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Review

How fear of falling can increase fall-risk in older adults: Applying psychological theory to practical observations

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ABSTRACT

It is widely reported that fear of falling (FOF) has a profound and largely detrimental effect on balance performance in older adults. However, the mechanisms by which FOF influence postural stability are poorly understood. In the current article, we use psychological theory to explain FOF-related changes to postural control. First, we review literature describing associations between FOF and the 'stiffening' strategies observed during control of posture, including observations of eye and head movements. Second, we present a framework illustrating the interactions between increased age, FOF, and altered attentional processes, which in turn influence balance performance and fall-risk. Psychological theory predicts that anxiety can cause attentional bias for threatening and task-irrelevant stimuli and compromise the efficiency of working memory resources. We argue that while the adoption of stiffening strategies is likely to be beneficial in avoiding a loss of balance during simple postural tasks, it will ultimately compromise performance in dynamic and highly demanding functional tasks. The adoption of stiffening strategies leads to inadequate acquisition of the sensory information necessary to plan and execute dynamic and interactive movements. We conclude with some suggestions for future research.

1. Introduction

The detrimental effect of fear of falling (FOF) in older adults (OA) has received much attention in the literature since the early 1980s. FOF has been identified as an independent risk factor for reduced quality of life, activity restriction, loss of independence, and fall-risk; a leading cause of injury, morbidity, and mortality [1]. Moreover, FOF is prevalent in community-dwelling older adults, with estimates of the frequency of falls ranging between 29% and 77% [1].

Hadjistavropoulos et al. [1] presented a model depicting strong associations between FOF and reduced balance performance. However, the mechanisms underpinning this relationship were not articulated. In the current article, we review literature describing FOF-related alterations in the control of posture and gait. Moreover, we review existing psychological theory surrounding the influence of anxiety on the attentional processes required for maintaining postural control. We argue that the influence of FOF on fall-risk is mediated by changes in the allocation of attention and associated alterations in motor control. We present a framework that rationalizes how FOF can influence attentional processes and jeopardize the acquisition and retention of sensory information necessary for the planning of safe stepping actions during complex locomotor tasks. In latter sections, we discuss the implications of our approach for future work and identify specific empirical questions that have yet to be adequately addressed in the literature.

2. Anxiety and postural control

With respect to the control of posture and gait, many researchers have investigated behavioral responses to perceived threat, mostly by raising the height (or perceived height) of a support surface (for a review, see Staab et al. [2]). These researchers have consistently shown that behavioral correlates of FOF are indicative of a conservative 'stiffening strategy'. When adopting this stiffening strategy people reduce the range of motion of their center of mass by reflexively co-contracting tibialis anterior, soleus, and gastrocnemius muscles, resulting in lower amplitude and higher frequency postural sway [3,4]. These adaptations vary linearly with platform height [4]. Furthermore, when standing at height, people: (1) self-report increased FOF and reduced balance confidence [2]; (2) show hallmarks of increased autonomic activity, such as greater galvanic skin conductance [2]; and (3)

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lean backwards away from the platform edge [5]. These adaptations are exacerbated by increased cognitive demands [6,7]. For example, when performing a non-threatening second task (e.g., mental arithmetic), modest reductions in postural sway are observed [6]. These trends are more evident in OA compared to young adults, indicating age-related increases in the attentional demands of postural control [6]. Conservative behaviors are also seen during walking, where anxious people will reduce the range of motion and joint angular velocities in their lower limbs, resulting in shorter strides and reduced gait speed [2,8].

