

1 **Active vision task and postural control in healthy, young adults: synergy and**  
2 **probably not duality**

3  
4 Cédric T. Bonnet<sup>1,\*</sup>

5 Stéphane Baudry<sup>2</sup>

6 <sup>1</sup>Cognitive Science and Affective Science Laboratory, Universities of Lille, CNRS,  
7 France.

8 <sup>2</sup>Laboratory of Applied Biology and Neurophysiology, Université Libre de Bruxelles,  
9 FNRS, Belgium.

10  
11  
12 Running head: testing theories in dual-task paradigms

13  
14 **Abstract**

15 In upright stance, individuals sway continuously and the sway pattern in dual tasks (e.g.,  
16 a cognitive task performed in upright stance) differs significantly from that observed  
17 during the control quiet stance task. The cognitive approach has generated models  
18 (limited attentional resources, U-shaped nonlinear interaction) to explain such patterns  
19 based on competitive sharing of attentional resources. The objective of the current  
20 manuscript was to review these cognitive models in the specific context of visual tasks  
21 involving gaze shifts toward precise targets (here called active vision tasks). The  
22 selection excluded the effects of early and late stages of life or disease, external  
23 perturbations, active vision tasks requiring head and body motions and the combination  
24 of two tasks performed together (e.g., a visual task in addition to a computation in one  
25 head). The selection included studies performed by healthy, young adults with control  
26 and active ó difficult ó vision tasks. Over 174 studies found in Pubmed and Mendeley  
27 databases, nine were selected. In these studies, young adults exhibited significantly  
28 lower amplitude of body displacement (center of pressure and/or body marker) under  
29 active vision tasks than under the control task. Furthermore, the more difficult the active  
30 vision tasks were, the better the postural control was. This underscores that postural  
31 control during active vision tasks may rely on synergistic relations between the postural  
32 and visual systems rather than on competitive or dual relations. In contrast, in the  
33 control task, there would not be any synergistic or competitive relations.

34  
35 **Keywords:** postural control; postural sway; active vision tasks; cognitive models;  
36 young adults

37  

---

  
\* Corresponding author at: Cédric Bonnet, SCALab, Faculté de Médecine, Pôle recherche, 5<sup>e</sup> étage, 1  
place de Verdun, 59045 Lille cedex, France. Tel.: +33 320 446281. Fax: +33 320 446732. E-mail address:

1 **1. Dual-task paradigms and associated models**

2 Upright standing in humans is characterized by continuous postural sways due to  
3 inherent biomechanical constraints [1] and the inability of the central nervous system  
4 (CNS) to maintain constant the force produced by postural muscles [2]. An increase in  
5 the amplitude of fluctuations of the center of mass (COM) or center of pressure (COP)  
6 is often interpreted as a sign of less efficient postural control [3,4]. The related  
7 underlying assumption is that the CNS tries to minimize postural sway [2] as greater  
8 postural sway may be considered as a threat to keep balance [5].

9 Previous work has investigated the brain areas and the level of attentional resources  
10 involved in postural control [6] by asking participants to maintain upright standing  
11 (considered to be the CNS's primary task; [7]) while performing simultaneously a  
12 secondary task [7]. This is what is commonly called the dual-task paradigm. In this  
13 paradigm, two methodological features are often used. First, participants are instructed  
14 to stand as steady as possible, eliminating thereby unrestrained postural sway. Second,  
15 variables characterizing the two tasks are measured during both tasks performed  
16 separately (single-task situation) and together (dual-task situation; 6,8). Differences in  
17 the dependent variables measured in single- and dual-task situations are usually used as  
18 an index of interference between tasks. The level of interference has been hypothesized  
19 to reflect limited attentional resources that cannot allow the CNS to perform the two  
20 tasks simultaneously with the same level of efficiency [5,6,9,10]. When individuals  
21 stand without performing an additional task (i.e. the most simple quiet stance control  
22 task), the allocation of attentional resources to postural control can be at its greatest. If a  
23 secondary active task is performed simultaneously (e.g. mental counting), both postural  
24 control and the active task can be performed optimally as long as the sharing of  
25 attentional resources do not exceed the maximal attentional capacity of the CNS  
26 [11,12]. According to the model of limited attentional resources, increasing the  
27 difficulty of the active task should alter the secondary task performance and/or increase  
28 postural sway (Figure 1) [5,6]. It is usually assumed that decreased cognitive  
29 performance and/or increased postural sway reflect an increase in interference [5,12]. A  
30 simple representation of this model is shown in Figure 1.

31 The secondary task can be either purely mental (e.g. mental counting) or combine  
32 activities with a change in body motion (e.g. a concomitant motor task such as grasping  
33 an object with the hand) or induce a change in sensory interaction with the environment  
34 (e.g., tracking a dot simply with short gaze shifts). In the rest of the present manuscript,  
35 these types of secondary tasks were referred to as "active mental", "active body motion",  
36 and "active sensory" tasks, respectively. The active body motion tasks also involved  
37 active sensory interaction with the environment but this aspect was out of the scope of  
38 the present manuscript. The term "active vision tasks" referred to any kind of precise  
39 visual tasks (i.e. a gaze-shift task, the alignment of two visual targets or pursuing a  
40 moving visual target) while the term "control (visual) task" either referred to the  
41 stationary-gaze task or to the task of randomly looking at a target.

