, young adults in unrestrained stance conditions to extend the validity of the model. These stance conditions were more ecological because individuals usually stand quiet in everyday life, rarely as stiff as possible. Based on our previous work (Bonnet & Baudry, 2016b), we hypothesized that the absence of the stiffness instruction should not contradict the synergistic model. Our primary hypothesis was to find significant negative correlation specifically between the characteristic of eye fixation and the amplitude of head and neck movements in the search task, as in Bonnet et al. (2017). As we could not be sure whether the relevant eye-COP/body movement variables could be exactly identical as in our former study, we performed secondary exploratory analyses with additional dependent variables to test our primary hypothesis more extensively. These secondary analyses tested significant negative correlation between the eye and COP/body movements in the search task and non-significant (*ns*) correlation between the eye and COP/body movements in the free-viewing task. Our third hypothesis was the lack of significant correlation between the eye and COP/body movements in the search task when the effect of the subjective cognitive involvement was controlled .

2. Experimental procedure

2.1. Participants

Twelve healthy students (6 males, 6 females) from the University of Lille were included. Their mean age, bodyweight and height were 20.8 ± 2.3 years, 65.0 ± 9.8 kg and 172.0 ± 9.7 cm, respectively. The study was approved by the ethics committee of the university of Lille and the participants gave their written informed consent to participation.

2.2. Apparatus

A magnetic tracking system (Polhemus Liberty 240/8-8 System, Colchester, VT; 240 Hz) was used to record head, neck and lower back markers. The markers were positioned near the occiput (head marker on a baseball cap), at the seventh cervical vertebra (neck marker) and at the fifth lumbar vertebra (lower back marker, on a chest belt). A dual-top force platform (AMTI, Watertown, MA, USA; 120 Hz) was used to record COP displacement. The position of the feet was standardized with a stance width of 14 cm and a stance angle of 17° (McIlroy & Maki, 1997). This procedure avoided the position of the feet to influence/bias the results. A head-mounted eye-tracker (SensoMotoric Instruments, Teltow, Germany; 50 Hz) was used to record eye movements. A MATLAB script was used to synchronize all devices with the image projected onto the wall.

2.3. NASA-TLX test

A validated French version (Cegarra & Morgado, 2009) of the NASA-TLX (Hart & Staveland, 1988) was used to quantify the subjective cognitive involvement in each task.

2.4. Where is Waldo?

The six images projected to the participants came from a puzzle for children called "where is Waldo" in the USA (Collection Waldo by Martin Handford). In this game, the player had to locate Waldo in the picture. This game is challenging because Waldo is well hidden and difficult to find. Two typical images are shown in Figures 1A and B.

2.5. Experimental tasks

The participants stood on the dual-top platform and could see the experimental images projected in a circle of 22°, 3.40 m ahead of them. They looked at the six images for 60 sec: participants "a" looked at images 1-3 in the free-viewing task and images 4-6 in the search task and participants "b" looked at images 1-3 in the search task and images 4-6 in the free-viewing task, with only one image per trial. An even number of participants performed the study so that the same number of images was watched in both tasks. For each participant, Waldo was present in the three images of the search task but not in the three images of the free-viewing task. In the three images of the free-viewing task, Waldo was replaced by another personage. The change was unnoticeable because Waldo was very little and well hidden in the original pictures.

In all trials, the participants had to fixate on the black cross for the first 10 seconds. The black cross then disappeared and the participants could freely explore the image as they liked (Figures 1A and 1B). In the free-viewing task, they had no specific goal and they knew that Waldo was not present in the image. In the goal-oriented visual task (search), the participants had to find Waldo as best and as quickly as possible. When they had found Waldo, they had to fixate the personage for 5 sec before moving their eyes outside of the image. The trial stopped immediately once the participants had found Waldo. When they had found Waldo, they had to tell us how confident they were of having found the correct personage on a 5-point scale, 5 indicating the highest degree of confidence.

In all trials, the participants were told to relax and keep their hands by the side of their body. They had to avoid voluntary movement unrelated to the task performed (for a definition of the stiffness requirement, cf. Bonnet, 2016).