The majority of researchers have interpreted stiffening strategies as an intuitive preparatory strategy aimed at accommodating potential destabilizing factors [3,4,8]. Providing the demands of the task are relatively low (such as during quiet stance), it is likely that a stiffening strategy will be beneficial in avoiding potentially destabilizing motor patterns [3,8]. However, activities of daily life are seldom simple as we are required to interact with features of our environment in a complex and dynamic fashion, often requiring a series of precise movements when negotiating multiple constraints. For example, a common activity for many OA would be to walk along an uneven pavement. The walker must gather precise information regarding the position and characteristics of environmental features and potential hazards in order to plan stepping actions toward areas of the intended path that are deemed safe, while, at the same time, orchestrating appropriate adaptations, such as evasive actions. Stiffening strategies may reduce the capacity to achieve these dynamic tasks, increasing the likelihood of misguiding balance, failing to produce a sufficient response to external perturbations and/or misplacing a step that could lead to tripping, slipping, and falling. Therefore, it is surprising that relatively few researchers have attempted to examine links between FOF and reduced performance in tasks that are more representative of functional activities of daily life.

3. Link between anxiety, visual behavior, and fall-risk

It seems plausible that falls resulting from tripping and slipping might be avoided with better movement planning. Several researchers have attempted to address this topic by measuring eye movement behaviors as an indicator of visual attention during adaptive locomotor tasks. It has been reported that OA with high self-reported anxiety will fixate a target (such as that illustrated in Fig. 1) earlier during the approach and for longer durations compared to OA with low self-reported anxiety [9]. These changes in visual search may reflect a compensation for age-related decline in central nervous system function by providing additional time to acquire spatial information regarding the target in order to ensure an accurate and safe approach. Such a compensatory strategy seems intuitive. However, when faced with multiple stepping targets anxious OA will demonstrate other visual behaviors that jeopardize walking safety [9,10]. Young et al. [9] found that when stepping on a target OA with high self-reported anxiety would transfer their gaze away from the target earlier (in order to fixate the subsequent stepping constraint in their path) compared to OA self-reporting lower levels of state-anxiety. High-risk OA would generally look away from the target approximately 400 ms before foot contact inside the target, resulting in poorer stepping accuracy and increased incidence of their foot contacting the raised edges of the target, thus increasing the risk of tripping and falling [9,10].

More recently, using a single case-study design, Young and Hollands [11] showed that prior to falling on two occasions, participant P8 (an 87-year-old female) self-reported low FOF and demonstrated both eye movements and stepping behaviors typical of a low-risk OA. However, thirteen days following the latter of the two falls, across a range of questionnaire-based assessments of balance confidence and state-anxiety, P8 self-reported 15%, 23.3%, and 37.5% increases in FOF. Furthermore, in the absence of any observed general decline in visual function (acuity, contract sensitivity, size of peripheral field), cognitive processing, visual-spatial working memory, or muscle strength, when stepping over multiple constraints P8's eye movement and stepping behaviors changed significantly and were indicative of that typically seen in high-risk OA with FOF [11]. Collectively, these studies show that FOF is associated with visual behaviors that are known to compromise walking safety in OA, by increasing the risk of producing an inaccurate step and tripping. However, the studies do not directly specify the underlying mechanisms through which FOF drives premature gaze transfer from the target. Young and Hollands [9] showed that FOF-related changes in the visual behaviors exhibited by OA existed during their entire approach to the initial stepping target. When facing a target followed by two obstacles, low-risk OA (who self-reported low FOF) frequently transferred visual fixation between each of the stepping constraints during their entire approach (Fig. 1a). However, high-risk OA (who self-reported higher FOF) demonstrated a different visual strategy, by fixating the initial target for the majority of their approach toward it, and fixating the subsequent constraints on significantly fewer occasions and for shorter durations compared to OA without FOF (Fig. 1b).

Without visually fixating the future constraints in their path, high-risk OA would be less able to generate a 'spatial map' of these

