PHYSICAL THERAPY

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History

- Virtual reality (VR) is now commonly used in many domains, such as for the training of aircraft pilots or workers ensuring the maintenance of nuclear sites, both for security and economic reasons.
- Similarly, in the medical field, VR has been used for instance in the training of surgeons, especially for laparoscopic surgery *(Yiannakopoulou et al., 2015).*
- Virtual rehabilitation for movement disorders has been developing more slowly than virtual technologies in other areas of healthcare.
- The interdisciplinary nature of rehabilitation research also presents challenges. The design of interfaces to accommodate persons with impaired movement requires skills that span orthopedics, neuroscience, biomedical engineering, computer science and multiple rehabilitation disciplines.
- The full potential of VR will only emerge after we gain a thorough understanding of how various sensory and haptic manipulations in VR affect neural processes *(Adamovich et al., 2009)*.

Definition Of Virtual Reality

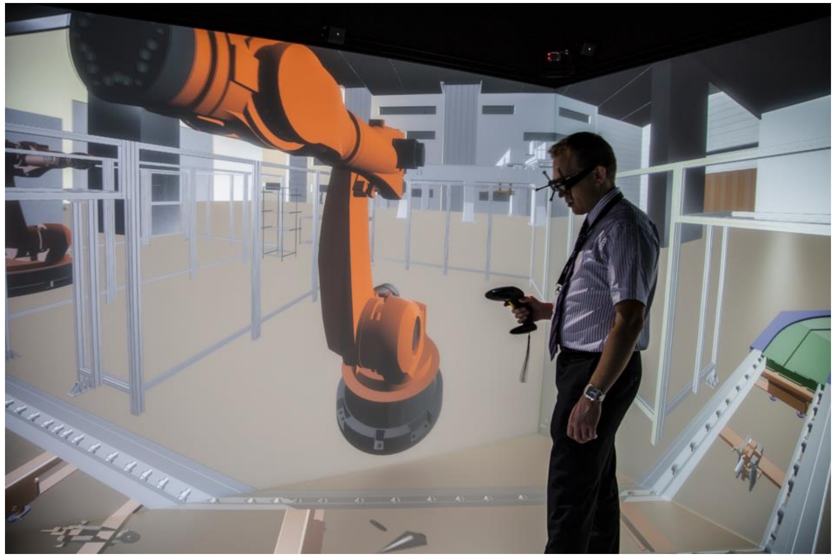
- VR aims to substitute the real-world sensations by computer-generated sensory information and to facilitate natural interaction with the virtual world *(Bermúdez i Badia et al., 2016)*.
- More precisely, VR consists of simulating the behavior of 3D entities that interact with each other in real time and with users, immersed in a pseudo-natural manner through sensorimotor channels *(Morel et al., 2015)*.
- VR and virtual environments (VEs) are created by using hardware and software that allow users to interact with objects and events that appear and sound, and in some cases feel, like those in the real world *(Wilson et al., 1997)*.
- VEs are used in a rehabilitation context as an approach to improve the motor and cognitive ability of persons with activity and participation limitations through the use of interactions with VEs *(Adamovich et al., 2009)*.
- Initial investigations into this family of approaches to rehabilitation emerged in the mid 1990's *(Adamovich et al., 2009)*.

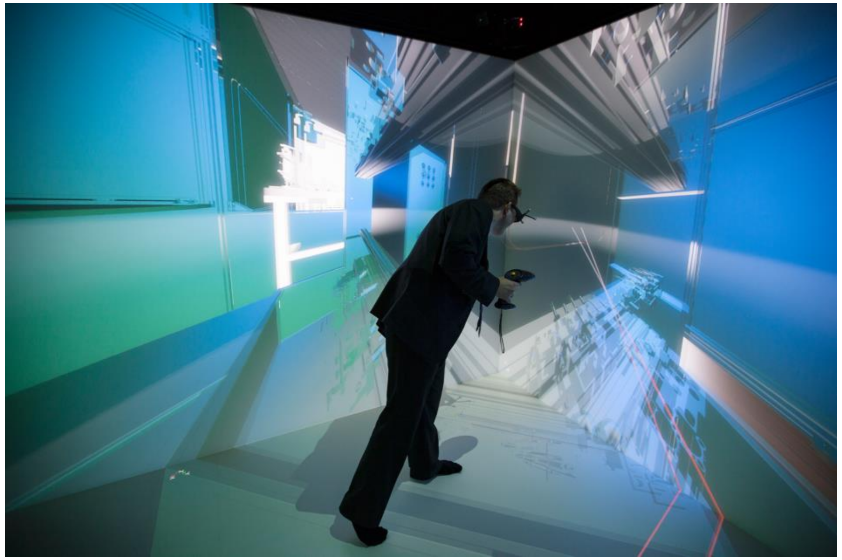
THEORETICAL ASPECTS OF FEEDBACK-BASED TRAINING AND VIRTUAL REALITY IN SENSORIMOTOR NEUROREHABILITATIVE PHYSICAL THERAPY

Virtual reality systems are generally classified by the visual presentations they provide to a participant, the presence or absence of somatosensory feedback and the modality used to collect data from the participant.

Visual stimuli are grouped by the level of immersion:

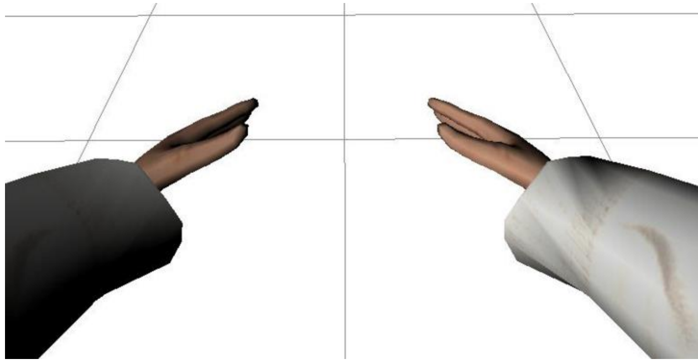
1. Two dimensional presentations are considered non-immersive.
2. Three dimensional presentations utilizing stereoscopic projections or displays with a fixed visual perspective are considered semi-immersive.
3. Fully immersive systems allow for changing visual perspective with head movement.
4. The most immersive system is the CAVE (University of Illinois at Chicago) which is a room-size, 3D video and auditory System *(Adamovich et al., 2009)*.

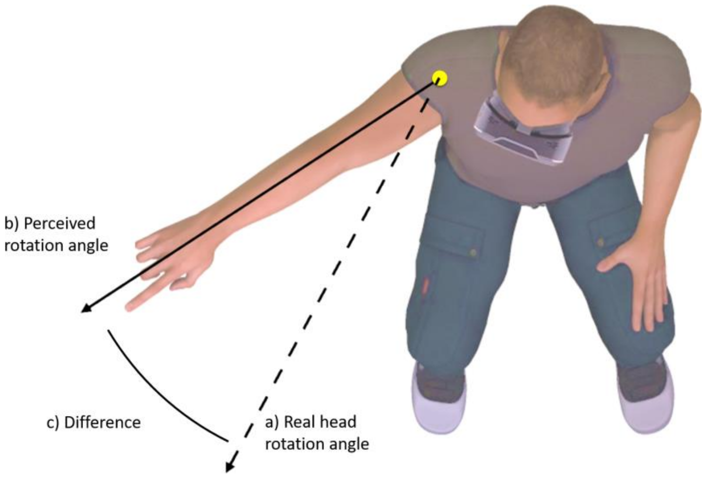




THEORETICAL ASPECTS OF FEEDBACK-BASED TRAINING AND VIRTUAL REALITY IN SENSORIMOTOR NEUROREHABILITATIVE PHYSICAL THERAPY (2)

- In healthy adults the salience of the VE, the hardware used to deliver the VE, and the personal qualities of the participants have been shown to interact in creating a sense of presence and immersion *(Rand et al., 2005)*.
- Complete immersion, however, is not a requirement for presence, as participants post stroke were shown to be present even in semi-immersive environments *(Rand et al., 2008)*.
- Thus, some characteristics of VR systems such as synchronism of stimuli *(Slater et al., 2009)*, alignment and continuity of the real and virtual bodies *(Perez-Marcos et al., 2012)*, and perspective *(Petkova et al., 2011)*, are determinants for inducing a sense of presence and embodiment and consequently are contributing factors in the effectiveness of VR-mediated therapies.