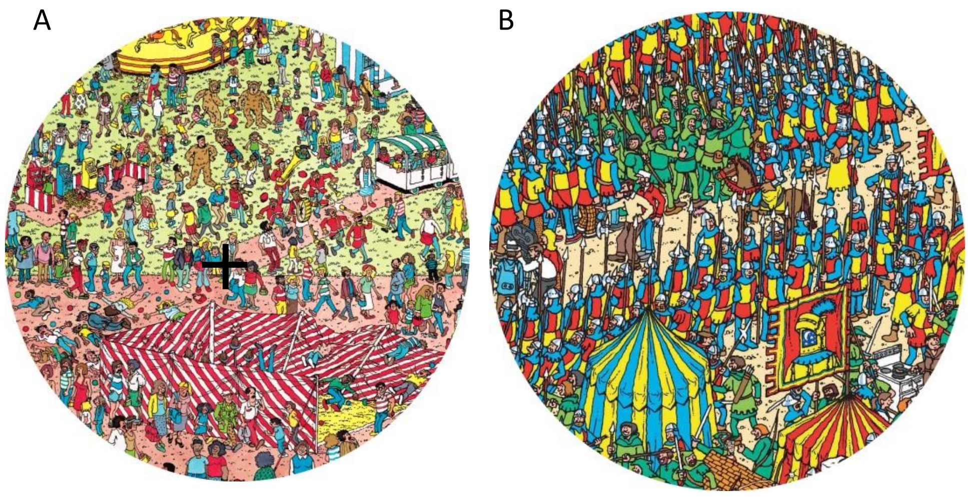

Figure 1. Two of the six images (subtending a visual angle of 22°) showed to the participants in the search and free-viewing tasks. In A), the image shows the black cross at its position the 10 first seconds in each trial. In B), the image does not have the black cross anymore (for the last 50 seconds in each trial). In the free-viewing task, once the black cross disappeared (after the first 10 seconds), the participants were free to look at the image randomly. In the search task, once the black cross disappeared, the participants had to search for and find Waldo in the image.

2.6. Procedure

After explanation of the various tasks and instructions, the participants were invited to look at the French version of the NASA-TLX (Cegarra & Morgado, 2009) and to read it in order to understand how to fill this questionnaire out. Then, the participants stood with their bare feet on the force platform. The room lighting was turned off so that the participants could clearly see the images. These ceiling lights were indeed close to the panoramic display and lowered too much the visibility of the display. The participants were not in the dark because a floor lamp was turned on in the back of the room. The tasks were performed one after another in a random order. After finishing each task, the participants sat to fill the NASA-TLX questionnaire. Before beginning each trial in the free-viewing task, the participants were recalled that Waldo was not present in the image and that they should not search for it or for anything else. At the end of each free-viewing trial, it was asked to the participants whether they had searched for Waldo or for anything else during the trial.

2.7. Dependent variables

The visual performance was calculated in the search task. We analyzed failure/success to find Waldo, the time spent to find Waldo and the confidence score. A failure was considered to have occurred when the participants had not found Waldo or when they had fixated on a wrong personage before moving their eyes outside of the circle.

For eye movement data, we analyzed both fixation and time-series characteristics obtained from Begaze (SensoMotoric Instruments). The data files with the characteristics of fixation reported the characteristics of the successive fixations in each trial. These data files only concerned a part of the data recorded in each trial because they did not show the characteristics of saccades and blinks. These data files showed the duration and location of each fixation, one after another. Begaze defined a fixation as an eye position with dispersion lower than 13 px for at least 80 ms. The eye fixation variables were used to know whether the fixations were close to each other or spread out. The number of fixations, their mean duration and the total duration of fixation per trial were also analyzed within each trial as in vision studies (Castelhano, Mack, & Henderson, 2009; Kowler, 2011). The time-series of eye movement were simply two columns of data showing the position of the right eye recorded at 50 Hz. The variables that studied time-series characteristics were concerned with the spatial and temporal characteristics of the eye movement. For both time-series and fixation characteristics, the variables were the range (R), standard deviation (SD), mean velocity (V) of movement or fixation in left/right and up/down directions as well as the path length and ellipse area. The ellipse area variable calculated the characteristics of an ellipse which captured 85 % of eye movements (Latash, Ferreira, Wieczorek, & Duarte, 2002). To distinguish fixation characteristics from time-series characteristics, the subscript 'F' was assigned at the end of each variable related to fixation characteristics (cf. Table 1).