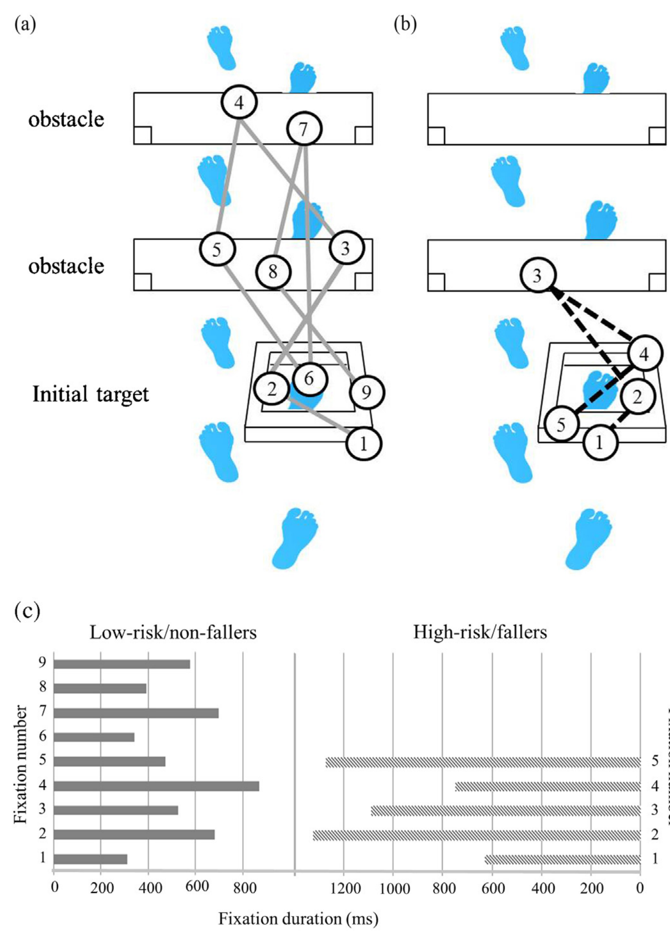

Fig. 1. A stylized representation of visual search behaviors exhibited by: (a) low-risk older adults with low fear of falling, and (b) high-risk older adults with high FOF, when approaching a series of stepping constraints on a level 8 meter walkway. The circled numbers represent the order of visual fixations on each constraint. The bar chart X-axis (c) illustrates the durations of each fixation on prior to stepping into the initial target. The number in the bar chart Y-axis corresponds to the fixation number in diagrams (a) and (b).

environmental features [12]. Without this spatial information, during the period when participants negotiated the initial target, there would be an ever-increasing need to fixate the upcoming constraints (in order to start planning future actions). This latter rationale is supported by a clear correlation between the number of obstacle fixations and the extent to which OA transferred their visual fixation from the target prior to foot contact (i.e., if participants fixated obstacles on fewer occasions, they would transfer visual fixation from the initial target earlier) [9]. Therefore, premature gaze transfer from a stepping target in OA with high FOF may not be a sole consequence of age-related deficits in central nervous system processing. Premature fixation of future constraints is likely to be driven as a consequence of suboptimal visual search behaviors during the approach. As such, it is pertinent to discuss possible reasons why OA with FOF will change the visual search behaviors required for the planning of future stepping actions.

4. Prioritizing visual stability

In this section, we consider the possible consequences of prioritizing head stability during visual search behaviors. Oscillations generated from the lower limbs during walking can reduce head stability. As the eyes require a stable platform in order to gather accurate spatial and temporal information regarding the visual scene, unless body oscillations are attenuated the fidelity of images reaching the retina would be compromised. Cromwell et al. [13] showed that increased age is associated with a reduced ability to produce head stabilizing movements, presumably due to deterioration in the acquisition and integration of sensory information. As a compensatory strategy, OA produce a tighter coupling (reduced range of movement) between the head and trunk compared to young adults. However, this coupling significantly deteriorates under no vision conditions; suggesting that older adults rely more on visual information to stabilize head movements, as they are less able to employ input from the vestibular system [15]. Furthermore, FOF is associated with dramatic reductions in head pitch plane variability when walking [8]. Consequently, the changes in gaze behavior described by Young et al. [9] and King et al. [14] may represent a degree of saccadic inhibition to preserve the stability of the visual image on the retina and maximize the fidelity of visual information required for maintaining head stability. These findings contribute to an emerging pattern; increased FOF leads to stiffening movement strategies that serve to minimize the amplitude and variability of: (i) the control of static posture [3–5]; (ii) the dynamics of gait [7,8]; (iii) head movements [8]; and (iv) visual search [9].