42  
43 

---

*Insert Figure 1 about here*

---

44  
45  
46 Unexpectedly, the concept of interference when posture and cognitive tasks are  
47 performed together was sometimes challenged by results showing that an easy active  
48 task can improve rather than deteriorate postural control [8,13]. These observations  
49 gave rise to the U-shaped "non-linear interaction model" [8,9]. A simple representation

1 of this U-shaped model is shown in Figure 2. Three hypotheses (constrained action,  
2 lower-level, level or alertness) have been developed to explain why individuals could  
3 sway less under easy dual tasks than under the control task. First, the "constrained  
4 action" hypothesis [14] highlighted a change in the focus of attention. Earlier work has  
5 shown that internal focus (i.e. thinking about one's own movements) deteriorated  
6 postural sway when compared with external focus (i.e. thinking about the performance  
7 to be achieved) [14]. In the literature, investigators explained that internal focus may  
8 lead to greater muscle activity and hence greater postural sway [9,15,16]. When subjects  
9 are asked to sway as less as possible, they can totally focus on their own motion. In the  
10 dual task, however, participants have to sway as less as possible and to perform  
11 simultaneously an active task that diverts their attention from their own motion. The  
12 shift in attentional focus during active vision tasks may explain why postural sway were  
13 sometimes found to be greater in quiet stance (i.e. when internal focus operated) than in  
14 dual tasks (when external focus operated). The better performance of golf players when  
15 they focused their attention on the goal of the task rather than on their own body  
16 motions could illustrate this hypothesis [17].

17  
18  
19  
20

---

*Insert Figure 2 about here*

---

21 The second hypothesis for lower postural sway in easy dual tasks related to the  
22 "lower-level" hypothesis. It has been suggested that stance control could become more  
23 automatic, or regulated by lower-level structures, in dual tasks in order to facilitate both  
24 postural control and the success in the dual task [5,8,13]. Consequently, higher-level  
25 brain structures could be more available for the dual task performance. Overall, this  
26 reorganization may improve both the dual task performance and postural control [13].

27 The third hypothesis for lower postural sway in easy dual tasks could be called the  
28 "level of alertness" hypothesis. As the risk of falls is higher in dual tasks, the CNS may  
29 increase the level of alertness to reduce postural sways and therefore to minimize the  
30 risk of falls. This hypothesis is based on a work discussing that the level of alertness  
31 may increase when the difficulty of the task increased [18]. This third hypothesis  
32 resembles the task prioritization model suggested by [8] because individuals would  
33 increase their postural stability (in this case reduce their postural sways) under dual  
34 tasks in order to avoid falls ("posture-first" strategy).

35 The objective of the present manuscript was to perform a review of the literature to  
36 challenge the validity of the conventional and U-shaped nonlinear interaction models of  
37 postural control (Figures 1 and 2) in the specific context of precise visual "here called  
38 active vision" paradigms. Other models (ecological: [19]; mixed: [20]) were not  
39 analyzed because the present manuscript only tested the validity of the existing purely  
40 cognitive models. The analyses showed that the published cognitive models did not fit  
41 the experimental results obtained in the context of active vision tasks. The present  
42 review thus questioned the concept of duality in this specific context.

43

## 44 **2. The literature data**

### 45 *2.1. Selection of articles to test the validity of the existing cognitive models*

46 The selection of articles included healthy, young participants. Studies which  
47 recruited a few middle-age adults were included in the selection as long as the group's  
48 mean age was lower than 40 years old. The term "healthy" meant that participants had

1 no known injury or disease and had good or corrected visual acuity to perform the  
2 different visual tasks. We did not include children (below 18 years), middle-aged adults  
3 (mean age group greater than 40 years old), older adults, or any kind of patients to avoid  
4 the effects of early or late stages of age and disease. However, if a study included two or  
5 more age groups with a group of young adults, the results for the latter were analyzed.

6 Several methodological requirements were used to test the validity of the limited  
7 attentional resources and U-shaped nonlinear interaction models (Figures 1 and 2)  
8 during active vision tasks. Firstly, the selected studies needed to include at least one  
9 active vision task performed with the eyes opened. Therefore, all manuscripts only  
10 testing different kinds of control stationary-gaze tasks and/or random-looking tasks on a  
11 white target were not considered for analyses. Indeed, the simple tasks of looking at a  
12 stationary dot or randomly looking at a white panel were both considered as control  
13 tasks. Studies simply testing eye motions with the eyes closed, or opened in the dark,  
14 were also not considered for analyses. Secondly, studies using a head-mounted display  
15 were not included because the device provided visual information that is unrelated to  
16 postural sway and to a natural interaction with the environment. Thirdly, participants  
17 had to perform only one active task within each trial and not several tasks at the same  
18 time (e.g., searching a target in a picture and counting in the head). Otherwise, the effect  
19 of the active vision task on postural control could be biased by the effect of the other  
20 active mental task. Finally, except for the visual tasks performed, the experimental  
21 conditions in both active vision and control tasks had to be similar. Hence, 1) the  
22 environment or feet support could not move in the active vision task and stay stationary  
23 in the control task; 2) participants could not move any body part intentionally to  
24 perform the active vision tasks and stay stationary in the control task. Otherwise, this  
25 would bias the analysis of postural and/or center of pressure sway when comparing the  
26 control task and the active vision task. In the context of active vision tasks, gaze shifts  
27 greater than  $15^\circ$  were assumed to require head motion [21]. Hence, we analysed studies  
28 with active vision and control tasks displayed on a visual angle lower than  $15^\circ$ . The  
29 existing models could also be tested with active vision tasks greater than  $15^\circ$  if  
30 investigators had measured the body's angular displacement (head rotation, for example)  
31 and ensured that this variable was similar in the active vision task and in the control  
32 task. Unfortunately, these controls of angular displacements were lacking in studies  
33 supposedly designed to test the cognitive models under active vision tasks greater than  
34  $15^\circ$  [8]. On exception is our recent study [22] in which participants were shown to  
35 perform the active vision task on an image of  $22^\circ$  without rotating their head, neck or  
36 lower-back significantly more than in the other control tasks. Therefore, only [22] and  
37 other studies with a visual angle below  $15^\circ$  were selected. Studies only including  
38 different kinds of active vision tasks without a control visual task were not selected as  
39 the lack of a control task did not allow to test whether participants improved their  
40 postural control when performing the active vision task. Search terms in Pub Med and  
41 Mendeley databases were: postural control, postural sway, postural stability, upright  
42 stance, gaze-shift, visual tasks, saccades. Additional references were also found in  
43 analyzing the references list in all published manuscripts. Overall, only nine  
44 manuscripts were included (Table 1).