Change in perceived body position (C) was operationalized as the difference between perceived head rotation (B) after movement during altered visual feedback, relative to during movement with normal visual feedback (A). Harvie et al., 2017

THEORETICAL ASPECTS OF FEEDBACK-BASED TRAINING AND VIRTUAL REALITY IN SENSORIMOTOR NEUROREHABILITATIVE PHYSICAL THERAPY (3)

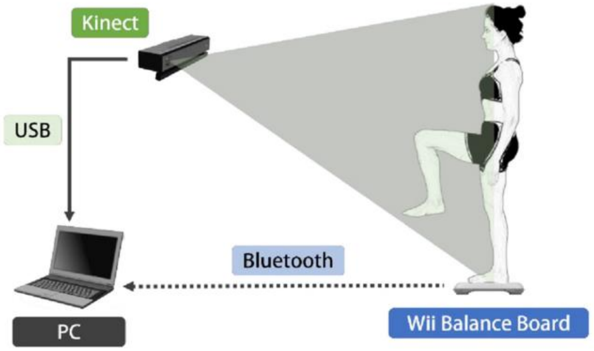
Motor learning principles are defined as the set of processes associated with practice or experience that lead to relatively permanent changes in the ability to perform actions *(Schmidt, 1991)*.

Motor learning principles embedded in VEs for motor rehabilitation:

1. Enriched environments
2. Augmented feedback
3. Practice dosing
4. Adaptation
5. Motivation
6. Task-oriented experiences

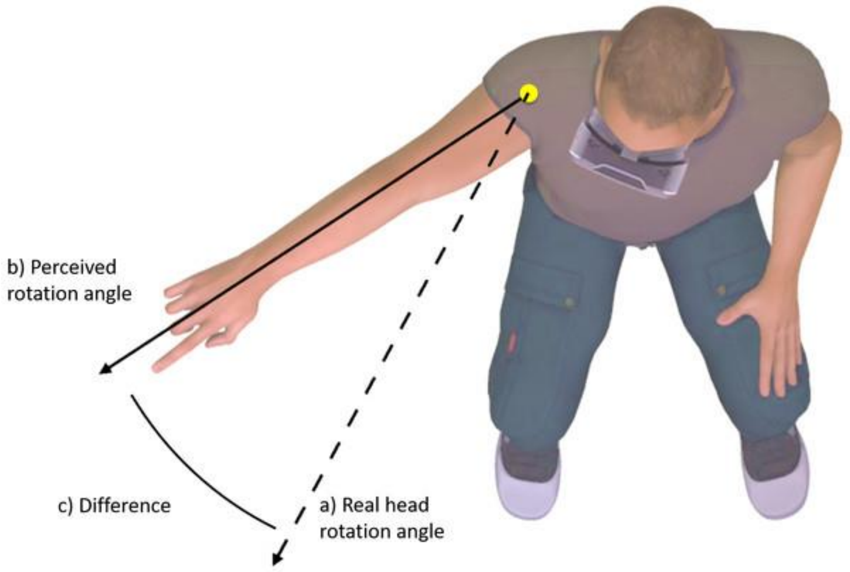
THEORETICAL ASPECTS OF FEEDBACK-BASED TRAINING AND VIRTUAL REALITY IN SENSORIMOTOR NEUROREHABILITATIVE PHYSICAL THERAPY (4)

- The video game industry has strongly progressed in the creation of low-cost systems such as ***Microsoft Kinect*** *(Microsoft Corp., Redmond, Washington)* or ***Nintendo Wii*** *(Nintendo Co. Ltd., Kyoto, Japan)*.
- This has facilitated the creation of a series of games for training and rehabilitation: the so-called "exergames" *(Smith and Schoene, 2012)*.



THEORETICAL ASPECTS OF FEEDBACK-BASED TRAINING AND VIRTUAL REALITY IN SENSORIMOTOR NEUROREHABILITATIVE PHYSICAL THERAPY (5)

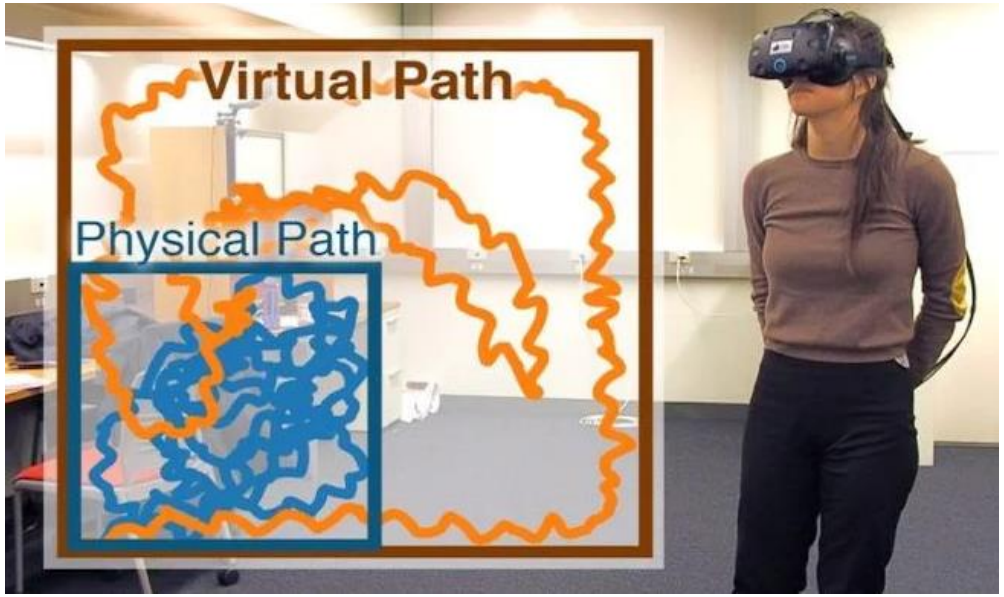
- It is suggested that illusory interventions, such as mirror therapy, might assist by altering the way the painful body part is encoded in the brain *(Ramachandran & Altschuler, 2009).*
- Because of the practical constraints of mirror therapy which relies on an unaffected and duplicated body part such as a hand or foot it cannot be used for spinal pain.
- Creating a perception of a healthy and free moving spine, however, might be achieved using virtual reality (Harvie et al., 2017).



Change in perceived body position (C) was operationalized as the difference between perceived head rotation (B) after movement during altered visual feedback, relative to during movement with normal visual feedback (A) *(Harvie et al., 2017)*.

