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Use of virtual reality technique for the training of motor control in the elderly

Some theoretical considerations

Decline in physical function is a common feature of older age and has important outcomes in terms of physical health related quality of life, falls, health care use, admission to residential care and mortality [1, 2]. The most common reason for loss in functional capabilities in the aged, however, is inactivity or immobility [3, 4, 5]. Even in the absence of overt pathology, motor functioning [cf. International Classification of Functioning (ICF) by the World Health Organisation, Geneva (see http://www.who.int/classification/icf)] can deteriorate, as is illustrated by the incidence and impact of falls in ageing populations [6]. Falls are amongst the most common reasons for medical intervention in the elderly and their occurrence might initiate a vicious circle that causes fear of falling, nursing home admittance and loss of independence [7]. Falls among older adult populations often occur during walking, and gait dysfunction is included among the many risk factors for falls [8, 9].

The most common reason for loss in functional capabilities in the aged is inactivity or immobility

Until recently, gait was considered an automated motor activity requiring minimal higher-level cognitive input [10]. Maintenance of postural control during activities of daily living does not usually place high demands on attention resources of healthy young or middle-aged people. In contrast however, when sensory or motor deficits occur due to natural ageing processes, the complex generation of movement may have to be restructured, and movements may then be controlled and performed at an associative or a cognitive stage [11]. When the benefits from the movement automation are lost, the postural control of aged people can be expected to be more vulnerable to cognitive distractions and additional tasks [11]. The link between cognition, gait, and the potential for falls is indeed being increasingly recognized [12] and is for example reflected in a special issue in the Journal of Gerontology: Biological Sciences and Medical Sciences (63A (12), 2008).

Negative plastic changes in the brain often occur naturally in later life when people begin to stereotype and simplify behaviors that previously were quite complex and elaborated. As people age, a self-reinforcing, downwards spiral of reduced interaction with challenging environments and reduced brain health significantly contribute to this cognitive decline [13].

Physical exercise to restore postural balance and walking function

Because difficulties of walking are a key factor in loss of independence for older individuals [14, 15] treatment of gait disorders is designed to optimize gait for the purpose of improving function. Previous studies have shown that physical exercise is effective [16] and may reduce gait variability in elderly [17]. Current evidence shows that interventions that aim to improve locomotor function in older people should preferably include strength training in combination with balance and coordination exercises [16, 18]. However, common interventions usually focus on the physical aspects of training while overlooking the specific rehabilitation of executive functions [19], a set of cognitive abilities that control and regulate other abilities and behaviors.

A central element of successful cognitive rehabilitation for older adults should be the design of interventions that either re-activate disused or damaged brain regions, or that compensates for decline in parts of the brain through the activation of compensatory neural reserves [20]. Cognitive activity or stimulation could be a protective factor against the functional losses in old age. Because spatial and temporal characteristics of gait are also associated with distinct brain networks in older adults it can be hypothesized that addressing focal neuronal losses in these networks may represent an important strategy to prevent mobility disability [21]. Interventions should, as previous research suggests, focus thereby on executive functioning processes [22] and should include enriched environments that provide physical activities with decision-making opportunities because these are believed to be able to facilitate the development of both motor performance and brain functions [23]. Executive cognitive functions are involved in the control and direction (planning, monitoring, activating, switching, inhibiting) of lower level, more modular, or automatic functions [24].

Virtual augmented exercises

Involvement of real-time simulation in an environment, scenario or activity that allows for user interaction via multiple sensory channels as an approach to user–computer interface can be defined as virtual reality [25]. Virtual reality (VR) system complexity ranges from cheap, readily available video gaming consoles such as the Nintendo Wii, Sony Playstation or Microsoft Xbox, through to dedicated, high costs systems such as the GestureTek IREX. The less complex and cheaper systems that require physical movement by the game player sometimes are referred to as exergames. VR techniques are rapidly expanding across a variety of disciplines. The use of virtual reality environments for virtual augmented exercise has recently been proposed as having the potential to increase exercise behavior in older adults [26] and also has the potential to influence cognitive abilities in this population segment [27]. The potential is based on strong presence (the feeling of being there) which is achievable in an interactive virtual environment and that is followed by greater distraction.

