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

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Running head: testing theories in dual-task paradigms

Abstract

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

Keywords: postural control; postural sway; active vision tasks; cognitive models; young adults

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1. Dual-task paradigms and associated models

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

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

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

Insert Figure 1 about here

Unexpectedly, the concept of interference when posture and cognitive tasks are performed together was sometimes challenged by results showing that an easy active task can improve rather than deteriorate postural control [8,13]. These observations gave rise to the U-shaped ñnon-linear interaction modelò [8,9]. A simple representation of this U-shaped model is shown in Figure 2. Three hypotheses (constrained action, lower-level, level or alertness) have been developed to explain why individuals could sway less under easy dual tasks than under the control task. First, the ñconstrained actionò hypothesis [14] highlighted a change in the focus of attention. Earlier work has shown that internal focus (i.e. thinking about oneôs own movements) deteriorated postural sway when compared with external focus (i.e. thinking about the performance to be achieved) [14]. In the literature, investigators explained that internal focus may lead to greater muscle activity and hence greater postural sway [9,15,16]. When subjects are asked to sway as less as possible, they can totally focus on their own motion. In the dual task, however, participants have to sway as less as possible and to perform simultaneously an active task that diverts their attention from their own motion. The shift in attentional focus during active vision tasks may explain why postural sway were sometimes found to be greater in quiet stance (i.e. when internal focus operated) than in dual tasks (when external focus operated). The better performance of golf players when they focused their attention on the goal of the task rather than on their own body motions could illustrate this hypothesis [17].

Insert Figure 2 about here

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

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

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

2. The literature data

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

The selection of articles included healthy, young participants. Studies which recruited a few middle-age adults were included in the selection as long as the groupôs mean age was lower than 40 years old. The term ôhealthyô meant that participants had no known injury or disease and had good or corrected visual acuity to perform the different visual tasks. We did not include children (below 18 years), middle-aged adults (mean age group greater than 40 years old), older adults, or any kind of patients to avoid the effects of early or late stages of age and disease. However, if a study included two or more age groups with a group of young adults, the results for the latter were analyzed.

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

Insert Table 1 about here

2.2. Results published in active vision tasks

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

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

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

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

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

One general limitation of the U-shaped non-linear interaction model (Figure 2) is the lack of clear boundaries. According to this model, easy tasks should improve postural control and hard tasks should deteriorate postural control (Figure 2, [9]. However, the inflexion point is not clearly defined; the literature still did not explicitly state under which level of difficulty a dual task may prompt individuals to exhibit less or more postural sway or better or worse postural control. When participants swayed more in a dual task than in quiet stance, investigators could assume that the dual-task was hard and that the ascending part of the U-shaped model was valid [9]. Conversely, when participants swayed less in a dual task than in quiet stance, investigators could assume that the dual task was easy and that the descending part of the U-shaped model was valid [9]. The vagueness of the U-shaped model is a relevant issue as it can make this hypothesis valid, regardless of the results. As long as a clear identification of the inflexion point is not provided, the existing U-shaped model can be validated by any kind of result and therefore remains unfalsifiable.

The limitation of the ñconstrained actionò, the ñlower-levelò and the ñlevel of alertnessò subtended hypotheses of the U-shaped nonlinear interaction model are discussed below.

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

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

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

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

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

In active vision tasks, instead of a negative interference between the two tasks performed simultaneously, the results from the literature suggest that upright stance may be functionally controlled to successfully perform the visual task. The assumption that one postural task performed simultaneously to an active vision task should be considered as a collaborative situation is supported by recent studies from investigators of the cognitive approach [9,12,16,26,29] with concepts such as ñtask-dependent postural controlò, ñadaptive postural patternsò [29]. One should note that these arguments come from the ecological approach, although these studies [9,12,16,26,29] did not state that they had validated the ecological (functional) model of postural control [19]. These authors used an explanation that was not cognitively grounded without mentioning such a bias. This evidences a state of confusion in the literature. In other words, a real issue is that the cognitive approach has not generated a functional model of postural control yet[2]. Indeed, the conventional model of limited attentional resources is not adaptive as the CNS does not seem to be able to adjust postural control when any kind of active task become more and more difficult (Figure 1). The U-shaped nonlinear interaction model only seems adaptive under easy active tasks but not under difficult active tasks (Figure 2). Indeed, first, the ñconstrained actionò hypothesis may not encompass a CNS adaptation because it considers that lower postural sway in active vision tasks is simply due to a change in attentional focus. Second, it remains controversial that in the ñlower-levelò hypothesis the CNS engages more high-level resources in quiet stance than under active tasks because postural control is worse in quiet stance than in active tasks (Table 1). Third, the ñlevel of alertnessò hypothesis also features a CNS adaptation but in a negative way: individuals would sway less to avoid falls rather than to better perform the task. This view obscures the brainôs adaptive role in computing, regulating and updating. For all these reasons, there is a crucial need to describe and define a functional cognitive model to explain postural control in active vision tasks.

