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Movements of older adults during exergaming interventions that are associated with the Systems Framework for Postural Control: A systematic review

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ABSTRACT

One in three older adults fall annually, in part due to impairments in the physiological systems that make up the postural control (PC) system. Exercise, particularly balance training, helps to prevent deterioration and even to improve outcomes in the PC system. Exergaming (exercise-gaming) is interactive computer gaming whereby an individual moves the body in response to onscreen cues in a playful format. Exergaming is an alternative method to standard practice for improving PC outcomes, which has been shown to reduce the risk of falling. Exergaming has received research attention, yet the intervention is still in its infancy. There could be benefit in exploring the movements trained with respect to a framework known for identifying underlying deficits in the PC system, the Systems Framework for Postural Control (SFPC). This may help target areas for improvement in balance training using exergames and shed light on the impact for fall prevention. A literature search was therefore conducted across six databases (CINAHL, EMBASE, PubMed, ISI, SPORTdiscus and Science Direct) using a range of search terms and combinations relating to exergaming, balance, exercise, falls and elderly. Quality assessment was conducted using the PEDro Scale and a custom-made quality assessment tool. Movements were rated by two reviewers based on the 9 operational definitions of the SFPC. Eighteen publications were included in the analysis, with a mean PEDro score of 5.6 (1.5). Overall, 4.99 (1.27) of the 9 operational definitions of the SFPC are trained in exergaming interventions. Exergaming does encourage individuals to stand up (3), lean while standing (4), move upper limbs and turn heads (6) and dual-task while standing (9), to some extent move the body forwards, backwards and sideways (1), and coordinate movements (2) but hardly at all to kick, hop, jump or walk (7), or to force a postural reaction from a physical force to the individual (5) and it does not mimic actual changes in sensory context (8). This is the first review, to our knowledge, that synthesises the literature on movements trained in exergaming interventions with respect to an established theoretical framework for PC. This review could provide useful information for designing exergames with PC outcomes in mind, which could help target specific exergames for multi-factorial training to overcome balance deficits. Some elements of PC are too unsafe to be trained using exergames, such as restricting sensory inputs or applying physical perturbations to an individual to elicit postural responses.

1. Introduction

1.1. Background

Falling is a consequential aspect of ageing, neurological or musculoskeletal disease [1–4]. Exercise is a well-established means to reduce the risk of falling in older adults by significantly improving the systems that constitute balance, muscle strength, flexibility and endurance [5,6]. To maintain balance, the visual, vestibular and somatosensory systems cooperate to create postural and kinetic reactions to the immediate environment and over time these systems inevitably begin to decline [7]. Balance based training has shown to improve the multitude of systems that constitutes the postural control (PC) system, which when impaired can be a strong predictor of falls for older adults [8–10].

Exergaming (exercise-gaming) is showing to be as effective as alternative methods at improving PC outcomes in community dwelling individuals [11,12]. Current methods employed include group-based classes based on fall prevention training programmes such as the Otago exercise programme [13] and the Falls Management Exercise programme (FaME) [14], which include key components such as balance,

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muscle-strengthening, flexibility and endurance [15] and well as Tai Chi and functional floor activities that train coping skills for confidence. The plethora of outcome measures used in exergaming interventions each hold individual limitations in higher functioning older adults, improvement retention has not been assessed longitudinally and the heterogeneity of intervention characteristics make generalising outcomes problematic [16].

Movement characteristics of exergames have been previously explored and have focused on stepping exergames due to their natural occurrence during gait and their importance in the prevention of falls [17]. The system setup used for exergames heavily influences the movements performed and therefore the movements trained during a given intervention. Although previous research has explored the importance of movement quality for designing future exergames for fall prevention, there is a need to utilise a framework based on postural control to fully understand the gaps in training for the underlying mechanisms. Outcome measures have been previously explored in a scoping review which identified components of PC included in standardised balance measures based on the Systems Framework for Postural Control (SFPC) [18]. The SFPC was designed to detect underlying balance problems from a balance assessment tool "BESTest" developed and validated by Horak and colleagues [19].