Weiss and colleagues [28] suggest that virtual reality platforms provide a number of unique advantages over conventional therapy in trying to achieve rehabilitation goals. First, virtual reality systems provide ecologically valid scenarios that elicit naturalistic movement and behaviors in a safe environment that can be shaped and graded in accordance to the needs and level of ability of the patient engaging in therapy. Second, the realism of the virtual environments allows patients the opportunity to explore independently, increasing their sense of autonomy and independence in directing their own therapeutic experience. Third, the controllability of virtual environments allows for consistency in the way therapeutic protocols are delivered and performance recorded, enabling an accurate comparison of a patient's performance over time. Finally, virtual reality systems allow the introduction of "gaming" factors into any scenario to enhance motivation and increase user participation [29]. The use of gaming elements can also be used to take patients' attention away from any pain resulting from their injury or movement. This occurs the more a patient feels involved in an activity and again, allows a higher level of participation in the activity, as the patient is focused on achieving goals within the game [30]. In combination with the benefits of indoor exercises such as safety or independence from weather conditions, such a distraction may result in a shift from negative to positive thoughts about exercise.

Gaming elements can be used to take patients' attention away from any pain

Many different forms of equipment can be used in order to create different kinds of virtual environments. The basic components of all forms are a computer, usually with a special graphics card for the fast computation and drawing of two- (2D) or three-dimensional (3D) visual images, display devices through which the user views the virtual environment, hardware devices used to monitor movement kinematics or that provide haptic and force feedback to participants, and especially written software that enables all of these components to work in synchrony [31]. There are both more immersive 3D and less immersive (2D) virtual environments. The latter are more kindred to looking through a window at a scene. Immersion refers to the establishment of the feeling of being inside and a part of the VR world.

VR and exergames as motor rehabilitation training

Although VR applications have been used in research and entertainment applications since the 1980s, it was only during the late 1990s that VR systems began to be developed and studied as potential tools to enhance and encourage participation in rehabilitation. Several studies have since emerged suggesting the potential of virtual reality as a successful treatment and assessment tool in a wide variety of applications, most notably in the fields of motor, and cognitive, rehabilitation.

In young subjects, it has already been shown that exercising on a stationary bike combined with a virtual cycling race enhances enjoyment and reduces tiredness [32], and promotes gains in cognitive function in brain-injured individuals [33]. For older adults interactive virtual environments can influence postural control and therefore fall events by stimulating the sensory cues that are responsible in maintaining balance and orientation [34]. Exergaming interventions (dance pad stepping, Wii balance board) improved parameters of static balance more than a traditional balance program in young healthy adults after 4 weeks of training [35]. Merians and colleagues [36] found that exercise conducted using a virtual reality interface enhanced the training of hand movements in patients post stroke, resulting in improved function of the fingers, thumb, and overall range of motion. These researchers also found that an improvement later transferred to real world tasks, demonstrating that VR based therapy has the potential to encourage a level of exercise intensity and participation that is comparable to conventional interventions [36].

The special value of VR training paradigms is believed to be due to the concordance of visual and proprioceptive information during training, thus updating the way seniors perceive their body with their environment [37]. Beside this stimulation, virtual environments provide salient feedback about the movement performance, and the difficulty of the task can be adapted according to the subject's ability which is particularly important for older adults. Virtual environments have also the potential to specifically include motor learning enhancing features that activate motor areas in the brain [38]. In addition the findings of You and colleagues suggest that VR training could induce reorganization of the sensorimotor cortex in chronic stroke patients [39]. However, the potential of such virtual reality trainings has yet to be explored for older adults.

In the following, to cite an example, we describe a low cost video game-based approach to training and rehabilitation of stepping ability that can potentially be used to reduce the risk of falls in older adults or for rehabilitation of balance control in stroke, spinal cord injury or other motor-impaired patients. We describe the theoretical considerations that indicate the potential of this technology for elderly together with some preliminary results from our research groups.

Exergame use for motor control training in the elderly

Interactive, user input devices such as dance pads are a low cost, interactive method of exergaming. These games, e.g. "Dance Dance Revolution" (DDR) or "Pump" are played on a dance pad sensor which measures about 1 m^2 and has between four and eight step panels (arrows). The pad is connected to a visual display screen such as a television or computer screen that provides step direction instructions to the player via a system of scrolling arrows that typically rise slowly from the bottom to the top of the screen. As the arrows scroll up to the top of the screen, they cross over a set of four corresponding arrow silhouettes. The player must step on the corresponding mat arrow as the scrolling arrow crosses its silhouette (■ **Fig. 1**). Sequences of steps can range in difficulty from simple marching or walking patterns to those with varied rates and irregular patterns that challenge co-ordination and attention.

It has been suggested that feed-forward planning of gait and posture is diminished in older adults. Motor adaptation is one mechanism by which feed-forward commands can be updated or fine-tuned [40]. The ability to make timely, appropriately directed steps underpins our ability to maintain our balance and move unaided through our environment [41]. Stepping, which involves changing the base of support (BOS) relative to our centre of mass (COM), also provides the means by which we are able to counter potentially destabilizing events such as slips, trips and missteps and avoid obstacles. Protective stepping may be initiated volitionally when a threat to balance is perceived, or induced reflexively when a disturbance moves the COM relative to the BOS at a speed that prevents engagement of volitional strategies.

