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A scoping review and a taxonomy of the use of motion-based technology centered on the end user. A special focus on elderly health

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Abstract

Motion-based technology (MBT) has been applied in the last decades with enormous success in a high number of applications. Its use continues growing and is specially interesting in the health area. Nowadays, its employment is being more and more specialised with respect to the profile of the end user (i.e., child, adolescent/teenager, adult or elderly). This paper first reviews the use of MBT centered in the end user from a global perspective. It also proposes a taxonomy that allows cataloguing the MBT employment directed to the end user. Then, from these results, the paper centers the review on the MBT application aiming to improve the health of elderly. The results highlighted in this paper can help to a better understanding of MBT, especially when it is applied thinking in elderly as the end users.

Keywords Motion-based technology · Elderly · Taxonomy · Digital games · Health

1 Introduction

Motion Capture (MoCap) can be globally defined as a technology that digitally tracks and records human motion in a fixed scenario. This technology has been used in many different areas with distinct applications related to robotics, surveillance, action/object recognition, entertainment or humanoid imitation, just to name a few [6, 46]. This paper deals with Motion-based technology (MBT), considered here as the use of MoCap to achieve distinct goals depending on the profile of the end user. Generally speaking, MBT also involves the interactive participation of the end user. MBT has been proved its efficacy in many distinct applications but it is specially successful in the area of Health. In the scientific literature, one can find a number of reviews centered on MoCap and its applications (e.g., [15, 44, 46, 94]). This paper revises the term by focusing on the end user and not on the application of the technology itself. In this sense, MoCap has been used to serve different groups of users (i.e., child, adolescent/teenager, adult or elderly) that differ in the age of their members. In fact,

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the profile of the end user has a clear influence in the design of user experiences based on MoCap. This paper deals with this issue and, in its first part, describes a scoping review of the use of MoCap with respect to the profile of the end user (i.e., a review of MBT). From this review, the paper also proposes a taxonomy of MBT that can be used not only to classify the existing works on MBT but also to help to the design of future user experiences based on MBT.

The second part of the paper focuses on the group of older people (i.e., elderly), which is the most marginalised but nonetheless important end users of technology. Note that ageing is the accumulation of cellular deterioration over time. This affects our organism physically (sensory, muscular, cardiopulmonary systems), cognitively (processing speed, working memory, recognition impairment) and mentally (loneliness, depression, frustration) [39]. Although this is a natural and non-reversible effect, it happens that physical activity can slow the process in those three aspects [32]. Nevertheless, sedentary lifestyle is still largely present in elderly where the main barriers are health issue, lack of access, lack of company and lack of motivation [52]. With the arrival of affordable motion-based sensors able to capture and detect human movements, the Human Computer Interaction (HCI) field made good progress towards the use of technology to support physical activity [22]. Research has identified, extracted and applied series of gaming elements, which were initially designed to entertain its audience across the whole experience, to improve motivation and engagement in using digital activities [74]. This technique is called gamification and it has shown beneficial effects on well-being, physical and cognitive skills in elderly [43, 55]. The gamification technique applied to physical activity creates a whole new genre called "exergame", which is half-way between sport and game [21]. A previous systematic literature review identified three clusters of application which are training, rehabilitation, and wellness [29]. Exergames showed health benefits on older adults [87], including frail older adults [92], with dementia [90] and with Parkinson disease [19]. Although exergaming is one way of exploiting motion-based sensors, it is not the only one. Motion-based sensors remain a focus of interest in several disciplines as a medium of interaction with digital activities, and it might result difficult to identify the existing gaps in the literature where such a technology could be beneficial.

This paper provides three main contributions: a review centered on the end user of the state of the art of motion-based technology, the proposal of a taxonomy for MBT, and a specific review of the field focused on elderly (and specifically on the use of the technology in the area of health).

2 Methods

2.1 Search strategy

We conducted the search, up to December 2021 with no domain and no year restrictions, on the following databases: *Scopus*, *IEEE Xplore*, *ACM Digital Library*, *PubMed*, and *Web of science*. We used the following search strings:

- **Technology**: *("motion-based" OR "gesture-based")*
- **Motor Detection**: *("motor skill" OR locomotor OR balance OR stability OR stationary OR manipulati*)*
- **Population**: *(child* OR adolescent OR teen* OR adult OR elderly)*

2.2 Eligibility criteria

In this scoping review, we performed a two-pass selection of the screened records. For the first pass, we included the articles that met the following criteria: (1) must use motion-based sensors to detect movements or gestures, (2) must conduct an evaluation study (excluding studies focused on design guidelines only), (3) must be written in English and (4) must have the full-text available online or in the university's library. Then, we performed a second pass by adding more restrictive criteria: (5) must include elderly and (6) must conduct an experimental evaluation study. Experimental studies aimed to analyse the effect of an intervention/variable by comparing several groups. Non-experimental or observational studies happen when researchers cannot control, manipulate or alter the subjects and base the conclusions on observation. Experimental studies reduce the risk of bias of the results.

2.3 Search results

The selection of the literature was conducted following the PRISMA statement [58] (see Fig. 1). 484 studies referenced in previous Literature Reviews were integrated individually in the list of records to screen, in addition to the database searches [18, 19, 21, 22, 25, 29, 42, 43, 45, 55, 56, 59, 61, 68, 87, 90, 92]. To ensure the uniqueness of the records, the titles were encoded with MD5 hash code and the duplicates were removed. Then, the screening phase was performed by reading the titles and the abstracts. The full papers were downloaded and selected according to the first pass of eligibility criteria. Then, 408 full-texts were reported with the following categories: 1. title; 2. year; 3. journal; 4. research application; 5. population (children, adult, elderly); 6. sensor; 7. body detection (lower-limb, upper-limb, full-body, etc); 8. motion detection (center of pressure, body movement, etc) ; 9. software type (video-game, ad-hoc solution, etc); 10. evaluation design method (non-experimental, (quasi-)experimental); 11. number of participants; 12. age (min and max); 13. diagnostic; 14.number of sessions; 15. duration of the sessions; 16. instruments of evaluation. The dataset generated during the current study is available online [2].