It seems likely that FOF-related shifts toward stiffening strategies represent attempts to minimize 'unnecessary' destabilizing movements even when, in the instance of visual search, they are required for picking up external information and movement planning during adaptive gait. In the following section, we attempt to explain possible mechanisms behind stiffening responses, by describing existing explanations of how anxiety can alter the allocation of attention and the consequences this can have on motor performance. We present a framework (Fig. 2) and some predictions with respect to FOF-related stiffening behaviors in OA.

5. Anxiety and the allocation of attention

In the field of experimental psychology, several researchers have used dot-probe tasks to demonstrate how young adults diagnosed with high anxiety exhibit an initial attentional bias toward threatening stimuli (hypervigilance) [15]. These findings have since been replicated in OA by Lee and Knight [16]. However, these authors showed that the type of attentional bias exhibited depends on the nature of the stimulus. For example, anxious OA exhibited a vigilance–avoidance response (an initial orientation of attention toward threat, followed by a reorientation of attention away from threat) to both angry and sad faces. However, the same participants adopted an avoidance–vigilance response to negative words [16]. The authors concluded that the differences in OA's responses between stimulus modalities were regulated by the extent to which the stimulus related to the observer, such that highly relevant stimuli would induce an avoidance–vigilance response. In the context of FOF, the self-relevance of any perceived threat to balance will be high. Therefore, one would predict that increased anxiety would result in an avoidance–vigilance response, resulting in the prolonged allocation of attention toward aspects of the environment that are perceived to pose the greatest threat to balance.

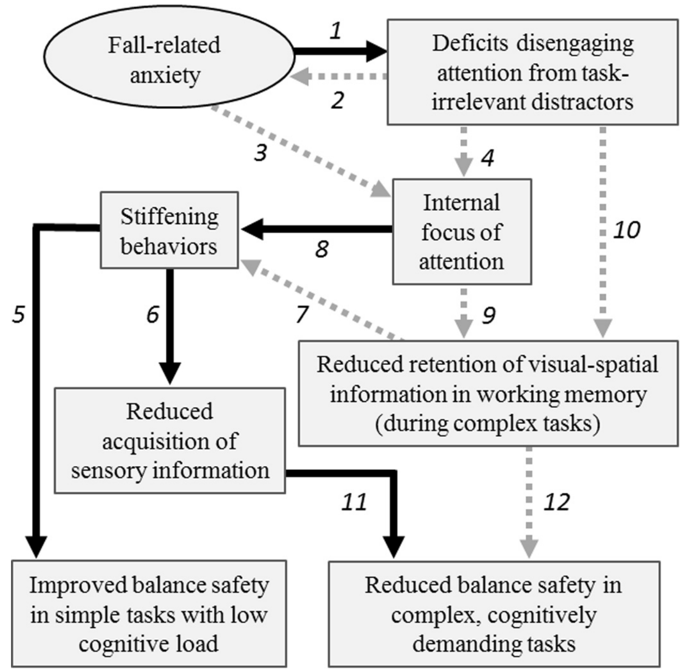

Fig. 2. Schematic diagram illustrating how fear of falling can influence balance performance. Solid black lines indicate associations strongly supported in the literature. Dotted gray lines represent partially supported/speculative predictions.

The above hypothesis was tested by Brown et al. [17] using stimuli specific to the context of FOF. A cohort of OA was separated in to one of two groups depending on whether they self-reported as being low or high in FOF. The authors reported that both groups of OA demonstrated an initial attentional bias toward fall-relevant threatening words, compared to threatening words un-related to falling. However, OA with FOF took longer to respond to the probe during conditions where it appeared in a location opposite to that containing a fall-relevant threatening word. These results indicate that OA with FOF are less able to disengage attention from threatening stimuli that is relevant to falling; behavior that could be described as a vigilant–vigilant response [17] (Fig. 2, link 1).