The ability to maintain equilibrium and postural orientation is reportedly context specific and the underlying physiological risk factors for balance are multifactorial, similarly to risk factors for falls [20]. In any of the six components of the SFPC (Table 1), a constraint can come about from neurological, musculoskeletal or medicinal factors and subsequently increase the risk of falls and injuries from falls. Biomechanical limitations in the feet and the base of support (BoS) can affect the limits of stability due to reductions in size, strength, range and control of the feet or increases in pain. Inaccurate representation of the stability limits from the central nervous system (CNS) may result in postural instability in basal ganglia disorders such as Parkinson's disease [20]. A tilted or inaccurate internal representation of visual or postural verticality can result in an incorrect automated alignment with respect to gravity, which in turn increases instability, such as in individuals with unilateral vestibular loss (tilted) or individuals with hemi-neglect due to stroke (inaccurate) [21]. Older adults at risk of falls have shown to use movement strategies to maintain postural stability more at the hip than at the ankle and have used stepping actions due to the lack of ability to exert angle torque at the ankle as a preliminary strategy [22]. There is also a lack of control of dynamics in older fallers in the form of larger than normal lateral excursions of the centre of mass (CoM) and more irregular foot placements. These limitations during gait or during postural transitions can lead to a trip, slip or fall depending on the context of the immediate external environment. Limitations in the ability to communicate sensory information in complex internal sensory environments can also put individuals at risk of falling in specific sensory contexts (stood in a well lit room with a solid floor versus stood in a field at night) [23]. Individuals with Alzheimer's disease may prohibit the re-weighting of sensory dependence from the CNS even with a reliable peripheral sensory system [20]. Cognitive processing is required for simple PC strategies and increase with the complexity of the task with the addition of a secondary task [24]. Neurological impairments can influence the ability to control posture and perform a secondary task and can lead to falls due to the lack of cognitive processing capabilities [20]. The use of the SFPC to rate exergames may help target areas that are or are not being trained in exergaming interventions and may provide recommended games for specific components of the framework to subsequently tailor future training.

Using the SFPC, this review will explore movement characteristics that train the PC system during exergaming interventions. We hope to systematically address which movements are being trained and which system set-up best meets the components of the SFPC. This approach may inform design of exergames in the future by addressing the underlying mechanisms of PC. The movements elicited during exergaming interventions may be dependent on the exergaming apparatus used, games played and movements required to drive the exergame.

1.2. Objective

Therefore, this systematic review aims to evaluate the movements trained with the consoles used in exergaming interventions associated with the components of the SFPC.

2. Method

2.1. Study selection criteria, search strategy and quality assessment

The reporting of this systematic review was performed according to the PRISMA guidelines [25]. Full details of the inclusion and exclusion criteria and the search strategy are provided in an earlier paper reporting interventions effects according to primary, secondary and

Table 1
Components of postural control operational definitions adapted from Sibley et al. [18].

Six components of SFPC		Operational Definitions	Does the game:
1. Biomechanical constraints: degrees of freedom, strength, limits of stability	1	Functional Stability	Test the ability to move the centre of mass as far as possible in the AP and ML directions within the base of support?
	2	Underlying Motor Systems	Test strength and coordination sufficiently through the physical activity of the game?
	3	Static Stability	Test the ability to maintain position of the centre of mass in unsupported stance when the base of the support does not change (May include wide stance, narrow, 1-legged stance, tandem, any standing condition)?
2. Orientation in space: perception of gravity, verticality	4	Verticality	Test the ability to orient appropriately with respect to gravity (e.g. evaluation of lean)?
3. Movement strategies: reactive, anticipatory, voluntary	5	Reactive Postural control	Test the ability to recover stability after an external perturbation to bring the centre of mass within the base of support through corrective movements (e.g. ankle, hip, and stepping strategies)?
	6	Anticipatory Postural Control	Test the ability to shift the centre of mass before a discrete voluntary movement (e.g. stepping-lifting leg, arm raise, head turn)?
4. Control of dynamics: gait, proactive	7	Dynamic Stability	Test the ability to exert ongoing control of centre of mass when the base of the support is changing (e.g. during gait and postural transitions)?
5. Sensory strategies: integration, reweighting	8	Sensory Integration	Test the ability to reweight sensory information (vision, vestibular, somatosensory) when input altered?
6. Cognitive processing: attention, learning	9	Cognitive influences	Test the ability to maintain stability while responding to commands during the task or attend to additional tasks (e.g. dual-tasking)?

AP = Anteroposterior, ML = Mediolateral.