THEORETICAL ASPECTS OF FEEDBACK-BASED TRAINING AND VIRTUAL REALITY IN SENSORIMOTOR NEUROREHABILITATIVE PHYSICAL THERAPY (6)

- Recent developments in virtual reality technology suggest that it can be used to alter perception of the body in space.
- A virtual reality concept known as `re-directed walking' uses altered visual feedback to manipulate perceived orientation, by shifting the virtual-world in ways that are not aligned with real-world movement (Steinicke et al., 2010).
- The goal of this is to induce corrections in real-world movement that, for example, enable a user to walk in a continuous straight line in a virtual world, while remaining within constraints of real-world environments where they are walking in a circle (Steinicke et al., 2010).



(Irving, 2018)

THEORETICAL ASPECTS OF FEEDBACK-BASED TRAINING AND VIRTUAL REALITY IN SENSORIMOTOR NEUROREHABILITATIVE PHYSICAL THERAPY (7)

- For example, Azmandian et al. (2016) showed that manipulating virtual arm movement can induce corresponding corrections in actual limb movement.
- Such examples of interactions between visual input and motion, that highlight the relationship between vision and bodily perception/kinesthesia, can be traced back to Helmholtz (1910), who's subjects mis-pointed at targets when wearing prism glasses that displaced the visual field to one side.

ADVANTAGES OF VIRTUAL REALITY

- Virtual reality (VR) is now commonly used in many domains because of its ability to provide a ***standardized, reproducible and controllable environment***.
- In balance assessment, it can be used to control stimuli presented to patients and thus ***accurately evaluate their progression*** or compare them to different populations in standardized situations.
- Moreover, with the development of low-cost devices, this rehabilitation can be continued ***at home***, making access to these tools much easier, in addition to their entertaining and thus motivating properties *(Morel et al., 2015).*
- The second advantage is the ability to have stereoscopic vision that gives the subject salient ***motion-in-depth*** information.
- VR technology allow for mass practice and provide training in ***complex environments*** that are sometimes impractical or impossible to create in the natural world.
- Finally, in addition to these advantages, VR is often seen as ***a fun training*** tool increasing the motivation of patients to continue their rehabilitation *(Morel et al., 2015)*.

ADVANTAGES OF VIRTUAL REALITY (2)

For example, the treatment of **anxieties and phobias** *(Price et al., 2008)* with VR has the advantage that the stimuli presented can be controlled, so that patients can face their fear gradually.

VR also allow for access to rehabilitation services through ***telerehabilitation*** *(Adamovich et al., 2009).*

LIMITATIONS OF VIRTUAL REALITY

- The ***latency of the system*** (the delay cumulated on each step of the process from data acquisition on the patients to multimodal outputs).
- ***Distance perception***, which tends to be underestimated in VR *(Morel et al., 2015)*.
- They can indeed alter patients' actions with for instance different amplitude, center of pressure or reaction times in VR compared to real situations.

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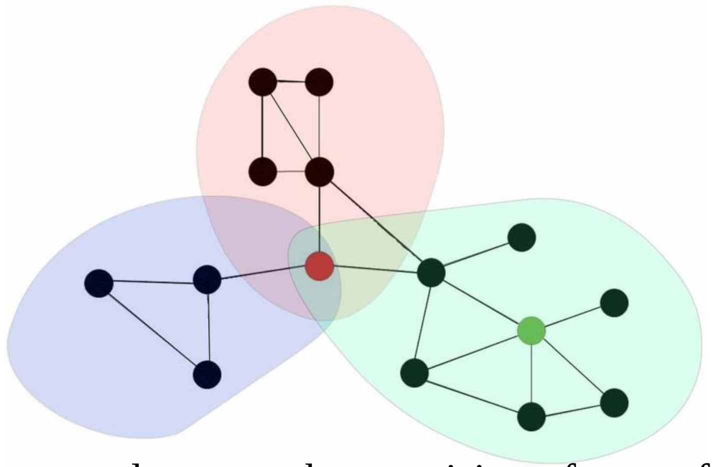
NEUROSCIENCE OF VIRTUAL REALITY

Known neurophysiological and behavioral benefits of movement observation *(Buccino et al., 2006; Celnik et al., 2006)*, imagery *(Butler and Page, 2006)*, repetitive massed practice and imitation therapies *(Gaggioli et al., 2006)* in facilitating voluntary production of movement can be easily incorporated into VR to optimize the training experience and allow the clinician to use sensory stimulation through VR as a tool to facilitate targeted brain networks, such as the motor areas, critical for neural and functional recovery *(Adamovich et al., 2009)*.



Brain networks can be represented as a graph comprising of a set of nodes (black dots) and a collection of edges (black lines in between the black dots) (*Ting To et al., 2018).*

NEUROSCIENCE OF VIRTUAL REALITY (2)

- The "wiring" of the brain lends nicely to using visual feedback in VR to augment distributed, but interconnected, cortical regions *(Adamovich et al., 2009)*.
- For instance, single unit recordings demonstrate that a substantial number of motor, premotor, and parietal neurons are modulated by visual information *(Kakei et al., 2003)*, suggesting that visual information can provide a potent signal for reorganization of sensorimotor circuits.
- At the behavioral level, movement errors in the visual domain can influence motor cortical areas during motor learning *(Hadipour-Niktarash et al., 2007; Bray et al., 2007; Richardson et al., 2006)* and active / rewarded practice, can be used to reduce movement errors through feedback, and can shape neural activity in motor and premotor areas *(Bray et al., 2007).*
- Finally, even observation of actions (images and video clips), if performed repetitiously and intentionally, can facilitate the magnitude of motor evoked potentials (MEPs) and influence corticocortical interactions (both, intracortical facilitation and inhibition) in the motor and premotor areas *(Stefan et al., 2005; Leonard and Tremblay, 2007)*.

NEUROSCIENCE OF VIRTUAL REALITY (3)

True recovery is based on behavioral change associated with ***brain plasticity*** or ***neuroplastic changes*** *(Bermúdez i Badia et al., 2016)*.

- The motivation of using VR in sensorimotor rehabilitation after a brain lesion is the administration of specific experiences that drive cortical reorganization to support the reacquisition of motor skills.
- Consequently, neural plasticity is commonly used as an efficacy measure of VR training.
- Neurophysiological adaptations to training in virtual and real-world environments by people with stroke have been shown to rely on similar neural reorganization processes *(Adamovich et al., 2009)*.
- Two early studies were done by You and Jang et al. on locomotor and upper extremity interventions, respectively *(You et al., 2005; Bütefi sch et al., 2003)*.
- Subjects in both studies demonstrated decreased activation of the non-lesioned primary motor cortex and increased activation of the lesioned cortex following intervention *(Bermúdez i Badia et al., 2016)*.

NEUROSCIENCE OF VIRTUAL REALITY (4)

- It was earlier assumed that the adult brain was not capable of producing new neurons.
- It is now generally admitted that neurogenesis occurs in the hippocampus and in the layer of cells around the lateral cerebral ventricles (the subventricular zone); moreover, physical activity initiates this proliferation.
- Therefore, scientific research data on the relationship between physical activity and cognitive/academic performance in childhood, adolescence and aging has been recently in the focus of attention.
- There are evidential data that merely a modest amount of moderate intensity physical activity is required to take advantage of the brain's natural capacity for plasticity, resulting in improved cognitive performance, better learning skills, and reduced risk for dementia.

NEUROSCIENCE OF VIRTUAL REALITY (5)

- The brain is naturally plastic; it is malleable, changes with experience and is never quiet.
- However, there are variety of elements that affect both the ability and range of brain plasticity during whole life.
- This is where the kinesiology joins with psychology and neuroscience.
- Diamond categorises core executive functions into inhibitory control, working memory and cognitive flexibility; meanwhile, reasoning, planning and problem solving are identified as higher-level executive functions (EF).
- This higher-level cognition to a greate extent overlaps with metacognition, i.e., the ability to supervise and control cognitive processes as well as use knowledge to govern behaviours.
- The most evidence-based data, and most commonly-measured outcome, have been associated with executive functions, especially inhibition and working memory.