Abstract · Zusammenfassung

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Use of virtual reality technique for the training of motor control in the elderly. Some theoretical considerations

Abstract

Virtual augmented exercise, an emerging technology that can help to promote physical activity and combine the strengths of indoor and outdoor exercise, has recently been proposed as having the potential to increase exercise behavior in older adults. By creating a strong presence in a virtual, interactive environment, distraction can be taken to greater levels while maintaining the benefits of indoor exercises which may result in a shift from negative to positive thoughts about exercise. Recent findings on young participants show that virtual reality training enhances mood, thus, increasing enjoyment and energy. For older adults virtual, interactive environments can influence postural control and fall events by stimulating the sensory cues that are responsible in maintaining balance and orientation. However, the potential of virtual reality training has yet to be explored for older adults. This manuscript describes the potential of dance pad training protocols in the elderly and reports on the theoretical rationale of combining physical game-like exercises with sensory and cognitive challenges in a virtual environment.

Keywords

Geriatric adults · Vitual reality · Virtual environment · Physical activity · Indoor exercise

Einsatz der virtuellen Realität für das Training der motorischen Kontrolle bei Älteren. Einige theoretische Überlegungen

Zusammenfassung

Eine durch virtuelle Realität ergänzte Bewegungsausführung stellt eine neue und sich schnell entwickelnde Technologie dar. Sie fördert die Lust zur Bewegung, vereinigt die Vorteile von Indoor- und Outdooraktivitäten und vermag sogar das Bewegungsverhalten von älteren Menschen zu verbessern. Eine starke Ablenkung von der eigentlichen Bewegungsausführung, verursacht durch ein überzeugendes Gefühl des Eintauchens in eine virtuell-interaktive Umgebung, kann dazu führen, dass sich die Meinung über Bewegung vom Negativen zum Positiven hin wendet. Neuste Erkenntnisse mit jungen Personen zeigen, dass das Training in einer virtuellen Umgebung Vergnügen bereitet, die Gemütslage und den Energielevel anhebt. Bei älteren Menschen kann eine virtuell-interaktive Umgebung die Haltungskontrolle beeinflussen und auch als Sturzprophylaxe dienen, in dem sie die sensorischen Bereiche stimuliert, die für die Kontrolle des Gleichgewichts und der Orientierung zuständig sind. Dennoch muss das Potenzial eines Trainings in einer virtuellen Umgebung bei älteren Menschen noch weiter erforscht werden. Dieser Artikel beschreibt die Möglichkeiten eines Einsatzes von elektronischen Tanzmatten bei älteren Menschen und erklärt die theoretischen Hintergründe der Kombination von körperlicher Aktivität mit gleichzeitigen sensorisch-kognitiven Aufgaben in einer virtuellen Umgebung.

Schlüsselwörter

Ältere Menschen · Virtuelle Realität · Virtuelle Umgebung · Körperliche Aktivität · Indoorbewegung

Fig. 1 ▲ Training set-up for the dance pad game. The core game play involves the player moving his or her feet to a set pattern, stepping in time to the general rhythm or beat of a song. During normal game play, arrows scroll upwards from the bottom of the screen and pass over a set of stationary arrows near the top (upper *red circle*) referred to as the "guide arrows" or "receptors". When the scrolling arrows overlap the stationary ones, the player must step on the corresponding arrows on the dance platform (lower *red circle*), and the player is given a judgement for their accuracy (Marvelous, Perfect, Great, Good, Boo/Almost, Miss/Boo) [51]

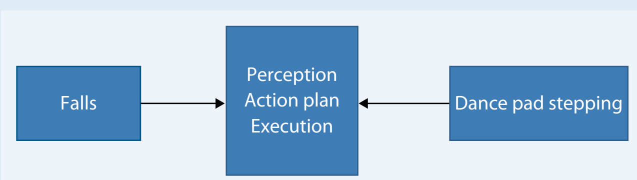

Fig. 2 ◀ Processes involved in avoiding a fall and in dance pad stepping

Initial studies suggest that both volitional and induced stepping abilities are significantly impaired in older versus younger individuals and are good predictors of falls. Compared to younger adults, older adults, particularly those with a history of falling, tend to be slower in initiating volitional step responses [42], make inappropriately directed or multiple short steps in response to an external perturbation of balance [43] and in response to lateral perturbations have an increased chance of collision between the swing and stance legs during compensatory stepping [44]. There is evidence, however, to suggest that the timing of volitional stepping [45, 46], as well as the execution of successful steps for recovery of balance following an induced slip [47], can be significantly improved in older adults following repetitive training of stepping responses.