The prolonged allocation of attention toward negative words in anxious OA has been interpreted as representing a form of worrying [16,17]; a strategy adopted by anxious individuals to cope with increased arousal caused by threatening stimuli. Brown et al. [17] raised the prospect that dwelling on elements of the environment that constitute a threat to balance may elevate an individual's fear-response (i.e., there may be a closed loop system whereby increased FOF induces an attentional bias that prioritizes the processing of threatening stimuli, which in turn serves to propagate FOF (Fig. 2, link 2)).

The majority of the findings presented above are derived from dot-probe tasks, which present several limitations. For example, they mainly refer to spatial allocation of attention and only provide a gross estimate of how attention is allocated over time. Therefore, attempts have been made to develop theoretical models that can account for the complexities of this topic and can be scrutinized using a variety of experimental paradigms. The most relevant and prominent theoretical framework is Attentional Control Theory (ACT) [18] which builds upon its predecessor Processing Efficiency Theory [19]. Several predictions arise from ACT. First, task performance is compromised in anxious individuals due to their inability to ignore distractors/task-irrelevant stimuli, leading to a broad impairment in attentional allocation. According to this view, increased anxiety will disrupt the balance between goal-directed and stimulus-driven attentional systems by increasing the influence of bottom-up processes.

Second, ACT proposes that, coupled with attentional bias toward task-irrelevant stimuli, increased anxiety will inhibit the reallocation of attention toward task-relevant stimuli. When walking, hazards represent a threat to safety, yet being vigilant to this threat is still relevant to the task of safe negotiation. Therefore, anxiety-related difficulties in disengaging from threatening stimuli [16,17] do not necessarily constitute an attentional bias for task-irrelevant stimuli. That is, unless attentional resources are no longer engaged in pragmatic processes of perceiving relevant information guiding action, but are instead directed toward to the threat of falling in a more general sense, meaning that attention is consumed by worrisome thoughts about falling. This behavior has been described as 'rumination', where individuals will continuously dwell on a single common theme [20].

In regards to this second prediction, we suggest that anxiety-related deficits shown when OA disengage attentional resources from threatening stimuli is likely to inhibit the necessary switching of attention between postural control and any additional tasks of daily life. Lundin-Olsson et al. [21] showed that OA often stop walking when they are required to engage in conversation. The authors argued that age-related increases in the cognitive demands of regulating walking actions lead to difficulties in carrying out a secondary cognitive task, such as talking. Furthermore, the incidence of stopping during walking when talking was strongly associated with fall-risk [21]. It is widely thought that this increased fall-risk is not a sole consequence of age-related physiological deterioration in balance control mechanisms, but rather due to an inability to allocate attentional resources effectively during multi-task scenarios [6]. According to this logic, any FOF-related influences on attentional processes such as attention switching could have a significant impact of fall-risk.

A third hypothesis emerging from ACT constitutes a major component of its predecessor Processing Efficiency Theory (PET [19]). A suggestion is that anxiety reduces the efficiency of the central executive part of working memory [22]. Therefore, OA engaging cognitive resources in processing task-irrelevant factors (such as ruminating on the threat of falling) is predicted to compromise the capacity of working memory during cognitively demanding tasks. For example, during compensatory balance adjustments, young adults will rely on previously-stored visuo-spatial information (regarding surrounding environmental features) that has been acquired through overt visual scanning and fixating salient features [12]. King et al. [14] showed that compared to young adults, OA were less likely to visually fixate a handrail when entering a room, despite being twice as likely to reach for the rail following a platform perturbation. The finding that older adults do not visually search their environment for salient task-relevant features [13,14,23] seems counterintuitive. King et al. [14] speculated that the most likely explanation for this behavior relates to possible age-related deficits in visual-spatial memory, such that if OA cannot retain a 'spatial map' of their surroundings, there is little purpose in using proactive visual search behaviors.