NEUROSCIENCE OF VIRTUAL REALITY (6)

- It has been proven that executive functions are highly predictive of academic achievement with early assessments of executive functions predicting later educational success.
- Working memory, one of the components of executive functions, may be considered to predict vocabulary and mathematical reasoning tasks.
- Recently, associations between PA and academic success have been studied extensively, with more than 230 published articles addressing related topics among school-age children.
- Chronic participation of school-age children in physical activity has been associated with different mental health benefits, such as improved self-perceptions (e.g., self-esteem, self-efficacy), emotional regulation (e.g., anxiety, depression) and cognitive functioning (e.g., information processing, memory, attention).
- Chronic physical activity interventions have been defined as long lasting repeated bouts of exercise aimed at improving physical fitness.

NEUROSCIENCE OF VIRTUAL REALITY (7)

- Expertise and training in motor skills are often associated with changes in the brain structure and function [14].
- Long-term training in activities that require precise fine motor control (e.g., musical training) may result in structural changes in brain areas linked to motor function, as well as in cortical areas involved in sensory, spatial, and attentional processes [15, 16].
- It has also been shown that expertise in athletic activities that demand high levels of hand-eye coordination, such as golf, gymnastics [17], or racquet sports [18], may lead to changes in the brain structure and function [19].

NEUROSCIENCE OF VIRTUAL REALITY (8)

- In both humans [22] and primates [23], physical activity improves attention and performance on cognitive tasks [3].
- One study has shown that greater physical activity in the elderly is associated with greater brain volume in the frontal, temporal, parietal lobes and the hippocampus, mitigating their risks for Alzheimer-related dementia by 50%.
- In addition, better physical fitness is associated with greater gray matter volume in the hippocampus [6].
- The hippocampus, a structure that has a fundamental role in memory processing, is one of the main brain regions affected by physical activity [24].
- Findings indicate that higher fitness is associated with larger bilateral hippocampal volume; meanwhile, greater fitness and hippocampal volume are associated with better spatial memory performance [25].

NEUROSCIENCE OF VIRTUAL REALITY (9)

- Another study has shown that brain-derived neurotrophic factor (BDNF) level is decreased in individuals with Alzheimer’s dementia.
- Increased BDNF levels have also been observed in young, healthy individuals with short-term vigorous and long-term endurance exercise.
- This seemingly suggests that younger individuals who are consistently active and exercise or do sports have a significantly reduced risk for developing dementia in their old age [26].

NEUROSCIENCE OF VIRTUAL REALITY (10)

- At present, there are three hypotheses clarifying how physical activity may impact executive control [3].
- Physical activity may increase oxygen saturation [27] and angiogenesis [28] in brain areas responsible for task performance. Kramer et al. [27] have found that walking exercise increases the rate of oxygen consumption in healthy older adults and is associated with better reaction time and improved performance in executive functioning tests.
- The second hypothesis proposes that physical activity increases brain neurotransmitters, such as serotonin and norepinephrine, thus facilitating information processing [26]. Increased excitation detected by brain electroencephalogram (EEG), have been determined in persons exercising at less than 70% of their maximum oxygen capacity (considered within the moderate training zone) [22].

NEUROSCIENCE OF VIRTUAL REALITY (11)

- The third, and obviously best studied, hypothesis is that physical activity upregulates neurotrophins, such as BDNF, insulin-like growth factor (IGF-I) and basic fibroblast growth factor (bFGF), which support neuronal survival and differentiation in the developing brain and dendritic branching and synaptic machinery in the adult brain (for review see [29].
- It is evident that youth with physical disability, with brain ripe for new learning and sometimes with concomitant cognitive challenges, may necessitate physical activity even more than adults [3].

NEUROSCIENCE OF VIRTUAL REALITY (12)

- Ageing-related studies show that endurance exercise is protective against cognitive decline, especially executive planning and working memory [30].
- Aerobic exercise in adults has been shown to increase brain volume in frontal lobe regions implicated in higher order processing, attentional control and memory [31].
- Moreover, scientific data demonstrates that older adults who are more physically active in recreational activities or have higher cardiovascular fitness are at a lower risk for cognitive decline in comparison with inactive older adults [32, 33].
- Rovio et al. [34] have demonstrated that leisure-time PA in midlife (age 44–57 years) is associated with a reduced risk of dementia later in life; meanwhile Verghese et al. [36] have shown that intensified participation in leisure activities for individuals ≥75 years old reduced the risk of developing dementia and Alzheimer's disease.

NEUROSCIENCE OF VIRTUAL REALITY (13)

- Imaging studies (e.g., EEG) accomplished during locomotion support the hypothesis that movement may be cognitively demanding beyond simple automated motor control [19].
- Locomotion activates several brain regions, including prefrontal, parietal, and parahippocampal regions, which are generally associated with executive functions, spatial navigation, and memory; besides, high-speed locomotion (e.g., running) increases cognitive demands and related neural activity [39].
- For example, walking or running through complex environments may activate several components of executive function including volition, self-awareness, planning, inhibition, monitoring, attentional switching and multi-tasking, as well as motor control [40].

NEUROSCIENCE OF VIRTUAL REALITY (14)

- Physical activity impacts on executive function are not dose responsive, i.e., better fitness does not necessarily lead to larger cognitive gains.
- In fact, smaller adavantages in fitness are associated with larger cognitive effect sizes.
- Studies in children with reading difficulties also demonstrate that children gained cognitive benefits from a programme combining balance, timing and co-ordination exercises, rather than cardiovascular fitness [41].
- According to these data physical activity levels that benefit cognition may not necessarily be as intense as those levels required to increase cardiovascular fitness.

NEUROSCIENCE OF VIRTUAL REALITY (15)

- Aerobic fitness in children correlates with higher measures of neuroelectric responsiveness (P3 amplitude in brain evoked potentials), faster cognitive processing speed [48] and better performance in executive control tests [49].
- Chaddock et al. [50] have used structural MRI (i.e., a neuroimaging approach to discriminate between gray matter, white matter, and cerebral spinal fluid in the brain) and observed that specific regions of the basal ganglia (i.e., regions of the dorsal striatum: caudate nucleus, putamen, globus pallidus), supporting EF, are larger in higher-fit children aged 9 to 10 years in comparison to lower-fit children of the same age.
- Accordingly, the findings provide initial evidence that fitness is related to the volume of specific subcortical structures within the striatum, which support behavioural interactions during tasks that require EF modulation [50].

NEUROSCIENCE OF VIRTUAL REALITY (16)

- It has also been found that children randomized to the PA intervention demonstrated greater white matter integrity in the uncinate fasciculus from the baseline to the post test compared with children assigned to the attentional control group [51].
- Such findings suggest that greater aerobic fitness may result in a selective and disproportionate influence on cognitive functions, which are supported by specific subcortical structures, rather than lead to an all-inclusive influence on brain structure and cognition [47].

NEUROSCIENCE OF VIRTUAL REALITY (17)

- Moreover, correlational studies where blood oxygen level-dependent fMRI was used demonstrated that higher-fit children had increased recruitment and activation in frontal and parietal regions during tasks that modulated EF [50].
- That is, differences in physical activity were related to activation of different brain regions that govern monitoring (anterior cingulate cortex) of adjustments in attentional control (middle and inferior frontal gyrus and precentral gyrus) in the presence of distracting information and response conflict (superior parietal cortex), as well as the preparation and execution of a motor response (supplementary motor area) [52].
- More importantly, fitness-related differences in fMRI activation were increased when task requiring greater amounts of EF were performed [47].