---

45  
46 *Insert Table 1 about here*

---

48  
49 *2.2. Results published in active vision tasks*

1 The nine selected studies systematically showed that healthy, young participants  
2 swayed significantly less under active vision tasks than under control visual tasks  
3 (Table 1). These participants swayed significantly less when searching to detect the  
4 location of a target within an image than when randomly looking at similar images  
5 and/or looking at a stationary dot [22], they swayed significantly less when searching a  
6 letter in a text than when randomly looking at a white panel [23,25]. They also swayed  
7 significantly less when they had to gaze a dot appearing either right or left at a constant  
8 frequency and amplitude relative to the control stationary-gaze task [16,24,26-28] and  
9 when they had to perform only one saccade toward a target relative to the stationary-  
10 gaze task ([9], Table 1). The significant reduction of body sway was found at least at  
11 one level of the body (COP, head, shoulder, lower-back), at least in one direction  
12 (anteroposterior, mediolateral) and at least in one of the dependent variables used  
13 (standard deviation, range, surface area, mean velocity, root mean square, COP-COM,  
14 Table 1).

15 One of the nine above manuscripts should be described more carefully because it  
16 reported ambiguous results [9]. Indeed, [9] found a significant reduction in COP  
17 excursion when subjects performed the two pro-saccade tasks than the control task. In  
18 these pro-saccade tasks, participants had to perform either a reactive or voluntary  
19 saccade to gaze a target as soon as it appeared on the screen. This result was consistent  
20 with the eight other studies mentioned in Table 1. In contrast, COP excursion was  
21 greater when subjects performed the anti-saccade task than any of the two pro-saccade  
22 tasks. In the anti-saccade task, participants had to perform a saccade in the direction  
23 opposite to the appearing target. This result was not in contradiction with the former  
24 ones because the authors did not compare COP excursion in the anti-saccade vs. the  
25 control task but in the anti-saccade vs. pro-saccade tasks. Moreover, the anti-saccade  
26 task actually could not test the validity or invalidity of the conventional cognitive model  
27 because participants did not need to perform a precise gaze shift ó as in all other active  
28 vision tasks shown in Table 1 ó but simply to perform a random saccade on a white  
29 space in opposite direction to where the distractor appeared. In contrast, a precise gaze  
30 shift was required to perform the pro-saccade task in which individuals swayed  
31 significantly less.

32 Overall therefore, none of the results in the nine selected studies could be predicted  
33 by the conventional model of limited attentional resources.

34

### 35 *2.3. Limits of the U-shape nonlinear interaction model to explain postural control under* 36 *active vision tasks*

37 The results in the nine selected studies also cannot be well explained by the U-  
38 shaped non-linear interaction model (Figure 2) because the published active vision tasks  
39 were not easy but actually difficult or very difficult. In some studies, participants could  
40 not succeed perfectly well all the time in active vision tasks [22,23,25], hence showing  
41 that the tasks were hard. The active vision task was even extremely hard in [22] with  
42 mean task performance lower than 40%. Overall, the success in precise saccades on  
43 specific target when the body oscillates cannot be considered as a trivial task, especially  
44 because postural sway is, at least partly, unpredictable [22].

45 One general limitation of the U-shaped non-linear interaction model (Figure 2) is  
46 the lack of clear boundaries. According to this model, easy tasks should improve  
47 postural control and hard tasks should deteriorate postural control (Figure 2, [9].  
48 However, the inflexion point is not clearly defined; the literature still did not explicitly

1 state under which level of difficulty a dual task may prompt individuals to exhibit less  
2 or more postural sway or better or worse postural control. When participants swayed  
3 more in a dual task than in quiet stance, investigators could assume that the dual-task  
4 was hard and that the ascending part of the U-shaped model was valid [9]. Conversely,  
5 when participants swayed less in a dual task than in quiet stance, investigators could  
6 assume that the dual task was easy and that the descending part of the U-shaped model  
7 was valid [9]. The vagueness of the U-shaped model is a relevant issue as it can make  
8 this hypothesis valid, regardless of the results. As long as a clear identification of the  
9 inflexion point is not provided, the existing U-shaped model can be validated by any  
10 kind of result and therefore remains unfalsifiable.

11 The limitation of the "constrained action", the "lower-level" and the "level of  
12 alertness" subtended hypotheses of the U-shaped nonlinear interaction model are  
13 discussed below.

14 In seven of the nine selected studies, participants stood comfortably with no  
15 requirement to sway as less as possible [22-28]. Participants were simply asked to  
16 perform both control and active vision tasks as naturally as possible, and these studies  
17 showed a reduction of spontaneous COP and/or body sway in the active vision task. In  
18 the two last studies [9,16], participants were required to stand as steady as possible. The  
19 findings were similar as in the former studies. Overall, the presence or absence of the  
20 steadiness requirement did not change the main outcome of the nine studies (Table 1).  
21 In other words, the "constrained action" hypothesis was not sufficient, by itself, to  
22 explain better postural control in active vision tasks.