3 Results from a general perspective

3.1 Key terms

The first selection pass of the literature does not take into account the population profile (i.e., children, teenager, adult, elderly) and includes a selection of 408 articles. The word cloud of the titles (see Fig. 2) reveal key words from 5 categories:

1. **Population**: children, older adult;
2. **Diagnostic**: Multiple sclerosis, Parkinson, Developmental Coordination Disorder, Autism, Stroke;
3. **Motor detection**: Balance, Physical activities, Gesture, Motor skills, Upper extremity;
4. **Software technology**: Virtual reality games; Serious game, Active video game;
5. **Hardware technology**: Virtual reality, Nintendo Wii/Fit/Balance Board, Leap motion, Kinect, Wearable.

Note that children and older adults are the main targets as end users.

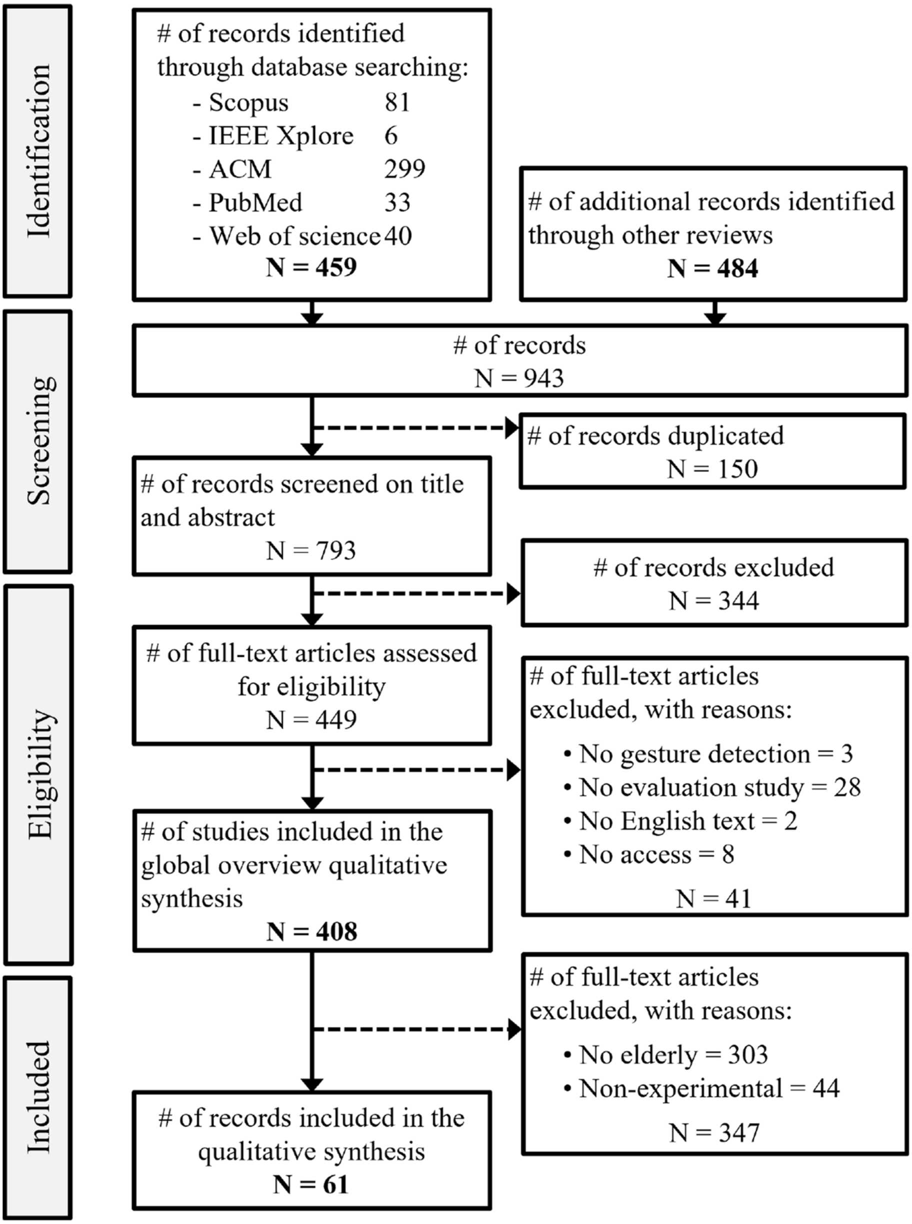

Fig. 1 PRISMA flow diagram

3.2 Taxonomy of motion-based technology

One of the objective of this scoping review is to help newcomers have a proper vision and understanding of the research in the field. In that sense, we establish a taxonomy based on the studies selected in this review.