NEUROSCIENCE OF VIRTUAL REALITY (18)

- It has been recognized that children with apparent impairment in the development of fine and gross motor coordination may struggle in academic achievement [56].
- Lopes et al. [57] have found that children with insufficient motor coordination or motor coordination disorders advertised a higher probability of low academic achievement than their peers with normal-to-good motor coordination.
- Furthermore, a study by Verschuren et al. [58] has demonstrated that a 45-minute programme (twice per week for 8 months) not only improved aerobic capacity, strength and function but also significantly boosted cognition and quality of life in people with cerebral palsy aged 7–20 years.
- Even more striking is that 4 months following completion of the programme, participants were able to maintain the cognitive benefits while fitness measures returned to a baseline.
- These studies support the concept of an exercise-cognition interaction in children with disabilities.

NEUROSCIENCE OF VIRTUAL REALITY (19)

Visuomotor Representations

- It is known that cortical areas involved in the preparation and execution of motor actions undergo plastic changes *(Richards et al., 2008)* either due to repeated sessions of proprioceptive stimulation through passive physical training *(Carel et al., 2000)* or as a result of task-oriented physical training *(Jang et al., 2003)*.
- Motor deficits do not only arise from the directly damaged tracts by stroke but the networks they disrupt. Hence, its recovery also depends on the intra- and interhemispheric interactions among motor regions *(Grefkes and Fink, 2011)*.
- For instance, bilateral recruitment of motor networks can result from unilateral motor movements in hemiparetic stroke patients *(Grefkes and Fink, 2011; Cramer, 2008)*.

NEUROSCIENCE OF VIRTUAL REALITY (20)

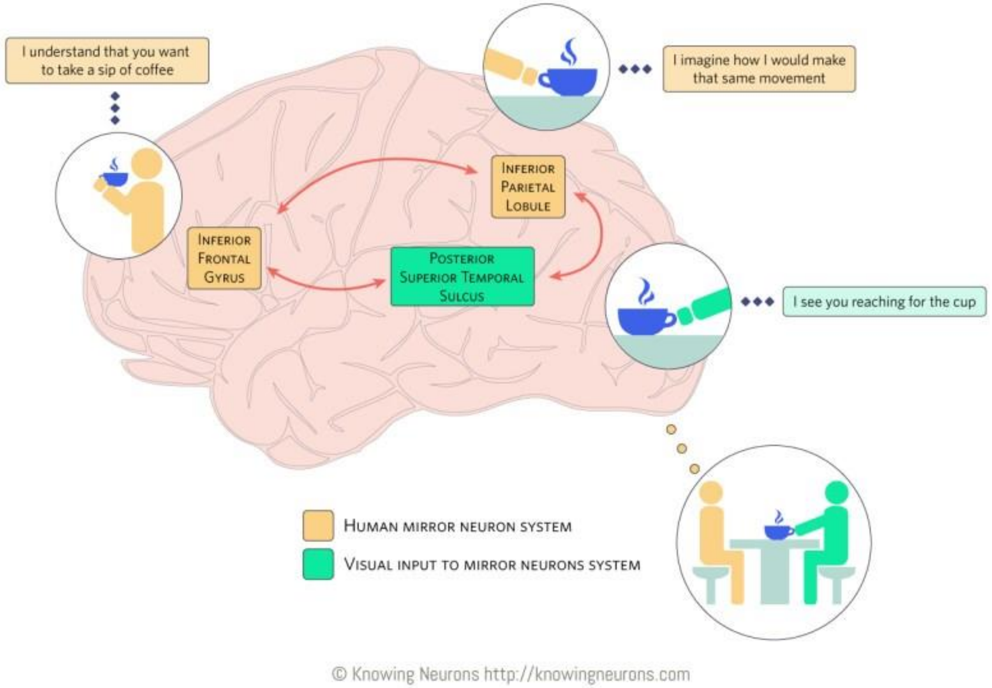
Visuomotor Representations (2)

- Human mirror neuron system (MNS), which is primarily composed of neurons located in the inferior parietal lobe, the ventral premotor cortex, and the caudal part of the inferior frontal gyrus.
- These are candidate areas for sensory control of action, movement imagery, and imitation (Iacoboni et al., 1999).
- Imaging studies have shown that the combination of first-person observation VR and motor imagery is more effective at recruiting more task-related networks than other conditions for both lower limb (Villiger et al., 2013) and upper limb (Bermúdez et al., 2013) movements.

NEUROSCIENCE OF VIRTUAL REALITY (21)

Visuomotor Representations (3)

- Human mirror neuron system (MNS) is of great relevance because it has been shown to be active during performance of goal-directed actions, their passive observation and their mental simulation *(Grezes and Decety, 2001)*.
- The MNS has been hypothesized to be involved in action understanding and imitation *(Rizzolatti and Craighero, 2004)*, and, as such, it may represent an important neurophysiological substrate for regaining impaired motor function after stroke *(Buccino et al., 2006, Garrison et al., 2010).*
- Recently, it was suggested that the mere observation of goal-oriented motor actions can be used as a driver *(Buccino et al., 2001)*, and findings corroborate that the use of passive observation of goal-oriented actions can have a positive effect in motor recovery after stroke *(Sale and Franceschini, 2012; Ertelt et al., 2007)*.



NEUROSCIENCE OF VIRTUAL REALITY (22)

Visuomotor Representations (4)

- From the findings, it is clear that the manipulation of the visual feedback for motor rehabilitation purposes can be an effective ingredient of VR systems.
- Maeda et al. (2002) showed that movement observation can directly enhance and facilitate the motor outcome of the muscles involved in the observed action.

- Consequently, there is strong evidence supporting that VE interaction can be effective in engaging primary and secondary motor areas for upper extremities (August et al., 2006), locomotion (You et al., 2005), as well as the mirror mechanisms (Modrono et al., 2013; Prochnow et al., 2013).

NEUROSCIENCE OF VIRTUAL REALITY (23)

Visuomotor Representations (5)

- The ability to distort visual feedback (small errors during virtual rehabilitation activities enhance motor training outcomes) is an area of inquiry that has been investigated as a possible method to optimize motor adaptations to VR-based rehabilitation activities as well *(Abdollahi et al., 2011).*
- One possible mechanism for this effect might be an increased level of cortical activity necessary for the brain to rectify virtual movement amplitude that is not scaled to participant movement *(Tunik et al., 2013)*.
- One distortion of visual feedback that has been associated with poor responses has been temporal lags between participant movement and corresponding movement within the VE. This may interfere with feedforward/feedback control of movement making delayed visual feedback confusing *(Lewis and Griffin, 1997)*.

Summary

- After stroke, relearning of motor function is mediated by neuroplasticity. Evidence shows that VR can be a valid tool to drive motor networks, brain plasticity, and functional recovery.
- Research has shown that after stroke, a window opens when networks become more excitable, and VR has revealed as an effective tool to engage visuomotor processes such as the ones related to action execution, observation, understanding, and mental simulation.
- In fact, the manipulation of visual representations has been shown to engage motor networks during passive observation and mental simulation and facilitate the movement of muscles.
- Thus, the manipulation of these processes through VR not only can enhance neural activation but improve motor outcomes as well (Bermúdez i Badia et al., 2016).

THE ROLE OF MULTISENSORY STIMULI AND INTERFACES

Visual, auditory, and haptic stimuli all contribute important elements to promote user interactivity, while interfaces are required to deliver and augment sensory information *(Adamovich et al., 2009)*.