We suggest that the type of anxiety-related reductions in visual search behavior reported by Young et al. [9] may occur through a form of conditioning where anxious OA do not perform proactive visual search because they are less able to retain the visual-spatial information that such behaviors afford (Fig. 2, link 7). Consequently, anxious OA do not acquire sufficient relevant visual-spatial information to perform optimal planning and stepping safety is jeopardized as a result [9–11] (Fig. 2, links 6 and 11). Furthermore, acquired visuo-spatial information is less likely to be retained leading to compromised and ill-informed movement planning [12] (Fig. 2, link 12). A key objective for researchers in future should be to assess whether FOF (and associated deficits in disengaging from task-irrelevant distractors) compromises the retention of visual-spatial information, and if so, to ascertain whether these changes are associated with reductions in visual search behavior (i.e., scrutinize links 10 and 8 in Fig. 2, respectively).

A fourth proposal of ACT constitutes another major assumption of its predecessor Processing Efficiency Theory [19], namely, that when the demands of a task are low, anxious individuals can maintain performance through increasing mental effort. However, if task demands increase, there is a point where increasing effort is no longer sufficient to accommodate anxiety-related inefficiencies in working memory and performance declines. This latter rationale supports the dissociation between simple and complex tasks depicted in Fig. 2, as it is only when OA are engaged in dynamic and demanding postural tasks that FOF-related inefficiencies in working memory caused by deficits in disengaging from threatening/task-irrelevant stimuli (such as ruminating on worrisome thoughts about falling) are likely to compromise balance performance (Fig. 2) and increase fall-risk. As such, this discussion surrounding the predictions of ACT has less relevance to the performance of simple postural tasks. Presumably, FOF-related stiffening adaptations observed during static and relatively simple balance tasks are unlikely to be a consequence of changes in cognitive processing efficiency. Therefore, other mechanisms must be responsible for the stiffening responses observed. One likely candidate is discussed in the next section.

6. Freezing degrees of freedom: a motor learning perspective

In a seminal paper, Bernstein [24] observed that the musculo-skeletal system is complex and nonlinear such that synergies between activities in muscle groups can lead to an almost infinite array of motor outcomes. Likewise, the same action can be achieved by various different combinations of motor activity [24]. While such an approach provides a great deal of flexibility, there are many potentially redundant degrees of freedom within the system that must be controlled.

In early stages of learning ontogenetic skills, performers will rely largely on explicit movement goals; building knowledge about how to perform a given task using explicit verbal/declarative information (for a review, see Masters and Maxwell [25]). However, in an attempt to consciously guide movement and simplify the control process, novice performers subconsciously freeze redundant degrees of freedom within the kinematic chain [24,26]. As learning progresses, performance becomes more automatic, relying less on cognitive resources to guide movement as explicit performance knowledge has been consolidated into procedural knowledge and automatic control processes [25]. The progression from explicit to implicit guidance of movement is matched by a progressive freeing of the degrees of freedom, such that more skilled performers can exploit the inherent flexibility within the system [24,25].

The notion of freezing and freeing degrees of freedom within the motor system has been extended to the domain of visual perceptual skill. Savelsbergh et al. [27] describe how a visual scene affords various sources of information that can be used to perform the same task. These visual variables represent perceptual degrees of freedom and can be considered as a visual analog to that shown for motor performance as observers show a similar sequence of freezing and freeing the manner in which they exploit the available degrees of freedom at different stages of learning [27]. The argument is that there is considerable redundancy in how individuals, particularly skilled ones, pick up relevant information from visual scenes. Skilled individuals may often use more 'global' rather than 'local' processing strategies enabling them to pick up many different and alternative sources of information in a confirmatory manner to guide performance during goal-directed action. Such strategies present skilled individuals with considerable functional variability and adaptability in dealing with the unique constraints of any given situation [27].

Several researchers have suggested that under increased anxiety individuals regress to earlier stages of skill development by forcing them to allocate attention toward the co-ordination of movement rather than the performance goal, compromising automatic movement control processes [25,26]. The concept of a shift from less to more attention demanding control strategies is nicely illustrated by the phenomenon of 'reinvestment', where individuals re-invest cognitive effort into aspects of performance that had otherwise become subconscious as they become more anxious on a task [25].