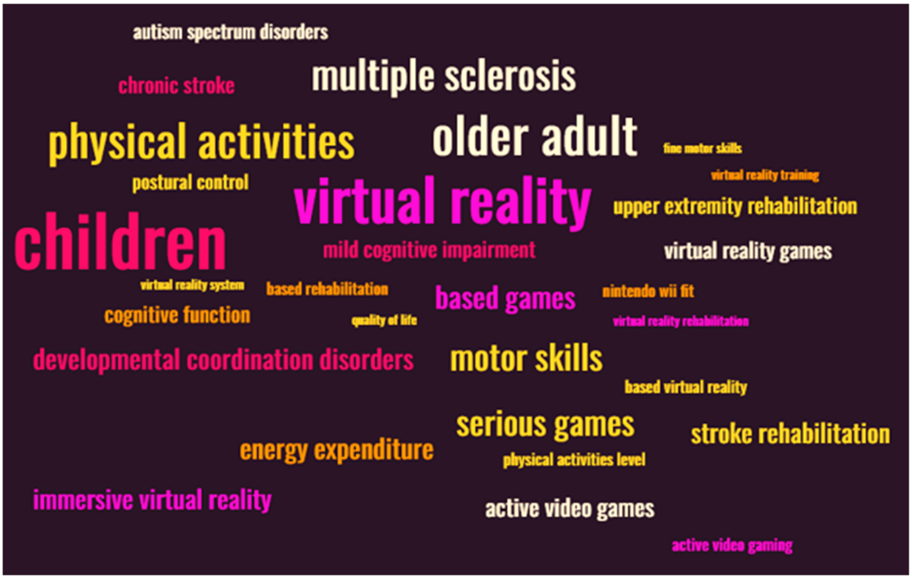

Fig. 2 Word cloud from the global overview of the field (408 studies)

After reading and classifying the 408 studies from the first selection pass, we realised that the motion-based technology was applied into 8 main **research fields of application** (see Fig. 3). Each of the studies used one of several **hardware** to **detect body motion**, which were implemented within **digital solutions**. These four main terms define our taxonomy (see Table 1).

With respect to the research application, the following 8 primary fields were identified:

- **Monitoring**: observes and detects the execution of specific motor skills to support the screening of motor/cognitive dysfunction
- **Assessment**: supports the diagnosis of potential physical/cognitive conditions

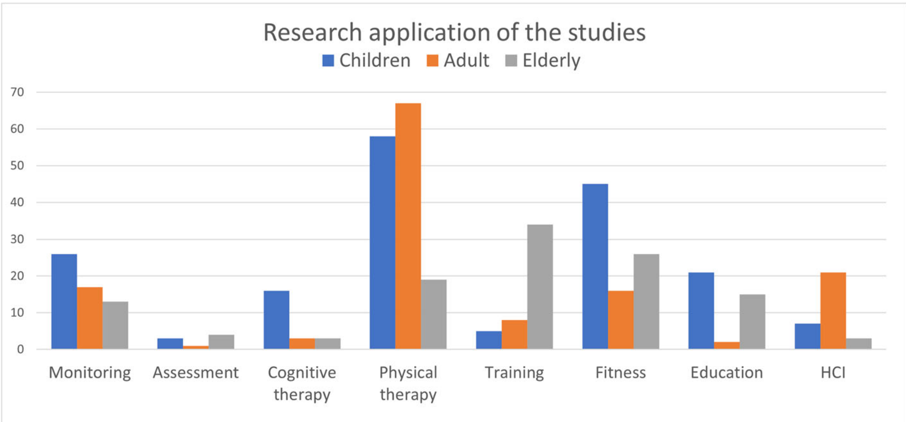

Fig. 3 Number of studies per population type and research application (408 studies)

Table 1 Overview of the terms of the taxonomy

Research application	Hardware	Body detection	Digital solution
Monitoring	Force plate	Full body	Commercial video-game
Assessment	Optical sensor	Upper-limbs	Ad-hoc solution
Cognitive therapy	Inertial Measurement Unit	Lower-limbs	None
Physical therapy	Multimodal sensor		
Training			
Fitness			
Education			
HCI			

- **Cognitive therapy**: aims to improve cognitive skills of people with a specific diagnostic
- **Physical therapy**: aims to improve motor skills of people with a specific diagnostic
- **Training**: trains or improves motor skills with no association to rehabilitation/therapy.
- **Fitness**: motivates participants to do physical activity.
- **Education**: supports cognitive skills learning through physical activity
- **HCI** (Human Computer Interaction), explores or provides guidelines in the use/development of motion-based technology.

With respect to the hardware employed in the research, 2 main types of sensors have been identified:

- **Optical sensors**: which, in general, have the ability to detect the scene from the light spectrum. For instance, these sensors are cameras that capture either the 2D coloured scene, or the "depth" by providing the distance of objects to the sensor (depth sensors).
- **Non-Optical sensors**, which do not use light to obtain data and employ other kind of measures such as magnetic/pressure/temperature/inertial values.

With respect to the parts of the body detected, the researches usually focus on the full body or specifically the upper limbs.

With respect to the digital solutions, the literature review reveals three types:

- **Commercial video-game**: video-games sold initially with the purpose of entertainment
- **Ad-hoc solution**: digital solution designed for a specific purpose such as:
  - *Serious game*: includes gaming mechanics (gamification)
  - *Artificial Intelligence*: computational models able to recognise or predict a specific outcome
- **None**: no digital solution was used

4 Specific analysis on elderly

By considering the profile of the end user, the original 408 articles employed in previous section can be segmented as follows: 177 studies involved children, 126 involved adults and 105 elderly. Elderly usually include participants over 65 years-old. Nevertheless, some studies focusing on elderly (or older adults) also included participants aged between 55 and

65. Technology is usually well integrated in children cohorts being born in the digital era, and well accepted in adults. However, older adults represent a minority in this field, and thus, we decided to perform a second selection pass in order to explore and understand what research has been conducted for such a population.

Thus, the 105 papers focused on elderly were analysed. From these, 44 papers were not taken into account as these conducted no experimental evaluation (see Fig. 1). In the subsequent sections, the remaining 61 papers were used as the base for the specific analysis focused on elderly.