The linear displacements of the COP, head, neck and lower back on the anteroposterior (AP) and mediolateral (ML) axes or across the two axes (path length, ellipse area) were recorded. As for the eye movement, we used R, SD and V, but this time on the AP and ML axes, and also the general path length and ellipse area. The first 10 sec of data – during the fixation of the black cross – were not considered to calculate all these variables.

The subjective cognitive involvement was assessed by the NASA-TLX global score (Cegara & Morgado, 2009; Hart & Staveland, 1988).

The trials in which the participants had found Waldo in searching were not considered for analyses because these trials were shorter than the other ones.

For appropriate analyses in cross-correlations, the data from the force platform and Polhemus systems were resampled at 50 Hz. The mean of the three trials per task for each dependent variable was used for analyses.

The SMI software put 0-values in the eye movement time-series to show the absence of recordings. 0-values could be found during blinks or in case of too large pupil dilatation caused by the light turned off. The computation of our dependent variables did not include these 0-values. All trials with more than 20 % of 0-value were discarded to avoid analyzing trials with less than 80% of existent data.

2.8. Statistical analyses

As already stated in the Introduction, the synergistic model is not concerned with the coordination between eye and body movements. It does not test relations between angular eye movements in relation to angular body movements. Instead, it is concerned with eye movement in relation to postural control. Here, postural control is tested in linear terms with increase or decrease of COP/body movements in upright stance, the traditionally called COP/postural sway. Overall therefore, the synergistic model tests significant relations between eye movements, expressed in angular terms, and COP/body movements, expressed in linear terms. No other study than Bonnet et al. (2017) performed such analysis in the literature reports.

Box plots were used to detect the presence of outliers in all the variables in the tables prepared for analyses. These prepared tables concerned each dependent variable for each trial in each task. In our context, an outlier was defined as an extreme value differing from all other ones and was represented by a star in the box plot. Outliers were the values outside the three box length range from the upper and lower value of the box. When an outlier was detected, we looked at the three values (i.e. each value for each trial) to delete the one that caused the deviant behavior. We recall that the tables prepared for analyses showed the average values of the three trials per task. The final preparation of the tables ready for statistics consisted of calculating the mean value of each dependent variable for each task (mean calculated with no outlier).

The normality of each data set was then verified with the Statistica software. Pearson correlations were used to analyze linear relations between eye and COP/body movement in the search and free-viewing tasks. To test our primary hypothesis, we performed Pearson correlations between the characteristic of eye fixations and head and neck movements in terms of R and SD. These analyses served to know if we could find exactly the same results as in Bonnet et al. (2017). The test of this primary hypothesis was informative to investigate exact consistency across studies. These results were not sufficient, by themselves, to decide whether the synergistic model was validated or invalidated. Indeed, our model did not specify which eye movement variable should be significantly associated which COP and/or body movement variable (cf. Bonnet & Baudry, 2016a). The model only specified general results, i.e. radical change in relations (negative vs. positive) between eye and COP/body movements in precise vs. imprecise visual tasks performed upright. For this reason, we also performed exploratory Pearson correlations to fully explore existing relations between eye and COP/body movements, i.e. to test our second hypothesis. Cross-correlations (between eye and COP/body movement time-series) were used to provide complementary analyses on the relations between eye and COP/body movements.

To test our third hypothesis, partial correlations were used to control for the effect of the NASA-TLX global score on the previous significant Pearson correlations, and only the significant ones. All the correlation analyses (Pearson, partial) were performed separately in both tasks.

An ANOVA for repeated measures was performed on the NASA-TLX global score. The Pearson correlations to test the primary hypothesis were performed at $p<0.05$. The other analyses for the exploration (correlations, ANOVAs) were performed with an adjusted p-value ($p<0.01$) with Statistica 10 (Statsoft Inc. Tulsa, OK, USA). For the exploration analyses, the alpha level was adjusted based on the test of several hypotheses and not on the number of correlations, as suggested by Rubin (2017).

3. Results

3.1. Performance to find Waldo in the search task

In searching, the participants moved their eyes out of the circle 16 times but Waldo was only found correctly 8 times out of 36 trials (success: 22.2%). In the 16 trials, the time spent to find the target was 26.93 ± 12.47 s. Overall therefore, the goal to find Waldo was very difficult.

