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Review

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

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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 one's head). The selection included studies performed by healthy, young adults with control and active – difficult – 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.

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 CNS's 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 considered 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 efficacy [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 (Fig. 1) [5,6]. It is usually assumed that decreased cognitive

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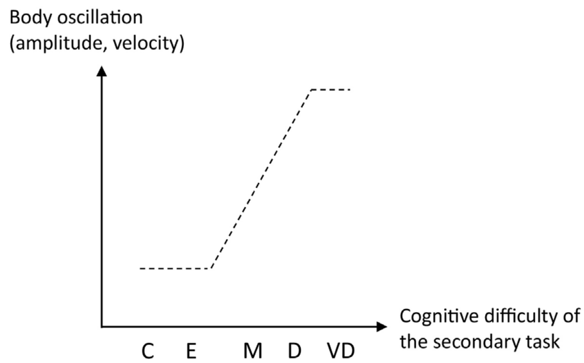

Fig. 1. Schematic representation of the limited attentional resources model. If the active task is easy or very easy (E), i.e. not cognitively demanding, the model states no change in center of pressure and/or postural sway compared with the control task (C). The greater the cognitive difficulty in the 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).

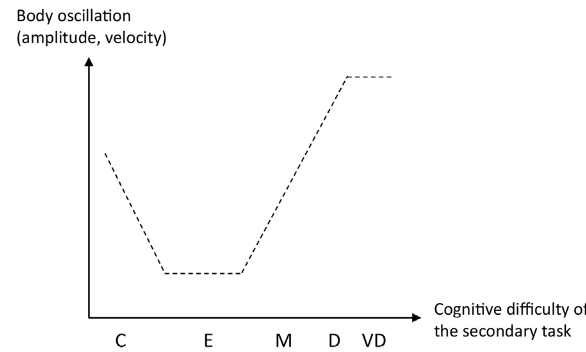

Fig. 2. Schematic representation of the U-shaped nonlinear interaction model. If the active task is easy or very easy (E), it is assumed that participants should decrease their center of pressure and/or postural sway compared to the control task (C) [8]. After a certain level of cognitive difficulty 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 [8,10]. 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. Literally, the ascending part of the U-shaped should be as long as the descending part in reference to the "U" 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).

performance and/or increased postural sway reflect an increase in interference [5,12]. A simple representation of this model is shown in Fig. 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 'active mental', 'active body motion' and 'active sensory' 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 'active vision tasks' 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 'control (visual) task' either referred to the stationary-gaze task or to the task of randomly looking forward.

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 non-linear interaction model [8,10]. A simple representation of this U-shaped model is shown in Fig. 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 "constrained action" hypothesis [14] highlighted a change in the focus of attention. Earlier work has shown that internal focus (i.e. thinking about one's 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 [15,16]. When subjects are asked to sway as less as possible, they can totally focus on their own motion whereas in dual task situation 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].

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

The third hypothesis for lower postural sway in easy dual tasks could be called the "level of alertness" 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 the fact that the level of alertness may increase when the difficulty of the task increases [18]. This third hypothesis resembles the task prioritization model suggested by Lacour et al. [8] because individuals would increase their postural stability (in this case reduce their postural sway) under dual tasks in order to avoid falls ("posture-first" 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 (Figs. 1 and 2) in the specific context of precise visual – here called active vision – 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