4.1 Analysis over the MBT taxonomy

In this section we developed the taxonomy defined on previous section for elderly. In particular, the analysis is centered independently on each of the 4 terms of the taxonomy, that is to say: field of the research application, type of hardware, part of the body to detect, and type of digital solution.

4.1.1 Research applications

The final 61 studies that involve elderly with an experimental evaluation study reveals that no relevant research has been performed in HCI. The following subsections will deepen into each of the remaining 7 fields. Figure 4 shows the evolution of the studies per research application over the time whereas Fig. 5 shows the distribution of the selected 61 studies across the taxonomy defined in previous section.

Monitoring Monitoring is the process that observes participants' execution of determined actions in order to track and detect when such actions happen and if these are performed correctly. Monitoring in older adults rises several ethical and technical challenges such as privacy and robust recognition and classification of activities [64]. The literature in this field is scarce since only 4 studies were found (about 7% of the studies). The activities recognised are gait [93], body movement [24], risk of falling [73] and daily activities [81].

Zhu et al. [93] used computer vision techniques to extract feet position and estimate stride length via the camera of a phone. Their results compare to more expensive motion

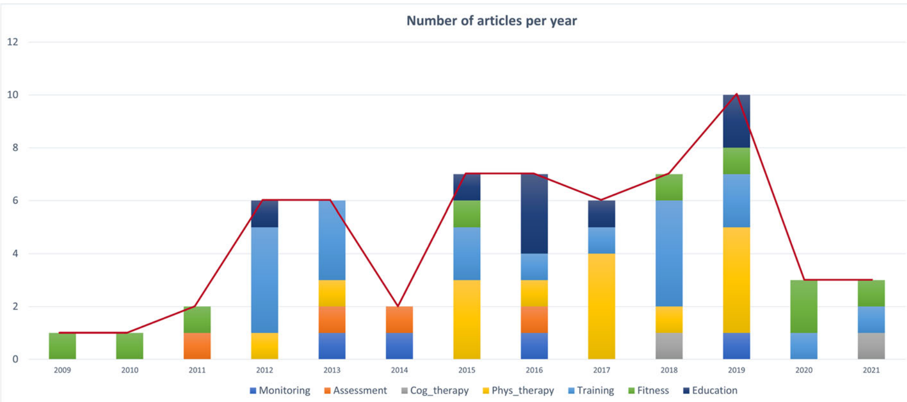

Fig. 4 Timeline of publications in elderly (61 studies)

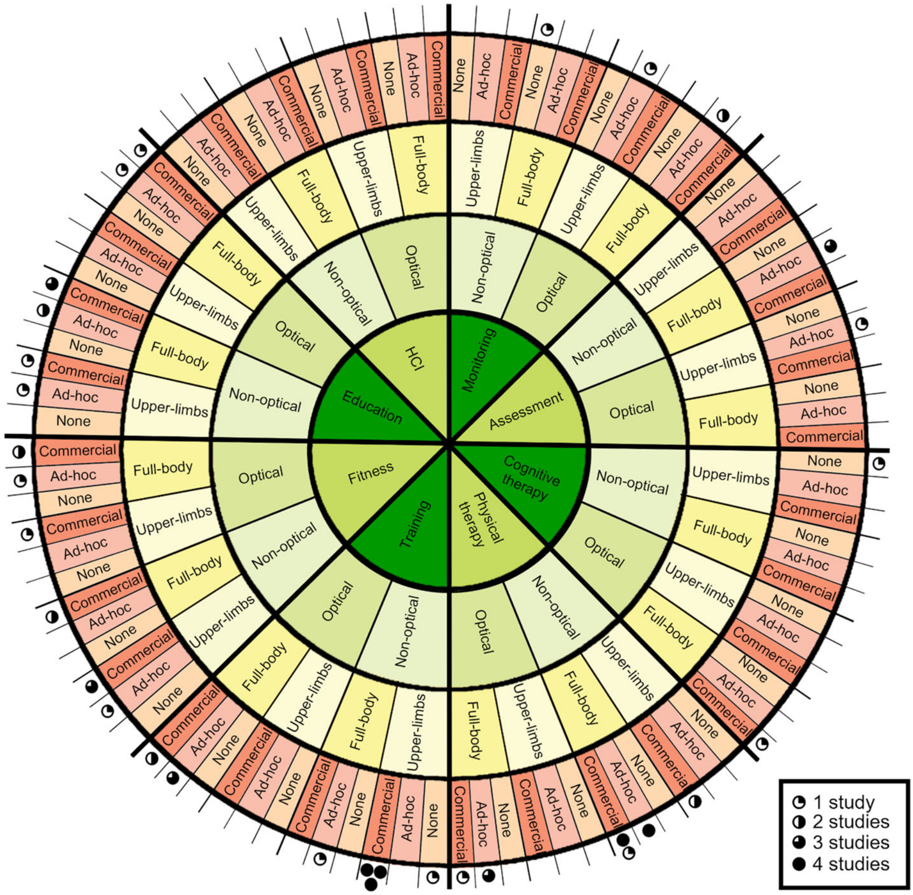

Fig. 5 Visual summary of the distribution of the studies (61 studies on elderly). Each inner circle represents one category of the taxonomy: field of the research application, type of hardware, part of the body to detect, and type of digital solution

devices which could improve accessibility in the identification of gait decrease in people with Parkinson disease.

Grammatikopoulou et al. [24] analysed movements of people with Parkinson disease while playing a serious game. The authors found different movement patterns and game scores according to the degree of the disease.

Schwenk et al. [73] combined the data from daily physical activity and fall history to increase the prediction of falling of people with dementia.

Tarnanas et al. [81] proposed a protocol to monitor daily activity in older adults with mild cognitive impairment. One of their criteria employs the Leap motion to detect finger tapping.