3.2. NASA-TLX

The ANOVA showed a significant main effect of task for the NASA-TLX global score ($F(2,22) = 14.42$, $p<0.01$; Figure 2). This score was significantly higher in searching than in free-viewing.

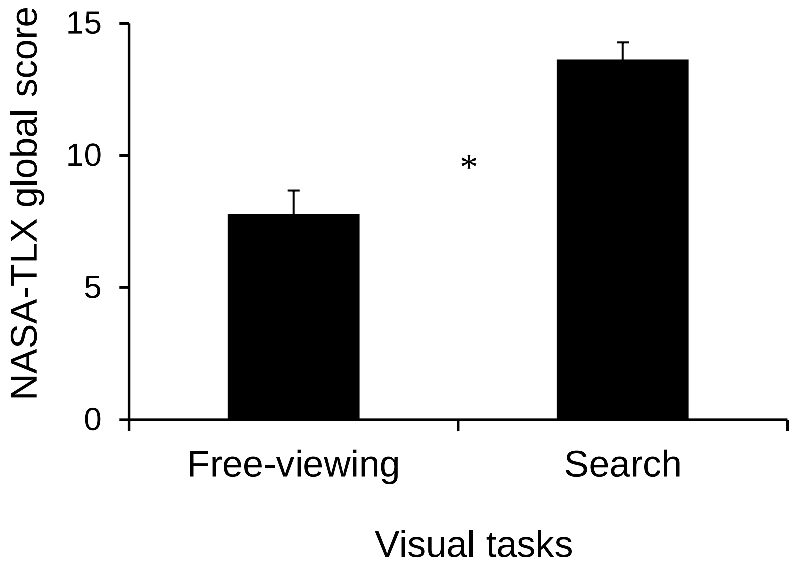

Figure 2. Significant main effect for the NASA-TLX global score (no unit). The two tasks performed were the free-viewing and search tasks (cf. text for more details). * indicate that the NASA-TLX global score was significantly higher in the search task than in the free-viewing task ($p<0.01$). The error bars represent standard error of the means.

3.3. Selection and choices of the data before analyses

Sixteen of the 72 (12 participants × 6 trials) experimental trials were not considered for analyses when the participants had – or thought to have – found Waldo. These trials could not be considered for analyses because the search task ended before the total duration of the trial. In the literature on postural control, it is conventional to compare data from trials that have the same duration. Two other experimental trials were excluded because Waldo was searched in a free-viewing task (based on a question asked to the participants after this task). Ten other visual trials were not considered for analysis because these trials contained more than 20% of 0-values. Eight and two of these trials came from the free-viewing and search tasks, respectively.

Preliminary analyses showed no outlier in the NASA-TLX global score and one outlier in all the final tables of eye movements (tables of data ready for analyses). In all the final tables of COP/postural data, there were 41 and 42 outliers in free-viewing and searching. In other words, there were in average of 1.33 outliers per task in the prepared table of data (prepared for each variable for each trial and for each dependent variable). These outliers were deleted as recommended by Tabachnick and Fidell (2013, pp. 76-77, 92, 100).

Overall, some participants had no data in one or more tasks due to the exclusions. The degrees of freedom were therefore sometimes lower in the Pearson correlations, as shown in Table 1.

3.4. Correlation analyses between eye and COP/body movements

Our first hypothesis was to find significant negative Pearson correlation between the characteristic of eye fixation and the amplitude of head and neck movements in the search task, as in Bonnet et al. (2017). Pearson correlations that tested the primary hypothesis did not show any significant result, p_s>0.05, *ns*.

Our second exploratory hypothesis was to find significant negative Pearson correlation between the eye and COP/body movements in the search task and no such negative correlation in the free-viewing task. In free-viewing and searching, four positive and four significant negative correlations were significant, respectively (Table 1; Figures 3A and 3B).