Point of View

- Most immersive and semi-immersive systems, and even some non-immersive systems, present first-person points of view of the workspace during virtual rehabilitation activities.
- These presentations typically include virtual representations of the participant's limbs or a landscape in which the person might be navigating or acting.
- This approach presents higher-quality information related to limb movement and reduces the need for the brain to rectify differences in somatosensory and visual information associated with the other approaches to VR *(Bermúdez i Badia et al., 2016)*.

THE ROLE OF MULTISENSORY STIMULI AND INTERFACES

Auditory Stimuli

- Auditory information is a key sensory component of most VEs and has broad impact on the participant’s experience.
- It is used to enhance immersion in the VE by providing sounds consistent with an activity *(Bermúdez i Badia et al., 2016)*.
- Spatial sound rendering can also be used to increase the realism of a VE and aid user navigation within a VE *(Rosati et al., 2013)*.
- Friedman et al. *(2011)* also found that the addition of music enhanced hand motor performance as well as motivation in the training of hand functional movements.

Haptic, Tactile Stimuli and Their Interfaces

- Simple or robotic haptic interfaces have allowed to provide haptic feedback that enriches the sensory experience, add physical task parameters, and provide forces that produce biomechanical and neuromuscular interactions with the VE that approximate real-world movement more accurately than visual-only *(Bermúdez i Badia et al., 2016)*.
- Collisions with virtual world obstacles can be used to teach normal movement trajectories such as to place an object on a shelf or the action required to step over a curb *(Jaffe et al., 2004; Adamovich et al., 2009; Wellner et al., 2006)*.
- In two small studies involving healthy subjects, this feedback combination was found to be more effective for skill learning than visual-only feedback in healthy subjects *(Huegel and O'Malley, 2010; Huang et al., 2007)*.

In the pictured simulation, the Virtual Piano Trainer, the magnetic tracker allows the participant to position their hand over the virtual keyboard and the Cyberglove allows them to strike keys with a specific finger.

The Cybergrasp can be programmed to provide haptically rendered collisions when keys are pressed or assistance in maintaining extension of non-cued fingers for more impaired subjects *(Adamovich et al., 2009)*

Summary

- The impact of auditory feedback on virtual rehabilitation is at an early stage of development but preliminary work supports the additive effects of rhythm and auditory rendering to the overall effectiveness of virtual activity.
- There is a larger body of evidence supporting that the visual stimulus has a direct, predictable impact on the motor output elicited during simulated activities.
- However, there is no evidence supporting the notion that higher-fi delity (fully immersive visual presentations) visual presentations during virtual rehabilitation translate into larger improvements in the ability of persons with disability to function in the real world.
- Research supports that motor skill learning within the VE is more efficient with tactile feedback. However this benefit comes at the cost of greater complexity and expense for these integrated systems *(Bermúdez i Badia et al., 2016)*.

MOTIVATING THROUGH GAMING ELEMENTS IN VIRTUAL ENVIRONMENTS

1. ***Intrinsic*** motivational factors in which the motivation is derived from the act of participation itself.
2. ***Extrinsic*** factors in which the person is motivated by the purpose of the activity *(Ryan and Deci, 2000)*.

- In the context of sensorimotor rehabilitation, the goal is to facilitate clients to be self-directed and motivated, both because the activity is interesting in itself and because achieving the outcome is important.
- There is agreement that gaming elements can improve motivation and that, if paired with other activities, they can be harnessed to engage users and achieve desired outcomes *(Wouters et al., 2013)*.
- Many elements have been suggested to be important for the design of a successful game, such as fun, flow, goals, feedback, game balance, pacing, interesting choices, and narrative structure among others *(Linehan et al., 2011)*.

MOTIVATING THROUGH GAMING ELEMENTS IN VIRTUAL ENVIRONMENTS (2)

Intrinsic characteristics:

1. Goal Setting - an appropriate balance of short, medium, and long-term goals has been shown to have a motivating effect in extending game play *(Linehan et al., 2011)*.
2. Rewards – VEs are extremely well suited to provide immediate and specific feedback to users, this feature being essential for sustained attention, learning, motivation, and fun *(Linehan et al., 2011)*.

   Actions can be rewarded with positive visual and auditory feedback, scores, and specific KP (knowledge of performance) and KR (knowledge of results) (auditory feedback related to successful task completion) *(Cirstea et al., 2006; Kilduski and Rice, 2003)*.

   Comparable negative feedback can be provided for unsuccessful performance (collision with an obstacle) *(Rosati et al., 2013)*.

MOTIVATING THROUGH GAMING ELEMENTS IN VIRTUAL ENVIRONMENTS (3)

3. Challenge – Ves *(virtual environments)* for motor rehabilitation should be adjusted in terms of movement demands and dynamics, avoiding situations in which patients lose the ability to directly control the task. It has been suggested that players desire a level of challenge that is neither too easy nor too difficult to perform.

- Recent developments in VEs for motor training already incorporate transparent and automated modules for the personalization of training, by adjusting task difficulty depending on patient’s success rate or by modifying time available to accomplish a goal *(Cameirão et al., 2010; Borghese et al., 2013)*.
- In the cases when VEs are designed to teach complex skills, complex and demanding tasks should be broken down into simpler and more achievable tasks *(Linehan et al., 2011)*.

MOTIVATING THROUGH GAMING ELEMENTS IN VIRTUAL ENVIRONMENTS (4)

4. Narrative Structure - narrative elements can be exploited to build an interesting dramatic arc around the training task to increase the engagement of patients, to facilitate the comprehension of the training objectives, and, most importantly, to deliver a clear sense of progress.

   Multiple elements can be used to shape a narrative curve, such as, story events, task difficulty, novel environments, new challenges, or skills.

   VEs designed to realistically simulate activities, such as navigating a virtual city or shopping in a virtual supermarket, generally provide richer narratives than tasks with simpler cognitive demands *(Gamito et al., 2015; Vourvopoulos et al., 2014)*.

EVIDENCE BASE: IMPACT OF VIRTUAL REALITY

Upper Extremities

- Studies examining custom- designed VR-based interventions targeting the upper extremity of persons with stroke make up the largest and most mature evidence base related to virtual rehabilitation *(Bermúdez i Badia et al., 2016)*.
- Several reviews of early pilots and controlled trials describe the ability of VR-based interventions to elicit measurable activity level improvements, comparable to those of traditionally presented training, mostly in persons with chronic upper extremity hemiparesis due to stroke *(Adamovich et al., 2009; Fluet and Deutsch, 2013; Saposnik and Levin, 2011; Henderson et al., 2007)*.

EVIDENCE BASE: IMPACT OF VIRTUAL REALITY (2)

- In 2012, the Wii™ fit game became available. This game was bundled with the Wii™ Balance Board, a force sensor that interfaces with the Wii™ console.
- These systems have been widely adopted in rehabilitation facilities and nursing homes without modification as a recreation and rehabilitation modality *(da Silva Ribeiro et al., 2015)*.
- Several studies of upper extremity rehabilitation have utilized the Wii™ system in patients with stroke. Subjects in several pilot studies of persons with stroke using the Wii™ have demonstrated statistically significant improvements in motor function and activity level clinical tests *(Shiner et al., 2014; Joo et al., 2010; Mouawad et al., 2011)*.