Assessment The assessment of a condition is typically organised in sessions with trained professionals who administer established evaluation tools, observe and analyse the person's tasks execution. Its multidimensional and interdisciplinary aspect make a real challenge to determine older adult's medical conditions, mental health or functional capability [77].

Regarding the 4 selected studies in this field (about 7% of the studies), the research mostly aim at recognising a diagnostic from the execution of body gestures.

Tarnanas et al. [82] proposed a virtual reality setup where participants interact with a series of serious games. From the interaction data, the authors are able to discriminate healthy participants and participants with mild cognitive impairment or Alzheimer disease.

Hsu et al. [26] analysed signals from an Inertial Measure Unit (IMU) to recognise gait parameters and balance capability while walking. The authors were able to point out differences between healthy participants and people with Alzheimer disease.

Similarly, [10] used machine learning models to predict diagnosis of Alzheimer disease based on postural control.

Barth et al. [4] attached an Inertial Measure Unit on the participants' feet in order to obtain gait features. By applying machine learning to the features, the authors were able to differentiate healthy participants from participants with Parkinson disease with a high rate of prediction.

Cognitive therapy Cognitive therapy consists of structured sessions which aim to treat or improve specific cognitive conditions. In elderly, cognitive therapy usually aims to improve depressive and anxiety disorders [86]. The literature shows that 2 studies used motion-based technology in that sense (about 3 % of the studies).

Zheng et al. [91] evaluated the impact of playing active video game with the Microsoft Kinect on cognition, quality of life and depression on people with dementia. The results showed that after 10 weeks of gaming, participants felt better.

Moyle et al. [53] tracked physical activity of older adults with dementia using an armband. Treatment consisted in using a toy robot to reduce anxiety. The results showed that the toy robot reduced agitation, but did not improve sleep patterns. In addition, the authors highlighted that the use of armband is challenging on the long term.

Both main cognitive therapy targets, depression and anxiety, had been studied. However, no experimental study aimed at quantifying the benefits of technology over conventional therapies.

Physical therapy Physical therapies for elderly aim to reduce pain and the decline in functional abilities caused by diseases or ageing process by improving range of motion, physical strength, flexibility, coordination and balance [62]. About 24% of the selected studies focused on physical therapy.

12 studies analyse the impact of using active video games as alternative to physical therapies for balance skill: 7 studies involved older adults with Parkinson Disease [14, 17, 33, 37, 54, 69, 88]; 4 studies involved frail older adults [3, 11, 76, 84]; and 1 study for hospitalised patients [7]. All these studies found that the use of active video game improved static and/or dynamic balance of participants, although only four studies found a significant increase compared to conventional therapeutic sessions [14, 33, 37, 84]. Amongst these four studies, two developed their own game solutions [14, 84].

2 studies aimed at functional reach of post-stroke patients [8], and chronic spine afflictions [78]. Both studies found improvements in functional reach after playing active video game although no significant differences was found compared to conventional therapies.

The last selected study looked at vestibular rehabilitation of participants with mild cognitive impairments and found a significant improvement with the use of Virtual Reality solution compared to traditional vestibular rehabilitation [47].

Overall, the studies found that the use of motion-based technology could be a good alternative for home-based rehabilitation.

Training In prevention to potential physical therapies, training sessions are recommended to postpone the decline of functional abilities such as range of motion, physical strength, flexibility, coordination and balance. Training is the most researched field with 31% of the selected studies.

The literature shows that balance is the main motor skill trained with motion-based technology with 13 studies. Amongst these studies, 2 studies compared the impact on balance skills between sessions of Tai chi and the use of Nintendo Wii Balance Board on healthy elderly [20, 63]. The two studies found similar improvement in both groups. 1 study compared the use of insole shoe on a regular basis with the practice of Nintendo Wii Balance Board and found no difference in static and dynamic balance skills but an improvement in muscle strength for the latter group [27]. 7 studies analysed the impact on balance skills from training with active video game compared to usual care and all found improvements in balance and muscular strength [5, 23, 34, 65, 85], [70] but one study who found no difference [51]. Finally, 3 studies compared the use of active video game with balance training programmes. Singh et al. [75] reported no difference of improvement between the two groups, [80] observed a significant improvement with the use of videogames, and [16] did not find any difference between the three groups (no intervention, conventional training, videogame training). Compared to the others studies, the latter evaluated only 6 sessions of 10-15 minutes.

The second main motor skill studied in the literature is training steps for falls prevention. Mirelman et al. [48] and [60] compared the use of non-immersive virtual reality games while walking on treadmills, with the use of treadmill alone for frail older adults and older adults with Parkinson disease, respectively. Both found significant improvement with the use of Virtual Reality. Song et al. [79] analysed the impact of training steps on older adults with Parkinson Disease with a dance pad game compared to no intervention. There were no difference between the two groups, however, the intervention group felt like they had improved their mobility. Similarly, [71] tested the same dance pad game with healthy elderly but in this case they found significant improvement compared to no intervention.

Decline in gait is an early symptom in Parkinson Disease, [41] detected arm swing movement with accelerometers, and analysed the improvements of range of motion with the use of music while walking. The authors found significant improvements.

In terms of improving sensory motor skills, [57] found no improvement between no intervention and the use of active video games in healthy older adults.

Most of the studies showed that the use of motion-based technology can have beneficial effects in terms of motivation and/or improvements. However, few studies comparing conventional with motion-based technology training found significant improvements [48, 60, 80].

Fitness The World Health Organization recommends adults and elderly should do at least 150–300 minutes of moderate-intensity aerobic physical activity per week. Research has showed that maintaining regular physical activity helps maintaining a good quality of life, health, and reducing falls in elderly [32]. About 15% of the selected studies aimed to increase physical activity with the technology.