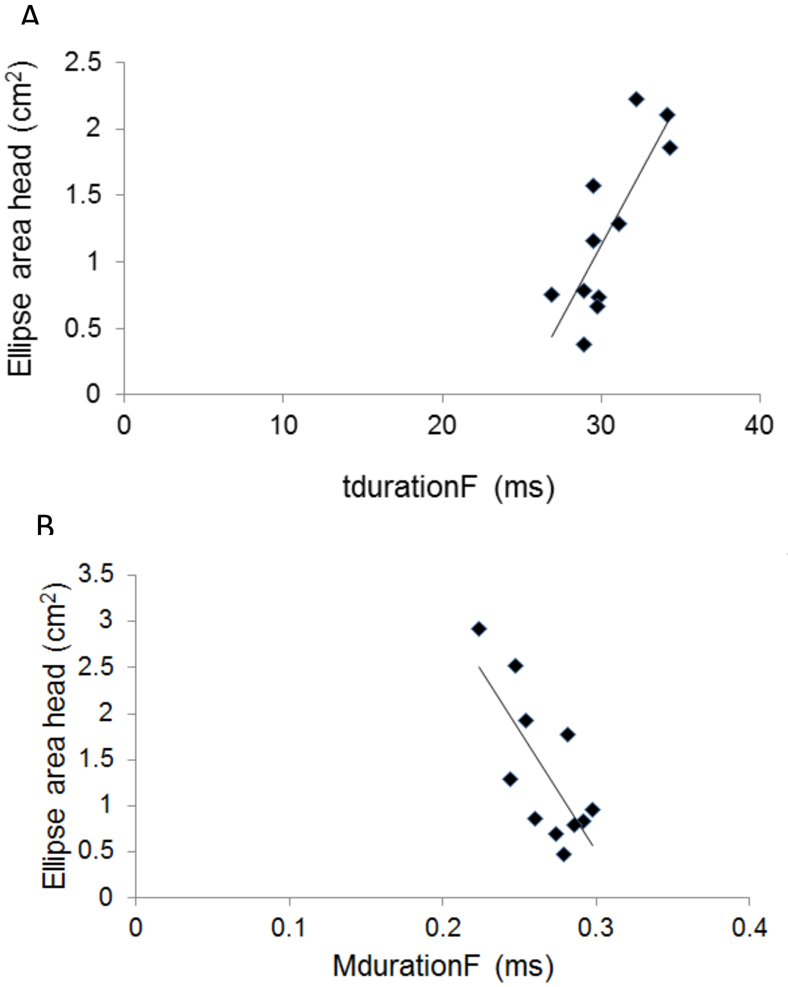

Figure 3. A) Significant Pearson correlation between the total duration of fixation (in milliseconds, ms) and the ellipse area covered by the head during the free-viewing task (area represented in cm^2). B) Significant Pearson correlation between the mean duration of fixation and the ellipse area covered by the head during the search task. The correlations were significant at p<0.01.

Table 1.

Significant correlations (Pearson correlations) between oculomotor behaviors and linear displacement of the center of pressure (COP), head, neck and lower back in the free-viewing and search tasks ($p<0.01$). These eight relations were no longer significant when the influence of the NASA-TLX was controlled (partial correlation, $p<0.01$).

	Free-viewing task	Search task
Characteristics of fixation and COP displacement	NumberF & SDap: $r(12)=0.72$	/
Characteristics of fixation and Polhemus displacement	tdurationF & ellipse area head : $r(11)=0.80$ tdurationF & ellipse area neck: $r(11)=0.81$ tdurationF & ellipse area lower back: $r(10)=0.84$	MdurationF & SDap head: $r(11)=-0.77$ MdurationF & Rap neck: $r(11)=-0.75$ MdurationF & SDap neck: $r(11)=-0.74$ MdurationF & ellipse area head: $r(11)=-0.74$

Note. For the oculomotor behavior, the dependent variables were the number of fixations per trial (NumberF), the total duration of fixation per trial (tdurationF) and the mean duration of fixation per trial (MdurationF). For the COP and markers (head, neck, lower back) displacements, the dependent variables were the standard deviation (SD) amplitude, the range (R) on the anteroposterior (ap) axis and also the ellipse area.

Our third hypothesis was to find a significant influence of the subjective cognitive involvement in the previous significant negative Pearson correlation analyses in the search task. In other words, we expected the four negative Pearson correlations between eye and COP/body movements in Table 1 to become *ns* when controlling for the influence of the subjective cognitive involvement by means of partial correlations. For control purposes, we also performed partial correlations for the four positive Pearson correlations in the free-viewing task. The results showed that the eight former significant Pearson correlations were no longer significant when the NASA-TLX global score was controlled in the partial correlations.