23 The "lower-level" hypothesis appears attractive because it assumes that a functional  
24 reorganization of the CNS is involved in the performance of dual tasks. If the CNS's  
25 high-level resources were freed from controlling upright stance (because postural  
26 control operates at a lower level; 8,13), then both postural control and the active vision  
27 task may be well performed with no interference or at least less interference or  
28 between tasks. However, one criticism of this "lower-level" hypothesis is that postural  
29 control may not be improved by automatic processes [10]. Indeed, automatic processes  
30 may only ensure a constant level of postural control in each task, not any improvement  
31 [10]. Carefully, sometimes, withdrawing some automatic processes can be negative for  
32 postural control, for example in older adults [5]. However, this situation may not mean  
33 than an increase in automatic processes or relative to baseline or would improve postural  
34 control; only the withdrawing of automatic processes, or also eventually the  
35 engagement of more controlled processes, could explain worse postural control in older  
36 adults. Even more remarkably, we recall that individuals swayed significantly more in  
37 quiet stance than in active vision tasks [22-28]. Therefore, it is definitely counter-  
38 intuitive to assume that the CNS would engage more attentional resources in the quiet  
39 stance task (if more automatic processes are required in dual tasks; 8,13,16] while  
40 postural control is worse in that quiet stance task. Why would the CNS engage more  
41 cognitive workload in quiet stance than in dual tasks if it is not functional and if it  
42 actually leads to worse postural control? Why would the CNS engage useless cognitive  
43 workload in the simplest quiet stance condition? Instead, the CNS should engage less  
44 cognitive workload in quiet stance, the process should be more automatic in this control  
45 task, as usually assumed in the literature reports [6,8]. Overall, this "lower-level"  
46 hypothesis may not explain why healthy, young adults swayed significantly less in  
47 active vision than in control tasks [9,13,22-28], Table 1).

48 When considering the "level of alertness" hypothesis, it is also counter-intuitive to  
49 assume that healthy, young individuals may be at risk of falls when they performed

1 active vision tasks that did not involve any body motion or motion of the environment.  
2 It has already been pointed out that even very difficult dual tasks only slightly  
3 challenged postural safety in healthy, young adults [6]. These individuals were also able  
4 to perform fast gaze shifts (at 0.5 Hz and 1 Hz) with a visual angle of 150° without  
5 losing their balance or needing to repeat any trial - even with their feet in narrow stance  
6 [3]. As during quiet upright standing, these individuals are far from their limits of  
7 stability [19,29], there is no need for them to limit their postural sway as much as  
8 possible in order to avoid falls. The chapter 5 shows that the results found in the nine  
9 studies (Table 1) could be explained by a more positive view of the role of the CNS to  
10 control upright stance.

11

### 12 **3. No duality between postural and visual systems during gaze-shift tasks in** 13 **healthy, young adults**

#### 14 *3.1. The cognitive models of postural control do not have a functional basis*

15 In active vision tasks, instead of a negative interference between the two tasks  
16 performed simultaneously, the results from the literature suggest that upright stance  
17 may be functionally controlled to successfully perform the visual task. The assumption  
18 that one postural task performed simultaneously to an active vision task should be  
19 considered as a collaborative situation is supported by recent studies from investigators  
20 of the cognitive approach [9,12,16,26,29] with concepts such as "task-dependent  
21 postural control", "adaptive postural patterns" [29]. One should note that these  
22 arguments come from the ecological approach, although these studies [9,12,16,26,29]  
23 did not state that they had validated the ecological (functional) model of postural control  
24 [19]. These authors used an explanation that was not cognitively grounded without  
25 mentioning such a bias. This evidences a state of confusion in the literature. In other  
26 words, a real issue is that the cognitive approach has not generated a functional model  
27 of postural control yet<sup>2</sup>. Indeed, the conventional model of limited attentional resources  
28 is not adaptive as the CNS does not seem to be able to adjust postural control when any  
29 kind of active task become more and more difficult (Figure 1). The U-shaped nonlinear  
30 interaction model only seems adaptive under easy active tasks but not under difficult  
31 active tasks (Figure 2). Indeed, first, the "constrained action" hypothesis may not  
32 encompass a CNS adaptation because it considers that lower postural sway in active  
33 vision tasks is simply due to a change in attentional focus. Second, it remains  
34 controversial that in the "lower-level" hypothesis the CNS engages more high-level  
35 resources in quiet stance than under active tasks because postural control is worse in  
36 quiet stance than in active tasks (Table 1). Third, the "level of alertness" hypothesis also  
37 features a CNS adaptation but in a negative way: individuals would sway less to avoid  
38 falls rather than to better perform the task. This view obscures the brain's adaptive role  
39 in computing, regulating and updating. For all these reasons, there is a crucial need to  
40 describe and define a functional cognitive model to explain postural control in active  
41 vision tasks.

42

#### 43 *3.2. The functional basis of Mitra's [4] mixed model is ecological, not cognitive*

44 Mitra's [4] adaptive resource-sharing model is a model mixing cognitive and  
45 ecological arguments to predict postural control. On one hand, it assumes that the CNS  
46 has limited attentional resources and that postural control should be deteriorated if the

---

<sup>2</sup> See below in Chapter 4.2. a comment about Mitra's [20] model

1 postural task is difficult enough (e.g., standing on a foam) and/or if the secondary task ó  
2 also called suprapostural task ó is difficult enough (e.g., performing a hard computation  
3 in one's head). On the other hand, this model also has an ecological basis because it  
4 predicts that under active sensory tasks (e.g., visual, auditory), postural control should  
5 be adjusted to succeed in the suprapostural task performed. If an active vision task was  
6 performed in a standard stance condition (on a rigid and stable floor), Mitra's [20]  
7 model would predict that healthy, young adults would sway significantly less in this  
8 active vision task than in the control task as our review showed [9,16,22-28]. One  
9 advantage of this model is that it is more flexible than both cognitive and ecological  
10 models, not either cognitive or ecological, it is an in-between model. One disadvantage  
11 is that the functional basis of Mitra's [20] model is not cognitive, it is ecological. [20]  
12 did not explain how the CNS could manage to stabilize postural control as it has limited  
13 attentional resources. He also did not explain how the CNS would perform both tasks  
14 together, which areas of the brain would be implicated. Hence, today, there does not  
15 seem to be any purely cognitive model that could predict the results discussed in Table  
16 1.