Maki and colleagues [48] have recently suggested a protocol for step training which specifically targets the kinds of stepping abilities that contribute to falls such as collisions between legs during lateral perturbation or the tendency for older adults to take multiple, short laterally directed steps in response to an anterior–posterior perturbation. Although the training techniques they suggest are well suited to specifically train compensatory stepping ability their approach requires use of large devices (custom motion platforms [48], treadmills [47, 49], systems employing weights and pulleys [46], low resistance slip platforms) or the supervision of trained therapists [45]. None of these techniques could be easily or economically incorporated into home-based training programs.

Dance pad games require the player to make rapid step responses from either leg to a target location in response to a presented visual stimulus.

▬ Therefore these games are ideally suited for the training of stepping in older people.

They not only involve controlled body weight transfers that are similar to the step responses required to avoid many falls as well as requiring a narrow base of support and well-coordinated quick movements. They further require cognitive work, e.g. sensing of stimuli, paying attention and making quick decisions. This interaction of sensory, information-processing and neuromuscular systems is similar to the step responses required to avoid many falls and is therefore suitable as an intervention in a fall-specific context (◘ **Fig. 2**).

One hurdle facing the successful use of such exercise video games (or exergames) in older adult and functionally impaired populations is that many off-the-shelf video games are too complex for use by these groups. Video games must therefore be developed to take into consideration the cognitive and physical limitations, as well as the interest sets, of older adults. In the following we discuss the ways in which research groups in general could address these issues and in which our respective research teams are presently involved.

The use of DDR to date

The Sydney-based research group at Neuroscience Research Australia (DS & STS) has recently begun a research program aimed at developing age-appropriate DDR (Dance Dance Revolution)-style video games. The aim of this group is to both engage older adults in home-based step training exercises to reduce their falls rate as well as monitoring fall risk. In particular they aim to develop a low-cost approach to engage older adults in fall prevention training that can be placed into the houses of individuals, many of them living in regional, remote parts of Australia.

A recently published paper [50] describes a series of studies conducted to develop and establish characteristics of DDR videogame play in older adults. Participants aged 70 and above were asked to make simple step movements in response to vertically drifting arrows presented on a video screen. Step responses were detected by a modified USB DDR mat and characteristics of stepping performance such as step timing, percentage of missed target steps and percentage of correct steps, were recorded by purpose built software. Drift speed and step rate of visual stimuli were modified to increase task difficulty. Performance of older adults decreased as stimulus speed and step rate were increased. Optimal step performance occurred for a stimulus speed of 17° of visual angle per second and a step rate of one step every 2 s. At fast drift speeds (up to 35°/s), participants were more than 200 ms too slow in coordinating their steps with the visual stimulus. Younger adults were better able to perform the stepping task across a wider range of drift speeds than older adults.

Data (unpublished) of another recently finished study from this group indicate that the dance pad is a valid and reliable assessment instrument to measure the choice stepping reaction time in old and young people, a test that has shown to be predictive for falls in the elderly [42]. This offers the opportunity to assess the fall risk of older adults on a regular basis from the comfort of their own home.

The aim of a recently finished study in Zurich was to assess and compare the effects of a physical training program that included a VR dance simulation computer game against usual care exercise interventions for elderly residential care dwellers on relative dual tasking costs of walking [51]. These costs refer to the fact that many older adults exhibit a reduced ability to perform two tasks at the same time, e.g. walking at preferred speed is compared to walking at preferred speed whilst counting backwards. This study (unpublished) showed that elderly who were training physically, in combination with a VR dance game that required decision making, showed significant decreases in the relative dual task costs (DTC) of walking. These walking parameters did not change in individuals that trained with more traditional forms of training in usual care programmes. The possibility of improving gait while performing dual tasks has not been well-studied in general [10] and, to the best of our knowledge, this study [51] is one of the first that showed an effect on DTC-related walking. This study, which has been submitted for publication as a full text article, used dancing in a virtual environment as dual task training, where subjects were expected to observe the environment for drifting arrows and at the same time were initiating dance steps (▪ **Fig. 1**).

Conclusions

For older adults virtual, interactive environments have large potential to influence postural control and fall events by stimulating the sensory cues that are responsible in maintaining balance and orientation and by improving stepping patterns. However, the potential of virtual reality training has yet to be explored in sufficiently powered randomized controlled trials. Dance pad games, where repetitive medio-lateral and anterior-posterior steps are required offer a novel, yet effective, technique for training stepping ability in older adults.
Future research should develop, implement and evaluate VR exercise scenarios for various sub-populations that can be identified within the elderly adult population. In such projects an attempt could be made to get insight into the concept of motor learning in VR and the relationship between cognitive functions and balance and gait skills in elderly.

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