Complementary cross-correlations between eye and COP/body movements tested the second hypothesis. The results showed that one of the eight cross-correlations was significant, i.e. between COP on the AP axis and eyes in the up/down direction ($F(1,10)=9.82$, $p<0.01$). The coefficient was significantly higher in searching (+0.09) than in free-viewing (+0.00).

4. Discussion

Our main objective was to test the validity of the synergistic model of postural control in ecological conditions, i.e. in performing visual tasks upright with no requirement of steadiness. Our primary hypothesis was invalidated because we did not find exactly the same results as in our former study (Bonnet et al., 2017). However our secondary hypothesis was validated because our data show the presence of stabilizing eye-COP/body movement relations in precise visual tasks. In contrast, the control free-viewing tasks did not show similar stabilizing relations. Also as expected, a higher subjective cognitive involvement was significantly related to the stabilizing eye-COP/body movement relations in the precise visual task. One interesting finding is that the present results were quite similar than in Bonnet et al. (2017), thus showing that the results may be consistent across similar studies.

4.1. Existence of stabilizing relations between eye and COP/body movement in the goal-directed search task

Table 1 and Figures 3A and 3B showed contrasted results in searching and free-viewing, i.e. negative and positive correlations between eye and COP/body movement. In searching, the negative coefficients showed that the further the participants moved their eyes to gaze a target, the less they swayed (Figure 3B). These correlations seemed to show a stabilizing behavior because it is generally assumed to be easier to find precise targets in swaying less than in swaying more (Giveans, Yoshida, Bardy, Riley, & Stoffregen, 2011; Rougier & Garin, 2007; Stoffregen, Hove, Bardy, Riley, & Bonnet, 2007). In our study, these negative correlations are remarkable because the target was large (22°) and may have induced head rotations. It is indeed known that gaze shifts greater than 15° are normally accompanied by head movement (Hallett, 1986), which in turn should increase COP and/or body sway, not decrease it (cf., Bonnet & Despretz, 2012). In contrast, the positive correlations between eye and body movements in free-viewing (Table 1; Figure 3A) may be considered as showing destabilizing relations. Indeed, in this instance, the further the eyes moved away, the more the participants swayed in upright stance. Carefully, we are not saying that the participants were unstable in free-viewing but only that they engaged their body in destabilizing-like relations in this task.

Our results found in unrestrained conditions were almost the same as in Bonnet et al. (2017) in restrained conditions. Indeed, in both studies, there were four significant negative and four positive eye-COP/body movement correlations in searching and free-viewing. The significant negative eye and COP/body movement correlations in searching were found at the head and neck levels in both studies. These results seemed stabilizing because the upper part of the body – where the eyes are located – has to be stabilized to enable precise gaze shifts. In the free-viewing task, the positive eye-COP/body movement correlations were found at the COP and lower back level in Bonnet et al. (2017) and at four levels in the present study (COP, lower back, neck, head). These results thus showed more diffuse destabilizing-like relations in the control free-viewing task. All these results validated our general hypothesis in showing that the visual and postural systems needed to be connected to each other to succeed in a precise visual task but not in a non-precise visual task (cf. Bonnet & Baudry, 2016a).