17

#### 18 **4. Limitation of the criticism of the existing models**

19 A shortcoming of the present work is that the existing conventional and U-shaped  
20 cognitive models were not refuted in all kinds of active tasks. Indeed, we assume that  
21 these models are well-grounded for other kinds of active tasks, such as active mental  
22 tasks (e.g., mental counting) or active body motion tasks (e.g., grasping task when  
23 upright). These models were only disapproved under active vision tasks and our review  
24 questioned the underlying mechanism of these models specifically in this context.  
25 Another limitation of the results found in active vision tasks (relative to the control task)  
26 was suggested by [25]. These authors explained that active vision tasks could provide  
27 more visual information useful to improve postural control than the control task. This  
28 issue indeed existed in [23] and [25] in which there was a text in front of participants in  
29 the active vision task and a white panel in front of them in the control task. In both  
30 studies, looking at a structured text, displayed on horizontal lines could have helped  
31 participants to be more stable in the active vision tasks independent of the task  
32 performed. However, in all other studies in Table 1 [9,16,22,24,26-28], there was no  
33 more visual information in active vision than in control tasks, as participants either  
34 stared at a stationary dot (displayed on a white background) or gazed a moving dot  
35 (displayed on a white background). In [22], participants stared at a stationary dot  
36 surrounded by an image or randomly looked at the same image in the control tasks.  
37 They also randomly looked at a similar image in the active vision task (see [22]).

38

#### 39 **5. Bases of a future cognitive functional model of postural control only concerned** 40 **with active vision tasks or more generally active sensory tasks**

41 The literature reports definitely showed that healthy, young participants exhibit a  
42 better postural control in active vision tasks than in control tasks [9,16,22-28], Table 1).  
43 Hence and specifically for active vision tasks, a new cognitive model should not be  
44 based on cognitive limitations of the CNS but instead on its adaptive, adaptable, nature  
45 to perform different kinds of task successfully. The CNS may indeed guide postural  
46 control in a goal-directed manner instead of being overwhelmed by active vision tasks  
47 [22]. In vision research, for example, there is no doubt about the cognitive nature of the  
48 functional goal-directed visual behavior. It is clearly assumed that the visual system is



1 actively goal-directed to get information and successfully perform the task; the visual  
2 system is not stimulus-bounded [Land & Tatler, 2009].

3 The literature reports in healthy, young adults ([9,16,22-28], Table 1) could be  
4 explained in considering synergistic rather than dual interactions [22]. On one hand,  
5 under precise gaze-shift tasks, the CNS would need to move the eyes to gaze a very  
6 precise location and therefore continuously adapt the amplitude of each saccade as a  
7 function of continuous postural sway. The task of performing precise vision tasks would  
8 be cognitively demanding because gaze shifts have to be planned and performed as a  
9 function of the magnitude of postural sway [22]. If postural sway was not taken into  
10 account by the CNS in these tasks, the precision of any oculomotor behavior would be  
11 lowered. The more both postural sway and oculomotor behaviors could be controlled in  
12 synergy, the easier it would be for the CNS to succeed in the visual task [22]. May be  
13 that healthy, young adults' CNS could adjust oculomotor behavior (length of the ocular  
14 path, saccades, fixations) and postural control (postural mechanisms, postural sway,  
15 postural coordination) in a synergistic manner to perform and succeed in precise active  
16 vision tasks. In contrast with the general idea that limitations in dual-task performance  
17 is relative to the increase in cognitive workload, the synergistic model considers as a  
18 requirement an increase in cognitive workload to succeed in the task [22]. Therefore,  
19 this new model definitely contrasts with the 'lower-level' hypothesis of the U-shape  
20 nonlinear interaction model. For recall, this hypothesis suggests a reduction of  
21 implication of higher structures of the CNS in postural control in active tasks (postural  
22 control performed in lower structures so that higher structures can be available to  
23 perform the active tasks), not an increase [13]. On the other hand, in the stationary-gaze  
24 task, there would be no need for the CNS to stabilize upright stance because the  
25 vestibular-ocular reflex could easily keep the eyes on the immobile target (regardless of  
26 the amplitude of postural sway) [22]. Hence, keeping the eyes on a stationary target  
27 would not require any synergy between postural and oculomotor behaviors, this control  
28 task would be less cognitively demanding, merely automatic. In our opinion, even the  
29 task of randomly looking at a small white target or at small image would be less  
30 cognitively demanding as there would be no need to conjointly adjust postural and  
31 oculomotor behaviors. Indeed, in this random-looking task, individuals would merely  
32 randomly look at the target or image with no goal. Importantly, this functional  
33 synergistic model of postural control would not explain changes in postural control as  
34 such (as all other models of postural control: limited attentional resources, U-shaped  
35 nonlinear interaction, functional ecological, adaptive resource-sharing), it would not  
36 explain changes in visual control as such, but it would explain changes in the synergy  
37 between postural and visual behaviors. In very difficult precise vision tasks, the synergy  
38 would be expected to exist and be related to 'explain by or caused by' an increase in  
39 cognitive workload while in any kind of random-looking visual tasks (random gaze  
40 shifts on a white target or on an image), the synergy would be low or at least not related  
41 to any change in cognitive workload. In our recent study [22], we tested this new model  
42 and indeed found these patterns of results.