EVIDENCE BASE: IMPACT OF VIRTUAL REALITY (3)

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Balance and Gait

- Building balance and walking VR-based systems require greater technical and space requirements to meet the special physical and safety challenges.
- There exists a modest body of work on the development and use of customized VEs for walking recovery and balance, which is reported in several topic specific reviews *(Booth et al., 2013; Deutsch and Mirelman, 2007; Darekar et al., 2015)* as well as in overview reviews *(Fluet and Deutsch, 2013; Laver et al., 2015)*.
- In contrast to the 397 participants who participated in the upper extremity studies included in Laver's Cochrane Review of Stroke Rehabilitation, there were only 58 persons involved in balance and mobility training, with only 30 participants in the three studies where gait speed was measured *(Laver et al., 2015)*.

Visual feedback is a common element in evidence- based interventions for balance training post stroke *(Barclay-Goddard et al., 2004)*. It is used to provide participants information about the verticality of their posture, which may be impaired due to sensory and perceptual deficits, as well as their weight distribution.

EVIDENCE BASE: IMPACT OF VIRTUAL REALITY (4)

- Walking on a treadmill interfaced with VE has been used to promote recovery of walking for persons post stroke. The inclusion of visual and vibrotactile augmentation while stepping over virtual objects during walking on a treadmill improved walking better than stepping over real- world objects *(Jaffe et al., 2004)*.
- The use of feedback provided by VR not only favored gait *(Yang et al., 2008 , Cho and Lee, 2013)* but also static balance, sit-to-stand movements, and the use of the paretic limb *(Cho and Lee, 2013; Yang et al., 2011)*.

EVIDENCE BASE: IMPACT OF VIRTUAL REALITY (5)

Activity Promotion

- Movement-based VR systems have focused on sensorimotor rehabilitation, but there is an emerging application to fitness promotion in persons post stroke.
- In addition to their use as movement reeducation tools, the off-the-shelf games that are designed to promote activity, also called exergames or active video games (AVGs), have been explored for people post stroke *(Kafri et al., 2014; Hurkmans et al., 2011)*.
- Games may be a valid tool for activity promotion, given their potential to increase motivation for exercise and to promote adherence *(Bermúdez i Badia et al., 2016)*.

EVIDENCE BASE: IMPACT OF VIRTUAL REALITY (6)

VR to treat Cerebral Palsy

- Jas known, children with Cerebral Palsy (CP) have difficulty controlling and coordinating voluntary muscle activity. Traditional therapies for muscle movement are repetitive and offer very little to keep a young mind occupied.
- VR has a positive impact on neuroplasticity in CP patients. fMRI analysis, prior to VR training of the upper extremity of a child with hemiplegic CP, showed predominately bilateral activation of the sensorimotor cortices and ipsilateral activation of the supplementary cortex. After training in a video capture based VR system, this bilateral activation disappeared and the contralateral sensorimotor cortex was activated *(You et al., 2005)*.
- These changes were closely associated with enhanced ability to perform reaching, dressing, and self-feeding tasks. VR's ability to create widely varying scenarios with a spectrum of difficulty also lends itself to gait training in CP patients *(Koenig et al., 2008)*.
- In a selective motor control study of CP patients *(Bryanton et al., 2006)*, children were asked to complete several ankle exercises using both video capture based training and conventional programs. The range of motion and hold time of stretch positions were greater in the VR group, thus the benefit of any movements was much greater during the VR exercises.

Summary

- Similarly, comparable outcomes have been reported when comparing virtual and real world upper extremity training in subjects with more acute strokes.
- The best developed area of this literature examines upper extremity interventions in subjects with chronic strokes using customized lab-based systems.
- These comparisons describe slightly better outcomes for virtual rehabilitation interventions. This advantage is more pronounced in mildly impaired subjects.
- This advantage is more pronounced in mildly impaired subjects. More, larger, and better controlled studies are required to draw definitive conclusions along these two lines of inquiry.
- Moreover, a nonsignificant trend toward better outcomes for virtual reality- based training as compared to real-world gait and balance training has been identified *(Bermúdez i Badia et al., 2016)*.

FEEDBACK-BASED INTEGRATED FUNCTIONAL ASSESSMENT AND PRINCIPLES OF NEUROMUSCULAR TRAINING WITH MULTIAXIS MOTORIZED PLATFORM

The HUBER® System has been initially developed to strengthen the deep spinal muscles and reactivate micro-movements and vertebral articulations mobility.

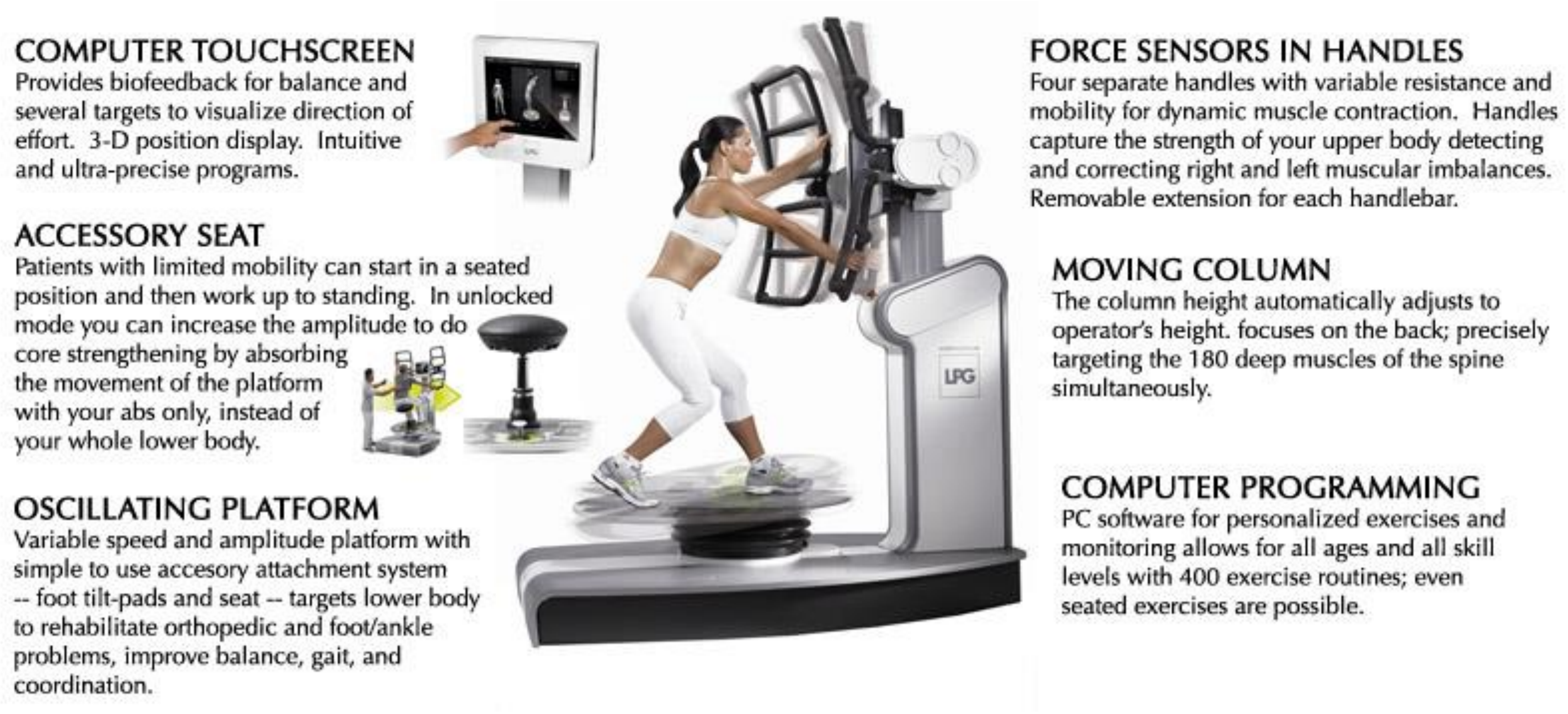
Among its numerous applications, HUBER® also allows the recuperation of the postural equilibrium and the improvement of adapted coordination skills.