The use of active video games is equivalent to light-moderate physical activity [36]. Besides, the entertaining aspects of the games seems to improve quality of life. For instance, [30] and [66] found that the use of active video games improved the perception of quality of life. Rica et al. [66] and [35] found that it also improves the mood thanks to the input of positive emotions. These results are also supported by [28] who found that playing active video games reduces loneliness and improves self-esteem.

On the other hand, [89] found that the use of active video game can reduce pain in patients with chronic pain. However, there were no improvement in terms of care-seeking, fear of movement/re-injury, or falls efficacy. This was also reported by [31] with no significant difference in the fear of falling between the use of active video games and regular gym activity.

2 studies did not aim at analysing the impact of active video games on quality of life but instead developed their own solution to improve motivation and engagement [9, 67].

Education A challenge in the ageing process is the cognitive decline which usually includes processing activity, perceptual and sensory deficiencies, and weaker performance [49]. Therefore, learning and training cognitive skills is relevant to postpone such a decline. 13% of the selected studies looked for educational solutions.

6 studies looked at the effect of motion-based technology on executive functions. Liao et al. [38] found no difference in executive functions between elderly with mild cognitive impairment using immersive Virtual Reality and traditional physical activity programme. However, they observed a better performance in dual task gait. 3 studies [13, 50, 72] compared conventional exercises against active video games, and found improvement in executive functions in both experimental and control groups, but no significant difference between groups. Maillot et al. [40] analysed the impact of active video game on healthy elderly and [83] the impact of immersive Virtual Reality on older adults with mild cognitive impairments. Both studies found significant improvements, however, the control group had no intervention.

In terms of attention, [1] found that the cognitive load in active video games can reduce slowness and complexity of electroencephalography and improve cognitive functions in elderly with mild cognitive impairment. Liao et al. [12] found that dance pad game can improve attention and working memory compared to the use of treadmill.

4.1.2 Type of hardware

The literature reveals the use of distinct types of devices when MoCap is applied to elderly.

- **Optical sensors**: In that category, the following devices are used:
    - ∗ Regular video-camera
    - ∗ Leap motion (depth sensor)
    - ∗ Microsoft Kinect (depth sensor)
- **Non-Optical sensors**, which include:
    - *Force plates* that can detect where the user puts some pressure on. The literature reveals 2 sensors in this category:
        - ∗ Nintendo Balance Board
        - ∗ Dance Mat
    - *Inertial Measurement Units (IMU)* that captures acceleration and rotational information. This includes:
        - ∗ Nintendo Wii-mote controllers
        - ∗ Regular IMU
        - ∗ VR (composed of headset and two IMU-based controllers)

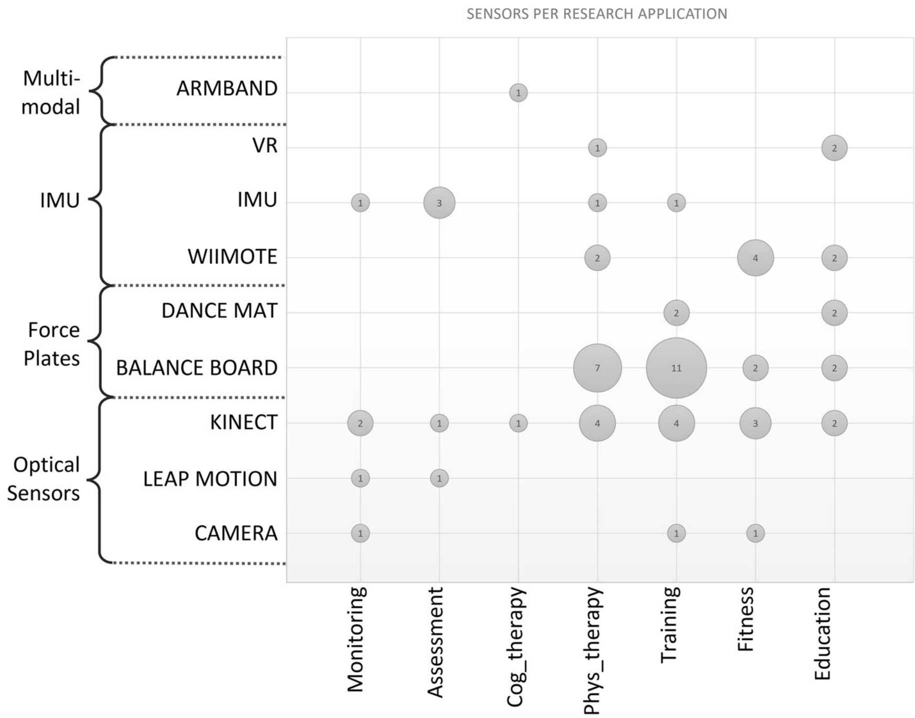

Fig. 6 Use of devices against purpose (considering elderly as end user)

- *Multimodal sensor* which combines different types of sensors to capture different types of information.
  - Armband which can record biometrics such as heart rate and it embeds IMU.

We plotted Fig. 6 in order to show the use of sensors across the different research applications. An horizontal reading will show when the sensor was used, and the vertical reading will show how many sensors a specific research application used. The Microsoft Kinect was the only sensor used across all the research fields. The Wii balance board and Microsoft Kinect are the main devices used with elderly.

4.1.3 Body detection

The selected studies used the above-mentioned sensors in order to capture different body motion. The motion-based sensors are able to detect either **upper-limbs** (including hands), or **full-body** (including lower-limbs and head) movements (see the first two columns of Table 2).