Similar arguments arise from the body of literature that has examined the relative importance of an internal and external focus of attention during learning and performance. Instructional sets that encourage an internal focus of attention are more likely to induce conscious processing strategies resulting in slower and more purposeful movements, increased pre-movement times [26,28], and increased co-contraction of antagonist muscle groups. For example, under instruction to direct attention internally young adults will increase the co-contraction of affecting muscle groups during a biceps curl [29]. In contrast, when attention is directed externally toward action-effects rather than the action itself, the control processes are more likely to be subconscious, less prone to forgetting and more likely to be resistant to external stressors such as anxiety [25,26].

According to Masters and Maxwell [25], the performance of complex ontogenetic skills will be more vulnerable to performance anxiety since they are more likely to be acquired using explicit instructional approaches that focus attention internally on to the underlying control processes rather than externally on the action-effects. The use of more explicit approaches to instruction is likely to result in the development of a set of explicit declarative rules that can increase the likelihood of progression-regression through reinvestment [25]. Such arguments would explain why, in a sporting context, performance anxiety is associated with decreased movement 'fluency' and a reduction in the co-ordination of fine motor tasks. For example, golfers will often report 'freezing' in their hands when performing putting actions in high-pressure situations; a condition known as 'the yips'. In addition, previously researchers have shown that motor performance following perceptual-training strategies that encourage explicit processing (compared to guided-discovery approaches that do not) is more susceptible to negative effects of performance anxiety [25]. Conversely, it is argued that phylogenic skills, such as controlling posture, have been learned early in childhood in the relative absence of explicit declarative information. As such, with phylogenic skills, it is not possible to revert back to earlier cognitive stages of learning. Therefore, when describing anxiety-related alterations in attempts to consciously control these types of movements, it is perhaps inappropriate to refer to the concept of reinvestment, but rather as an internal focus of attention (Fig. 2, link 3).

Nevertheless, the behavioral consequences of consciously controlling movement appear to be highly comparable between ontogenetic and phylogenic skills. For example, when performing a balance task, performance is enhanced when allocating attention externally (toward the movement of a platform on which participants stand), compared to focusing internally (toward the movements of participant's own feet) [29]. The above observations have been replicated in ontogenetic sporting skills such as a basketball free-throw [25].

Published reports involving dual-task paradigms suggest that conservative stiffening postural adaptations in OA are associated with a so-called 'posture first' strategy; where OA will show a reduction in the performance of a non-threatening secondary task under conditions of high postural threat (induced through raising the height of the support surface), compared to low-threat conditions [7]. These reports suggest that, independent from age-related increases in the cognitive demands of controlling posture and gait [6], performing postural tasks in threatening scenarios carries an increased attention cost. We suggest that these results can be rationalized according to the literature described above, such that OA with FOF will direct attention internally to control posture [30]. In a similar manner to that shown in young adults, this internal focus of attention leads to stiffening behaviors and freezing degrees of freedom [25] (Fig. 2, link 8). Furthermore, increased internal focus of attention could result in fewer resources being allocated toward additional cognitive or motor tasks [6,21], compromising the retention of visuo-spatial information stored in working memory (Fig. 2, link 9).

Wong et al. [30] showed that internal focus of attention was higher in OA fallers compared to non-fallers, particularly when task demands increased (when carrying tray with cup of water compared to when walking without a tray). The above research only shows direct associations between fall-risk and increased internal focus of attention. As such, evidence for a direct relationship between FOF and an internal focus of attention in OA is currently lacking. In a static standing task, Huffman et al. [5] showed that young adults would self-report higher FOF and levels of 'reinvestment' under conditions of high, compared to low postural threat (standing on a fixed position at high or low elevation, respectively) [5]. Further research is needed to ascertain whether this direct relationship between FOF and internal focus of attention is evident in OA (i.e., scrutinize link 3 in Fig. 2). In the final section, we make some specific suggestions for work that should be prioritized in this emerging field of research.