1. Improvement of coordination and strength in sport amateurs, sedentary subjects and seniors.
2. Improvement of equilibrium and posture on sporty subjects.
3. Effects on posture, equilibrium and muscular function.
4. Improvement of equilibrium and posture in aging subjects.
5. Action on chronic low back pain (CLBP) etc. *(LPG Scientific Research Department, 2006)*

FEEDBACK-BASED INTEGRATED FUNCTIONAL ASSESSMENT AND PRINCIPLES OF NEUROMUSCULAR TRAINING WITH MULTIAXIS MOTORIZED PLATFORM (2)

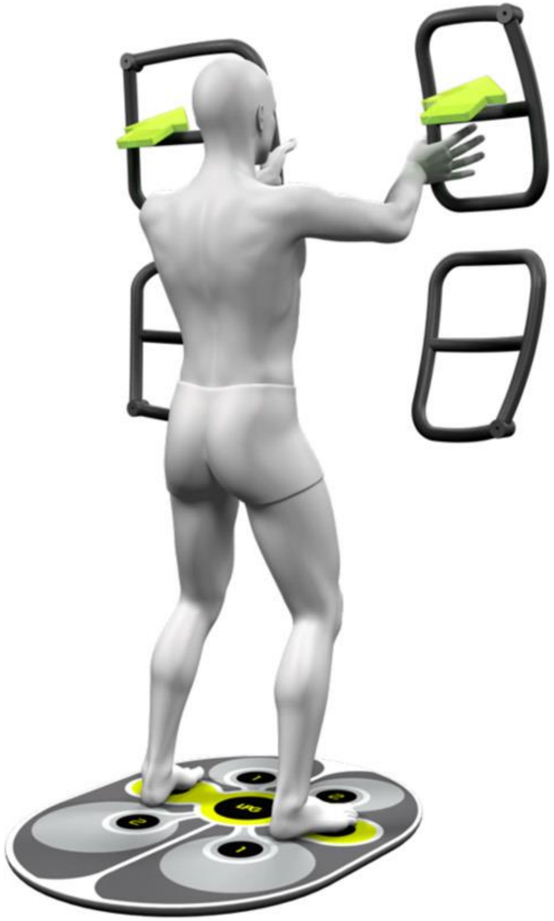
- The Huber Motion Lab (LPG Systems, France) is an oscillating Platform with 2 large handles mounted on a movable column.
- Several feet and hand positions are marked on the platform and handles, respectively .
- HML exercises consist of adopting Specific positions, defined as a combination of various foot and Hand positions, and developing low-high force levels against the handles.
- These actions require the synergistic activation of various muscle groups of the lower limbs, trunk and upper limbs.
- The handles are equipped with strain gauges, and feedback about the force developed is provided to users.
- Additionally, an interactive interface, shown as a target, informs the subject about their ability to maintain the required force level.
- This ‘‘game-like’’ control panel is intended to increase the user’s motivation to practice and adhere to the HML training program *(Guiraud et al., 2016)*.

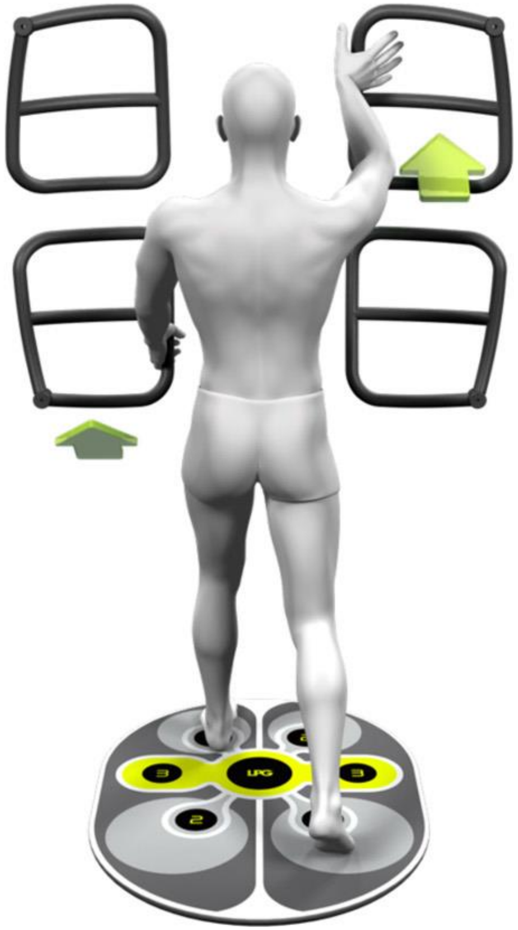
FEEDBACK-BASED INTEGRATED FUNCTIONAL ASSESSMENT AND PRINCIPLES OF NEUROMUSCULAR TRAINING WITH MULTIAXIS MOTORIZED PLATFORM (3)



In fact, these various elements stimulate a high proportion of the body’s muscles: in postural control, muscle contractions allow posture maintenance and stabilise joints (Couillandre et al., 2008).

Finally, the use of balance assessment and stabilometry can be used to assess postural control and inferences can be made to proprioceptive capabilities and neuromuscular control.





FEEDBACK-BASED INTEGRATED FUNCTIONAL ASSESSMENT AND PRINCIPLES OF NEUROMUSCULAR TRAINING WITH MULTIAXIS MOTORIZED PLATFORM (4)

- The Huber 360 is an innovative solution that can improve neuromuscular control and overall performance by training the four fundamentals of movement: ***posture and balance, flexibility and mobility, resistance and dynamic reinforcement***.
- The device offers targeted exercises to increase the user's range of motion, coordination of movements, strength, resistance and balance. Training with Huber 360 also improves the user's BMI and cardiovascular health.

FEEDBACK-BASED INTEGRATED FUNCTIONAL ASSESSMENT AND PRINCIPLES OF NEUROMUSCULAR TRAINING WITH MULTIAXIS MOTORIZED PLATFORM (5)

- The multiaxis platform trains the whole body and engages the user's cognitive skills to make the sessions more effective and fun.
- It can be used to treat 90% of common pathologies and offers a comprehensive performance assessment with seven reference tests and personalized reports on the patient's progress.
- The data is collected from the force sensors integrated in the platform and handles.
- The dynamic exercises available with the platform are short, intense and adapted to the users' physical condition for optimal results.

FEEDBACK-BASED INTEGRATED FUNCTIONAL ASSESSMENT AND PRINCIPLES OF NEUROMUSCULAR TRAINING WITH MULTIAXIS MOTORIZED PLATFORM (6)

- It has been shown that feedback-based training device that simultaneously captures balance, core stability and strength, and total body strength successfully improves physical functions in older adults *(Markovic et al., 2015);* force and balance in healthy adults (Couillandre et al., 2008); gain of chest force and the peak power output were improved in patients with coronary heart disease (Guiraud et al., 2016); significant improvement was found for patients with chronic low back pain and **multiple sclerosis (**LPG Scientific Research Department, 2006).
- The Huber 360 was proven to improve neuromuscular control and performance, also *cognitive functions (***Jurakic et al., 2017)** in elderly women.
- Moreover, the Huber 360 was found to be significantly more effective than Pilates in improving body composition, balance and trunk and leg strength.

PHYSICAL THERAPY

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