43 The vocabulary of this new cognitive model would need to be adapted and changed.  
44 The concept 'dual task' should not be used anymore because it emphasizes a 'duality'  
45 (of attentional resources), or competition between two tasks (posture, vision) instead of  
46 suggesting a cooperation, or unification, or synergy between the two tasks [22]. In this  
47 future cognitive model, there should not be a distinction between primary and secondary  
48 tasks but instead between control and unified-synergistic tasks. This reason explains  
49 why we preferred avoiding the term 'secondary' task as much as possible, preferring the  
50 neutral term 'active' task (vs. control task).

1        In conclusion, the present analysis showed that the limited attentional resources and  
2 U-shaped nonlinear interaction cognitive models were not well-suited to explain  
3 findings in active vision tasks. The results in Table 1 did not show that both visual and  
4 postural processes work in isolated and conflicting manners but instead that they work  
5 together. Hence, a synergistic vision-posture view of postural control should be  
6 proposed [22] and this new model will emerge in a future theoretical manuscript.

7

#### 8 **Acknowledgments**

9 Nothing to declare.

## 1 **References**

- 2 [1] Winter DA. Human balance and postural control during standing and walking. *Gait*  
3 *Posture* 1995;3:193-214.
- 4 [2] Loram ID, Maganaris CN, Lakie M. Human postural sway results from frequent,  
5 ballistic bias impulses by soleus and gastrocnemius. *J Physiol*, 2005;564:295-311.
- 6 [3] Bonnet CT, Desprez P. Large lateral head movements and postural control. *Hum*  
7 *Movement Sci* 2012;31:1541-1551.
- 8 [4] Mitra S, Knight A, Munn A. Divergent effects of cognitive load on quiet stance and  
9 task-linked postural coordination. *J Exp Psychol Human* 2013;39:323-328.
- 10 [5] Boisgontier MP, Beets IAM, Duysens J, Nieuwboer A, Krampe RT, Swinnen SP.  
11 Age-related differences in attentional cost associated with postural dual tasks:  
12 increased recruitment of generic cognitive resources in older adults. *Neurosci*  
13 *Biobehav R* 2013;37:1824-1837.
- 14 [6] Woollacott M, Shumway-Cook A. Attention and the control of posture and gait: A  
15 review of an emerging area of research. *Gait Posture* 2002;16:1-14.
- 16 [7] Bloem BR, Grimbergen YAM, Gert van Dijk J, Munneke M. The posture secondõ  
17 strategy: A review of wrong priorities in Parkinson's disease. *J Neurol Sci*  
18 2006;248:196-204.
- 19 [8] Lacour M, Bernard-Demanze L, Dumitrescu M. Posture control, aging, and attention  
20 resources : Models and posture-analysis methods. *Clin Neurophysiol* 2008;38:411-  
21 421.
- 22 [9] Swan L, Otani H, Loubert PV, Sheffert SM, Dunbar GL. Improving balance by  
23 performing a secondary cognitive task. *Brit J Psychol* 2004;95:31-40.
- 24 [10] Legrand A, Mazars KD, Lazzareschi J, Lemoine C, Olivier I, Barra J, Bucci MP.  
25 Differing effects of prosaccades and antisaccades on postural stability. *Experimental*  
26 *Brain Research* 2013; DOI10.1007/s00221-013-3519-z.
- 27 [11] Fraizer EV, Mitra S. Methodological and interpretive issues in posture-cognition  
28 dual-tasking in upright stance. *Gait Posture* 2008;27:271-279.
- 29 [12] Remaud A, Boyas S, Lajoie Y, Bilodeau M. Attentional focus influences postural  
30 control and reaction time performance only during challenging dual-task conditions  
31 in healthy young adults. *Exp Brain Res* 2013 ;231:219-229.
- 32 [13] Vuillerme N, Nafati G. How attentional focus on body sway affects postural  
33 control during quiet standing. *Psychol Res* 2007;71:192-200.
- 34 [14] Wulf G, McNevin N, Shea CH. The automaticity of complex motor skill learning  
35 as a function of attentional focus. *Q J Exp Psychol* 2001;54A:1143-1154.
- 36 [15] Bourgeois B, Berger L, Rougier PR. Le calcul mental renforcerait la stabilité  
37 posturale. In : Lacour M and van Celst M, editors. *Nouvelles méthodes de*  
38 *traitement du signal posturographique*, Solal, Marseille Inc ; 2004, p. 81-92.
- 39 [16] Rougier P, Garin M. Performing saccadic eye movements or blinking improves  
40 postural control. *Motor Control* 2007;11:213-223.
- 41 [17] Wulf G, Su J. An external focus of attention enhances golf shot accuracy in  
42 beginners and experts. *Res Q Exercise Sport* 2007;78:384-389.
- 43 [18] Barra J, Auclair L, Charvillat A, Vidal M, Pérennou D. Postural control system  
44 influences intrinsic alerting state. *Neuropsychol* 2015;29:226-234.