Detecting body motion allowed the recognition of specific motor skills (see Table 2). In terms of force plates, the Wii Balance Board was used to detect center of pressure and the dance mats specific located steps. Depth sensors were used to detect sway movements of the body (center of pressure and body movement), Functional Reach and steps. The information provided by IMU allowed the detection of center of pressure, body movement, functional

Table 2 Detection capacity of the motion-based sensors

Sensor	Full-body	Upper-Limb	CoP	BM	FR	HM	Steps	FD
Camera	✓	-	-	1	1	-	2	-
Leap Motion	-	✓	-	-	2	-	-	-
Kinect	✓	✓	5	10	16	-	3	-
Balance Board	✓	-	22	-	1	-	-	-
Dance Mat	✓	-	-	-	-	-	4	-
Wii-mote	✓	✓	1	-	8	-	-	-
IMU	✓	✓	2	1	1	-	3	1
VR	✓	✓	-	1	2	1	-	-
ArmBand	-	✓	-	-	-	-	1	-

Cop: Center of Pressure / **BM**: Body Movement / **FR**: Functional Reach / **HM**: Head Movement / **FD**: Fall Detection

reach, steps and fall detection. Camera was used to detect body movement, functional reach and steps. VR headset, besides body movement and functional reach, this device allowed the detection of head rotation. Finally, the armband was able to detect steps through its embedded IMU.

In terms of types of motion detected, besides falls and steps, no more advanced motor skills was recognised such as squat, shaking hands, etc. Although some sensors were used to detect different types of motion, no single device was able to detect all types of motion.

4.1.4 Digital solution

The appearance of commercial active video games had a big impact on society and most of the studies analysed their effects for therapies, fitness, training and education (see Table 3). Amongst these games the most used are Nintendo Wii-Fit [5, 11, 16, 17, 20, 23, 27, 31, 34, 37, 50, 51, 54, 63, 65, 75, 76, 89], Nintendo Wii-sport [28, 35, 40, 50, 69], Microsoft Kinect Sports [30, 36, 57, 66, 80], Microsoft Kinect Adventures [3, 36, 80], Stepmania [12, 13, 71, 79], Wii K-pop dance [33], Kinect Dr. Kawashima [1], and Kinect fruit ninja [91].

Table 3 Type of Software used in the different research applications

Research application	Commercial	Ad-hoc solution		None
		Serious Game	Artificial Intelligence	
Monitoring	-	2	1	1
Assessment	-	1	3	-
Cognitive therapy	1	-	-	1
Physical therapy	8	7	-	-
Training	14	4	-	1
Fitness	7	2	-	-
Education	5	3	-	-

The ad hoc solutions are developed by or with the researchers with the objective to personalise the content to specific purposes or audience. Most of the ad-hoc solutions consist of a series of mini-games either to improve balance control [7, 8, 14, 70, 84, 85, 88], exercising physical activities based on personal trainer [9] or soccer [67], or to train cognitive skills [38, 72, 83]. The stand-alone ad-hoc solutions were developed to control the execution of a specific motor skill [24, 47] or exercise daily activities, such as fire drill [81, 82], gardening [78], or hiking [48, 60].

Artificial Intelligence, was used to recognised gait features [93] and [26] or differentiating motion execution to predict a diagnosis of Alzheimer Disease [10] or Parkinson Disease [4].

Finally, two studies did not use any software. One analysed the effect of a robot on sleep pattern using armband to monitor physical activities [53]. The other study asked participants to wear an IMU and monitored movements over 24 hours [73].

4.2 An additional analysis: instruments/mechanisms of evaluation

The purpose of this section is to present the main instruments of evaluation that are used in the field and for what purpose. Thus, Table 4 classifies per research field (vertical reading) and per criteria (horizontal reading) all the instruments tools that were used at least in two different studies.

For instance, reading Table 4 horizontally shows that Mental condition is an important criteria which is applied in all the research applications. Indeed, these tests serve two purposes, first it is an eligibility criteria for the selection of the participants; second, it is also used as pre-post tests to observe potential improvements.

Reading the table vertically shows a clear difference between physical therapy and training research applications. Physical therapy mostly focuses on balance skills while training is more heterogeneous aiming at fall risks, reflex or manipulation . The vertical reading also brings out the two main objectives of the education research application, which is fitness/mobility and cognitive activity.

4.3 Reasoned analysis of the outcomes

More than half of the selected studies focused on physical therapy (15 papers) and training (19 papers). While training remains a trendy research with recent publications, no study was published on physical therapy since 2019 (see Fig. 4). Research in these two fields mostly used the Wii-balance board as motion-based device followed by the Microsoft Kinect (see Fig. 6) focusing mainly on the center of pressure and body/arm movement respectively (see Table 2). While physical therapy used equally commercial and ad-hoc solutions, training mainly focused on the impact of commercial games (see Table 3). This reveals a potential niche for future research in training since this field usually requires personalised solutions.