3.2. The functional basis of Mitraôs [4] mixed model is ecological, not cognitive

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

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[2] See below in Chapter 4.2. a comment about Mitraôs [20] model

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

4. Limitation of the criticism of the existing models

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

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

The literature reports definitely showed that healthy, young participants exhibit a better postural control in active vision tasks than in control tasks [9,16,22-28], Table 1). Hence and specifically for active vision tasks, a new cognitive model should not be based on cognitive limitations of the CNS but instead on its adaptive, adaptable, nature to perform different kinds of task successfully. The CNS may indeed guide postural control in a goal-directed manner instead of being overwhelmed by active vision tasks [22]. In vision research, for example, there is no doubt about the cognitive nature of the functional goal-directed visual behavior. It is clearly assumed that the visual system is actively goal-directed to get information and successfully perform the task; the visual system is not stimulus-bounded [Land & Tatler, 2009].

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

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

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

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Figure Caption

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

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

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

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_{AP} 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_{AP} and torso SD_{AP} 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_{AP} (near and far), COP mean velocity (near and far), head R_{AP} (near and far), shoulder R_{AP} (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_{AP} trunk and head sways, SD_{ML} 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_{AP}, COP-COM RMS_{AP} in both gaze shift tasks and Reduction of COP-COM RMS_{ML} 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_{ML}, head SD_{ML} in the gaze shift task. Study 2: Reduction of torso SD_{ML} and SD_{AP}, head SD_{ML} and SD_{AP} 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_{ML} in the 3 gaze shift tasks. Study 2: Reduction of torso SD_{ML} in the 0.5 Hz and 0.8 Hz, Reduction of torso SD_{AP} in the 3 gaze shift conditions, Reduction of head SD_{ML} in the 0.5 Hz and Reduction of head SD_{AP} in the 3 gaze shift conditions.

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

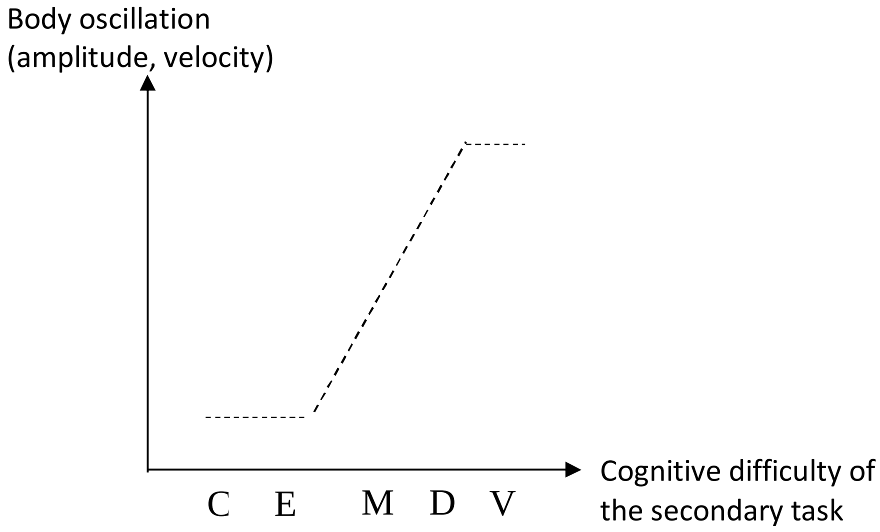
Body oscillation
(amplitude, velocity)
C
E
M
D
V
Cognitive difficulty of the secondary task

Figure 1.

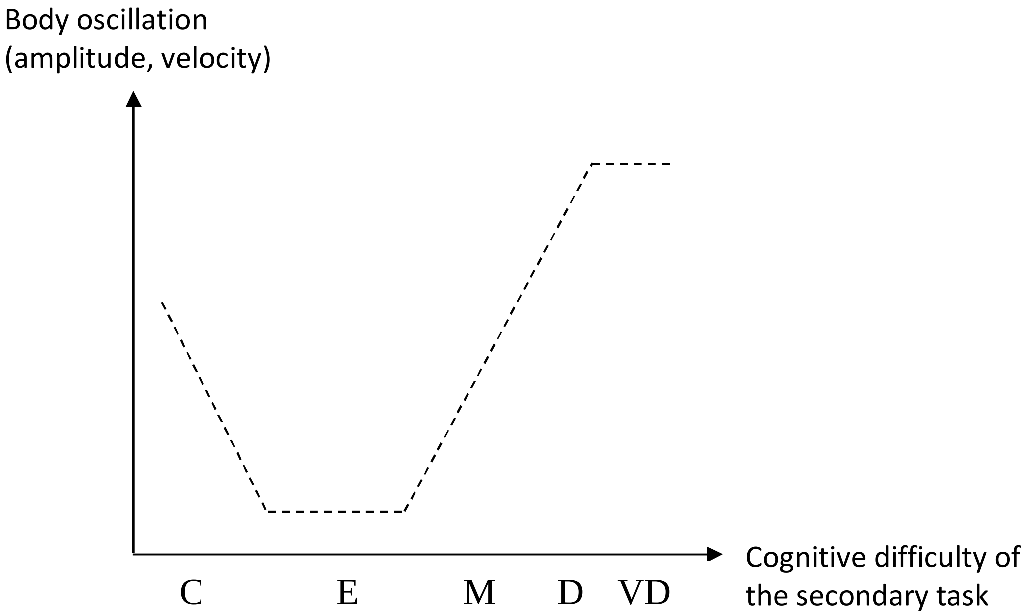
Body oscillation
(amplitude, velocity)
Cognitive difficulty of the secondary task
C
E
M
D
VD

Figure 2.