7. Future directions

Our current knowledge of the processes that underpin the relationship between FOF and stiffening behavior in posture and visual control is severely limited. As such, there is a clear need for more conceptually driven research using existing frameworks such as ACT to interpret behaviors observed within functionally relevant tasks. In future, researchers should endeavor to improve understanding as to whether stiffening behaviors are a consequence of: (i) inefficiencies in attentional processing compromising retention of information in working memory (Fig. 2, links 10 and 7, respectively); and/or (ii) an internal focus of attention leading to freezing the degrees of freedom in the motor system (Fig. 2, links 4 and 8, respectively). Ultimately, the development of effective therapeutic strategies aimed at reducing fall-risk in OA will depend on our understanding the possible interactions between these two hypothetical catalysts of stiffening behavior. Likewise, there is a need to establish possible associations between concepts of FOF-induced ruminating on task-irrelevant stimuli and adopting an internal focus of attention. However, the literature on this topic is currently in its infancy and the initial challenges for the scientific community should be to establish basic causal links between FOF and altered attentional processes identified in Fig. 2.

These basic questions could be answered using dynamic standing posture tasks, by manipulating the degree of postural threat (e.g., through altering support surface height) and the degree of task difficulty (e.g., placing participants on a stabilometer [26] and manipulating the base of support and device friction). First, researchers should establish whether stiffening behaviors in postural control and eye movements are observed in OA under high-threat and in more difficult task conditions. Second, researchers could establish the influence of FOF on the retention of visuo-spatial memory (e.g., by using a visual recall test); scores which could then be compared to measures of visual search behavior (scrutinize links 10 and 7 in Fig. 2, respectively). The degree to which OA adopt an internal focus of attention could be measured using self-reported scores from the Movement Specific Reinvestment Scale [25] indicating the degree to which FOF induces conscious movement regulation leading to freezing the degrees of freedom (scrutinize links 3 and 8 in Fig. 2, respectively). Self-reported measures of conscious movement control could be supplemented by neuroscientific evidence. For example, electro-encephalography can indicate the degree of frequency coherence (or communication) between the verbal-analytical (T3) region of the left hemisphere, and the motor planning frontal region (Fz) of the right hemisphere. Reduced coherence between these regions would imply a reduced conscious control and increased automaticity of movement [25]. Subsequent work should then look to manipulate: (i) the demands placed on each component of working memory; and (ii) the dynamic nature of the task (i.e., from standing posture to adaptive locomotion). An important prediction for future work is that during cognitively demanding tasks, the degree to which OA direct attention internally in order to consciously control movement, will be proportional to the: (i) degree of stiffening behavior in posture and visual search; and (ii) deficits seen in working memory regarding external information, such as visual-spatial memory of environmental features.

Finally, considering the complex nature of age-related decline in sensory, motor, and musculoskeletal function, along with numerous other cultural and social factors associated with FOF [1], there are likely to be many factors interacting with the psychological processes described above. Therefore, researchers should look to scrutinize the assumed applicability of ACT as a relevant guiding framework for research on this topic.

In summary, the objective of this paper was to describe FOF-related behavioral adaptations reported in the literature, and attempt to rationalize these observations using current psychological frameworks. We have shown that the manner in which OA with FOF control posture and gait, along with head and eye movements can be broadly conceptualized as 'stiffening strategies'. We have described how FOF-related alterations in attentional control and processing efficiency are likely to be largely responsible for these behavioral changes. Our capacity to understand these processes will rely on future interdisciplinary research that is both grounded in psychological theory, uses cross-disciplinary methods, and has translational impact on clinical practice. The principle objective of this article was to provide a broad framework to facilitate this new direction in research. It is our intention that researchers should look to scrutinize and supplement the assumptions made in this paper to progress scientific knowledge of this topic.

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Conflict of interest statement

The authors confirm that there are no known conflicts of interest regarding the work described in the current manuscript.

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