One main difference between the two studies is that the significant eye-COP/body movement correlations were all found with spatial eye movement variables (R and SD of the characteristics of fixation) in Bonnet et al. (2017) and with temporal eye movement variables (mean duration and total duration of fixation, Table 1) in the present study. For this reason, we rejected our primary hypothesis to find exactly the same results in both studies. This finding does not constitute a problem for the validity of the synergistic model, it only showed complementary results between studies. A posteriori, we can suggest that in our previous study, the participants may have controlled spatial head-neck movements because they were specifically required to sway as less as possible. In the present study, the participants may have used temporal eye movement variables because they did not need to care about the spatial characteristics of their head-neck body movements. Instead, they focused on finding the little personage and the more the fixed personage resembled Waldo, the longer they needed to precisely gaze this personage to succeed (cf Table 1). Hence, the fact of stiffening the body or not, and/or to move part of the attention away from the visual tasks had an incidence on the results. Another difference between the two studies is the novel result with the cross-correlation analyses showing that the link between visual and postural time-series was stronger in searching than in free-viewing. The significant cross-correlation coefficient was stabilizing in this relation because eye and COP movements moved in opposite directions. In fact, when the body swayed forward (positively), the eyes moved upward (positively) and vice versa, which is expected when precise fixations have to be performed to discriminate and detect targets. Overall these results also sustain the need of synergistic relations between visual functions and postural control in goal-directed precise tasks. We only discussed the results in our former study (Bonnet et al., 2017) and not any other ones because none of the results published in the literature report tested, or even could be used to test the synergistic model. Indeed, to test this model, both eye and COP/body movements have to be measured in a synchronous manner. Moreover, participants have to freely gaze their environment in both precise and non-precise visual tasks. Both methodological aspects, and especially the second one, are not conventional in published studies in which individuals performed visual tasks (e.g., Legrand et al., 2013; Mitra, Knight & Munn, 2013; Rodriguez et al., 2013). In all these studies, participants were almost never free – at least never completely free – to look when they liked. Hence, the present study is original at the methodological level (both for the visual tasks performed and for the correlation analyses between eye and COP/body movements) and also at the conceptual level (to test the synergistic model).

4.2. Cognitive requirement to link visual and postural variables in both tasks

In searching, the negative correlations required a higher level of subjective cognitive involvement for two reasons. Firstly, the subjective cognitive involvement was significantly higher in searching than in free-viewing (Figure 2). Secondly, the eye-COP/body movement correlations were no longer significant when the subjective cognitive involvement was controlled (Table 1). These results were consistent with our hypothesis and they validated the idea that the brain may be involved to create a synergistic link between the eye and body systems in precise visual tasks. This interpretation is quite important because it shows that the brain can be more involved to succeed in double tasks performed upright – as suggested by the synergistic model (Bonnet & Baudry, 2016a) without being overwhelmed, as suggested by most existing cognitive models of postural control (Lacour, Bernard-Demanze & Dumitrescu 2008; Swan, Otani, Loubert, Sheffert & Dunbar, 2004; Woollacott & Shumway-Cook, 2002). In other words, this finding is remarkable because it shows that the main concept of limitation of attentional resources is not exact by default to understand postural control in double tasks. Instead, it shows that the CNS can be efficient to succeed in tasks performed upright, it shows that the CNS can be – and is – capable of adaptation in upright stance, which is not the general message found in the literature report concerned with dual tasks. Instead, the message highlights the necessity to divide attention because of interference between the two tasks performed simultaneously (e.g., Boisgontier et al., 2013; Swan et al., 2004). The concept of “dual tasks” itself holds the notion of attentional resources that should be divided instead of work in synergistic manner, as we suggest.

In the free-viewing task, all the positive correlations (Table 1) seemed to be linked to the subjective cognitive involvement. These results were unexpected because the free-viewing task should not engage any cognitive involvement. It is indeed considered as a control task in our study. Moreover, these results are counter-intuitive and do not make sense because they would suggest that the CNS specifically increased its cognitive involvement to destabilize the body. We should recall however that the subjective cognitive involvement engaged in free-viewing was significantly lower than in searching, even very low, thus having a minor role, in free-viewing. We can therefore conclude that these significant positive correlations existed but only showed no practically significant relations.

4.3. Perspectives

In summary, the present study validated the existence of stabilizing eye-COP/body movement relations in precise visual searching. The results extended the findings Bonnet et al. (2017) in tasks performed with no steadiness requirement. A first limitation concerns the exploratory character of the secondary analyses, thus limiting their impact. In the future, we will need to validate the present result with focused a priori hypotheses to provide a stronger message. However, important is to mention that the exploratory analysis was also a strength in the present study in validating our initial hypothesis with unknown, unanticipated, relations between eye and body movements (Table 1; Figure 3B). A second limitation is that we only had a small number of participants and that many trials were lost in preparing data for analyses. Future researches should now investigate if significant negative eye-COP/body movement correlations in the search task also can be found in precise visual tasks performed on a large visual display and not only on a small visual display. This research would be appropriate to generalize our findings to large visual explorations more representative of everyday life exploration of our environment in upright stance.

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Declaration of interest

None

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