- 1 [19] Riccio GE, Stoffregen TA. Affordances as constraints on the control of stance. Hum  
2 Movement Sci 1988;7:265-300.
- 3 [20] Mitra S. Adaptive utilization of optical variables during postural and suprapostural  
4 dual-task performance: Comment on Stoffregen, Smart, Bardy, and Pagulayan  
5 (1999). J Exp Psychol Human 2004;30:28-38.
- 6 [21] Hallett PE. Eye movements. Handbook of human perception and performance.  
7 New York: Wiley;1986.
- 8 [22] Bonnet CT, Szaffarczyk S, Baudry S. (under review, 3<sup>rd</sup> revision in Cognitive  
9 Science, COGSCI-15-316\_R2). Functional synergy between postural and visual  
10 behaviors when performing a difficult precise visual task in upright stance.
- 11 [23] Bonnet CT, Kinsella-Shaw JM, Frank TD, Bubela D, Harrison SJ, Turvey MT.  
12 Deterministic and stochastic postural processes: Effects of task, environment, and  
13 age. J Motor Behav 2010;42:85-97.
- 14 [24] Giveans MR, Yoshida K, Bardy B, Riley M, Stoffregen TA. Postural sway and the  
15 amplitude of horizontal eye movements. Ecol Psychol 2011;23:247-266.
- 16 [25] Prado JM, Duarte M, Stoffregen TA. Postural sway during dual tasks in young and  
17 elderly adults. Gerontol 2007;53:274-81.
- 18 [26] Rodrigues ST, Aguiar SA, Polastri PF, Godoi D, Moraes R, Barela JA. Effects of  
19 saccadic eye movements on postural control stabilization. Motriz: Rev Educ Fis  
20 2013;19:614-619.
- 21 [27] Stoffregen TA, Bardy BG, Bonnet CT, Pagulayan RJ. Postural stabilization of  
22 visually guided eye movements. Eco Psychol 2006;18:191-222.
- 23 [28] Stoffregen TA, Bardy BG, Bonnet CT, Hove P, Oullier O. Postural sway and the  
24 frequency of horizontal eye movements. Motor Control 2007;11:86-102.
- 25 [29] Haddad JM, Rietdyk S, Claxton LJ, Huber J. Task-dependent postural control  
26 throughout the lifespan. Exercise Sport Sci R 2013;41:123-132.
- 27 [30] Land MF, Tatler BW Looking and acting. Vision and eye movements in natural  
28 behavior. Oxford University Press; 2009.

1 **Figure Caption**

2 Figure 1. Schematic representation of the limited attentional resources model. If the  
3 active task is easy or very easy (E), i.e. not cognitively demanding, the model states  
4 no change in center of pressure and/or postural sway compared with the control task  
5 (C). The greater the cognitive difficulty in the active task, the greater the increase in  
6 center of pressure and/or postural sway because of limited attentional resources of  
7 the central nervous system. M = task of medium difficulty; D = difficult task. In a  
8 very difficult task (VD), there should be no increase in body oscillation anymore to  
9 control the risk of fall (healthy, young individuals never fall in performing any kind  
10 of visual task). The schematic line is represented as a dotted line because there is no  
11 certitude (no literature report) that the suggested changes in line orientation should  
12 be linear (it could be nonlinear).

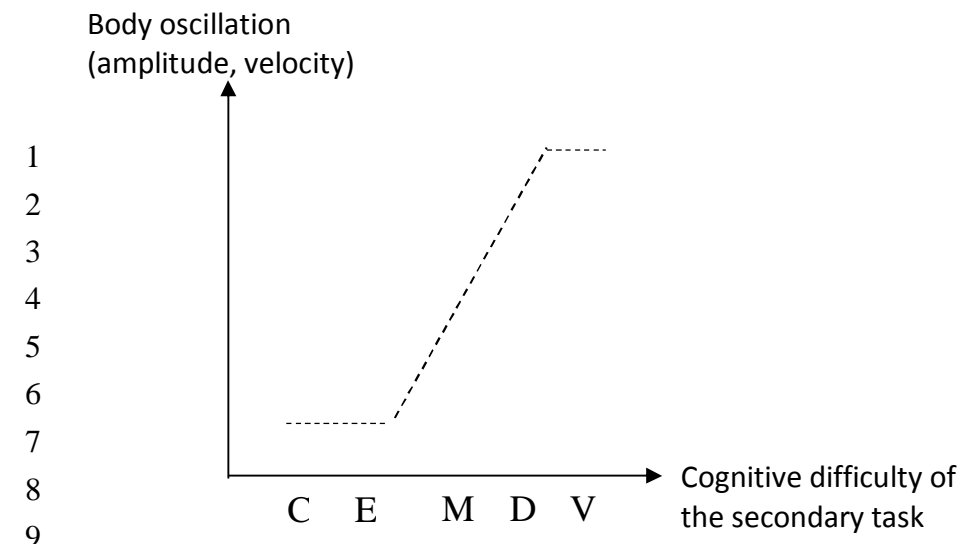
13 Figure 2. Schematic representation of the U-shaped nonlinear interaction model. If the  
14 active task is easy or very easy (E), it is assumed that participants should decrease  
15 their center of pressure and/or postural sway compared to the control task (C) [8].  
16 After a certain level of cognitive difficulty is reached, the model states that the  
17 greater the difficulty in the active task, the greater the increase in center of pressure  
18 and/or postural sway because of limited attentional resources of the central nervous  
19 system [8,9]. M = task of medium difficulty; D = difficult or very difficult task. In a  
20 very difficult task (VD), there should be no increase in body oscillation anymore to  
21 control the risk of fall. Literally, the ascending part of the U-shaped should be as  
22 long as the descending part in reference to the  $\delta U$  form. Obviously however, the U-  
23 shaped model includes a longer ascending than descending part to show that  
24 difficult or very difficult task should increase center of pressure and/or postural  
25 sway. The schematic line is represented as a dotted line because there is no certitude  
26 (no literature report) that he suggested changes in line orientation should be linear  
27 (it could be nonlinear).