Another two fields of interest in elderly are fitness (9 papers) and education (8 papers). Contrary to physical therapy and training, which mostly focused on the use of balance and upper limbs, fitness and education are not interested in a particular set of motor skills. This is perceived in Fig. 5 with homogenised research across the different categories and Fig. 6 where these two fields use several types of sensors homogeneously. Research in fitness mainly focuses on the impact of commercial games on energy expenditure (see Table 3). On the other hand, education tends to integrate fitness as main mechanism in exercising the sets of cognitive skills (see Table 4). Since ageing is a process that affects physically, cognitively,

Table 4 Use of evaluation instruments across the fields

Criteria	Test	Mon.	Ass.	CT	PT	Train.	Fit.	Edu.
Balance	BBS				●	●	○	○
	Tinetti				◐	●		
	ABC				◐	◐		
	FRT				◐	●		
	FGA				◐	◐		
	MiniBEST			○	○	○		
	CoP					●		
	DGI				◐	○		
Mobility	TMT		○			○		●
	10MWT				◐			○
	6MWT							◐
	HGS							◐
Fitness	HR						◐	○
	SFT				○			○
	8FT-UG					○		○
	SPPB					○		○
Fall risk	TUG	○			●	●	○	○
	FES-I	○				●	○	◐
	PPA					◐		
Reflex	ST					○		○
	ASRT					◐		
	CSRT					◐		
Manipulation	GS		○			○		
Healthy habits	SF-36					◐	◐	
	ADL	○	○					
Mood	GDS		○			◐		◐
	PANAS						○	○
	BDI						○	○
	CSDD	○		○				
Mental condition	MMSE	◐	◐	○		●		●
	MoCA		○	○	○	◐		◐
	UPDRS	○			○	●		
	PDQ				◐	◐		
Cognitive activity	TAP					○		○
	DSST							◐
	EEG							◐
User Experience	IMI				○	○		
Others	In-game	◐		○		◐		○
	Interview					◐	●	
	Kinematics		○			○		
	Biometric		○	○				

○: used once / ◐: used twice / ●: ≥ 3 times / “Mon.”: Monitoring / “Ass.”: Assessment / “CT”: Cognitive therapy / “PT”: Physical therapy / “Train.”: Training / “Fit.”: Fitness / “Edu.”: Education / BBS: Berg Balance Scale / ABC: Activities-specific Balance Confidence scale / FRT: Functional Reach Test / FGA: Functional Gait Assessment / MiniBEST: Mini Balance Evaluation Systems Test / CoP: Center of pressure / DGI: Dynamic Gait Index / TMT: Trail Making Test / 10MWT: 10 Metre Walk Test / 6MWT: 6 Metre Walk Test / HGS: Habitual Gait Speed / HR: Heart rate / SFT: Senior Fitness Test / 8FT-UG: 8 Foot Up and Go / SPPB: Short Physical Performance Battery / TUG: Timed Up and Go / FES-I: Falls Efficacy Scale Internationa / PPA: Physiological Profile Assessment / ST: Stroop Test / ASRT: Alertness and Simple Reaction Time / CSRT: Choice Stepping Reaction Time / GS: Grip Strength / SF-36: 36-Item Short Form Survey / ADL: Activities of Daily Living / GDS: Geriatric Depression Scale / PANAS: Positive and Negative Affect Schedule / BDI: Beck Depression Inventory / CSDD: Cornell Scale for Depression in Dementia / MMSE: Mini-mental state examination / MoCA: Montreal Cognitive Assessment / UPDRS: Unified Parkinson’s Disease Rating Scale / PDQ: Personality Diagnostic Questionnaire / TAP: Test of Attentional Performance / DSST: Digit Symbol Substitution test / EEG: Electroencephalogram / IMI: Intrinsic Motivation Inventory and mentally, it is important to research how personalised solutions can improve well-being in elderly via fitness and cognitive training.

Finally, this review shows that there is a limited total number of studies in both cognitive therapy (22 studies) and assessment (8 studies) with motion-based technology, which are reduced to 2 and 4 in elderly respectively. Indeed, most of the studies in those fields are focused on children, who easily adopt technology as good support to motivation. Besides, the selected studies of these two research fields combine both motor and cognitive skills, which is not as common as studying cognitive skills only. Regarding monitoring and assessment, these fields are usually controversial with technology since it is preferably undertaken by humans. Nevertheless, these research fields are primordial in health-related research, and thus, research should continue to seek for technological support.

This paper reviews a large number of studies using motion-based technology and limits its scope with generic keywords to obtain a global view of the research. Furthermore, as scoping review, there is no assessment or risk of bias of the included articles. In order to reduce bias, the selection and analysis of the studies is limited to (quasi-)experimental research. Despite such limitations, this scoping review identifies the state of the art and potential direction of research of motion-based technology with elderly.

5 Conclusions

This paper reviews the terminology of motion-based technology, which is when motion capture technology takes into account the profile of the end users with respect to their age. The paper reports an extensive analysis conducted on a large number of papers (above 400) that have been published in the scientific literature. Two main results have been achieved: a scoping review that will help the interested readers understand the context and a new taxonomy related to motion-based technology. This taxonomy identifies 8 main research fields of application, and then separates the research works with respect to three other aspects: the hardware, part of the body involved in the research and nature of the digital solution employed.

Then, in a subsequent phase, the research have been centered on elderly as end users. Out of 408 selected studies, 105 employed MoCap with older adults, amongst which 61 followed an experimental approach. More than half of the studies focused on physical therapy and training. These fields predominantly validated the impact of commercial videogames using the Nintendo Wii-balance board (centre of pressure) and the Microsoft Kinect (functional reach mostly). Other research applications such as monitoring, assessment and education took advantage of personalised experiences provided by ad-hoc solutions. In terms of motor detection, sensors are mostly used to follow simple movements (centre of pressure or upper limbs), with few studies aiming to recognise specific motor skills such as steps and falls. Overall, this paper shows a relevant number of studies that focuses on motor and cognitive skills. However, and as stated in the introduction, ageing affects physically, cognitively, and mentally. Therefore, we recommend that further research in the field should consider the social component as an additional value to MBT [55].

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Data Availability The dataset generated during and/or analysed during the current study are available online [2].

Declarations

Conflict of Interests The authors confirm that this work is original and has not been published elsewhere, nor is it currently under consideration for publication elsewhere. The authors have no conflicts of interest to disclose. The authors declare they have no conflicts of interest.

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