28

1 Table 1: *Characteristics of participants (number, age, weight, height), discussed*  
2 *experimental conditions (comparison of a control condition and an active vision*  
3 *condition below 15° of visual angle) and significant findings between these conditions*  
4

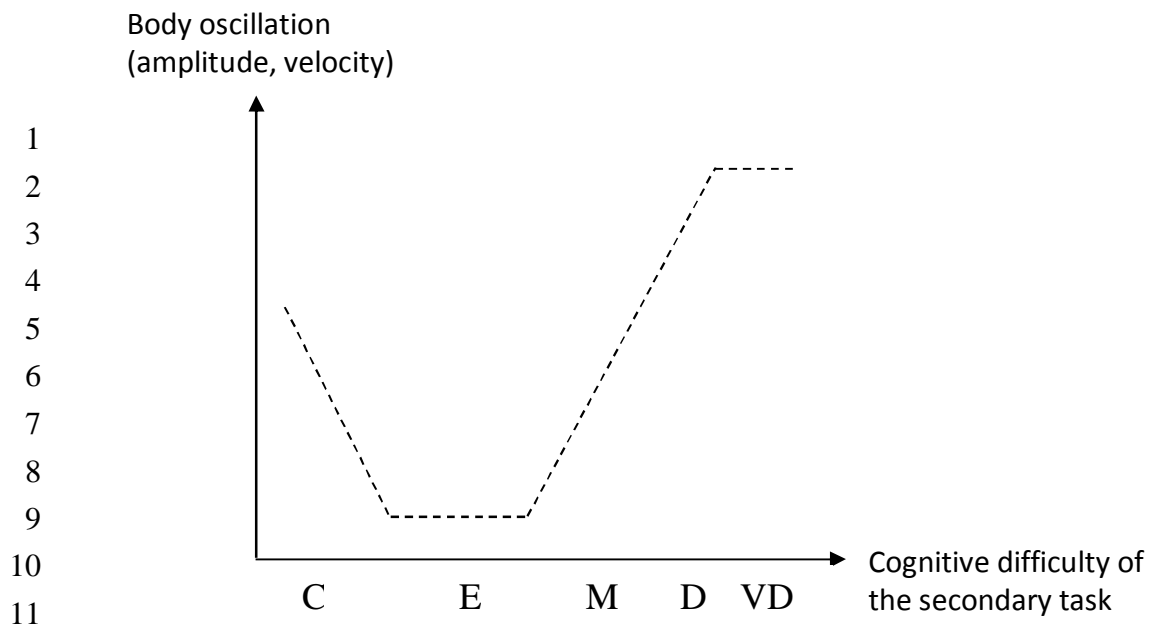
Citation	n°	Age (years)	Weight (Kg)	Height (cm)	Discussed experimental conditions	Significant results found (in comparison to the control task)
Bonnet et al. [23]	12	20.23±2.02	71.35±17.17	172±12	White target task vs. letter search task	Reduction of COP SD <sub>AP</sub> in the letter search task.
Bonnet et al. [22]	16	21.13±1.31	60.75±7.90	1.68±7	Stationary-gaze task vs. searching to locate a target in an image	Reduction of COP, lower-back, neck and head in the AP and ML axes for many variables (R, SD, V).
Giveans et al. [24]	12	22.3 (19-28)	162.6-182.9 (mean: 174)	/	Stationary-gaze task vs. gaze shift at 0.5 Hz horizontally at 9° of visual angle.	Reduction of head SD <sub>AP</sub> and torso SD <sub>AP</sub> in the gaze shift task.
Legrand et al. [9]	10	25±3	/	/	Stationary-gaze task vs. (reactive or voluntary) prosaccade task.	Reduction of COP surface in voluntary prosaccade task. Reduction of COP mean velocity in reactive and voluntary prosaccade tasks.
Prado et al. [25]	12	22-39	63±8	163±6	White target visualization task vs. letter search task.	Reduction of COP RMS <sub>AP</sub> (near and far), COP mean velocity (near and far), head R <sub>AP</sub> (near and far), shoulder R <sub>AP</sub> (near and far) in the letter search task.
Rodrigues et al. [26]	12	21.9±3.6	69.4±8.5	169±6	Stationary-gaze task vs. gaze shift at 0.5 Hz and 1.1 Hz at 11° of visual angle.	Reduction of SD <sub>AP</sub> trunk and head sways, SD <sub>ML</sub> trunk sway, trunk and head path length in both gaze shift tasks.
Rougier & Garin [16]	15	21-43	68.4±8.9	175±7	Stationary-gaze task vs. gaze shift at 1 Hz vertically or horizontally at 5° of visual angle.	Reduction of COM RMS <sub>AP</sub> , COP-COM RMS <sub>AP</sub> in both gaze shift tasks and Reduction of COP-COM RMS <sub>ML</sub> only in the horizontal gaze shift task.
Stoffregen et al. [27]	Study 1: 14 Study 2: 14	Study 1: 20 (18-29) Study 2: 21 (19-25)	Studies 1 and 2: /	Study 1: 70 (158-183) Study 2: 73.1 (152-195)	Stationary-gaze task vs. gaze shift at 0.5 Hz horizontally at 11° of visual angle (with eyes opened).	Study 1: Reduction of torso SD <sub>ML</sub> , head SD <sub>ML</sub> in the gaze shift task. Study 2: Reduction of torso SD <sub>ML</sub> and SD <sub>AP</sub> , head SD <sub>ML</sub> and SD <sub>AP</sub> in the gaze shift task.
Stoffregen et al. [28]	Study 1: 12 Study 2: 12	Study 1: 29.8 (21-47) Study 2: 22 (21-29)	Studies 1 and 2: /	Study 1: 173 (164-180) Study 2: 174 (160-192)	Stationary-gaze task vs. gaze shift at 0.5 Hz, 0.8 Hz and 1.1 Hz horizontally at 11° of visual angle.	Study 1: Reduction of COP SD <sub>ML</sub> in the 3 gaze shift tasks. Study 2: Reduction of torso SD <sub>ML</sub> in the 0.5 Hz and 0.8 Hz, Reduction of torso SD <sub>AP</sub> in the 3 gaze shift conditions, Reduction of head SD <sub>ML</sub> in the 0.5 Hz and Reduction of head SD <sub>AP</sub> in the 3 gaze shift conditions.

- 1 Legend: / = no precision; COP = center of pressure; COM = center of mass; AP =
- 2 anteroposterior axis; ML = mediolateral axis; R = range; SD = standard deviation; V =
- 3 mean velocity; RMS = root mean square
- 4



12 Figure 1.  
13





13 Figure 2.