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Review Article

Scoping Review on the Interactive Digital Tools Used for the Physical and Cognitive Stimulation of Healthy Older Adults

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As more of our lives are spent using electronic devices, it comes as a natural deduction that those digital tools could be used to maintain people's health. Gamified exercise or exergames are indeed promising means to motivate the population to get physically active and even cognitively active if paired with the appropriate games. Considering the global concern of an aging population which could benefit from both physical and cognitive stimulation, these tools appear to be an encouraging solution to keep the population healthier over time. This scoping review reports on the digital tools used in publications between January 2015 and December 2023 regarding the physical and cognitive stimulation of healthy elderly people. The search was conducted in PubMed, Web of Science, and ScienceDirect databases. Of the 1579 publications retrieved, a total of 68 publications were analyzed in this review. A wide variety of digital tools were used in the corpus for the combined physical and cognitive stimulation of the elderly. These tools can be categorized into six types of hardware: pressure plates, optical motion capture, inertial motion capture, virtual reality, ergometers, and driving simulators. The apparition of publications using virtual reality and an increase in publications using inertial motion capture in 2020 could be an indicator that digital tools used for cognitive and physical stimulation of the elderly are evolving. Another finding is the wide variety in evaluation tools used to monitor the outcomes of each protocol. A standardization of the testing process might be needed in order to improve comparisons between experiments.

Keywords: cognitive stimulation; elderly; exergame; physical stimulation

1. Introduction

Despite the common perception that video games are primarily associated with boys or teenagers, it is noteworthy that 48% of gamers in the United States as of 2022 identify as female, with the average player being 33 years old [1]. It is also worth noting that, according to [2], more than 40% of baby boomers worldwide engage with gaming [2] and that video games have been used to stimulate elder's physical and cognitive abilities [3].

The global population is indeed getting increasingly older and supporting the elderly in order for them to age while being as healthy as possible is a primary concern for the world [4, 5]. One of the primary concerns is the financial strain associated with elderly care, evident in OECD countries allocating an average of 1.8% of their gross domestic product to long-term care in 2021 [6]. This is especially pertinent given that individuals aged 60 and above constitute the largest demographic requiring such care [7]. A striking example would be the case of Norway reported by Kalseth and Halvorsen [8], stating that adults 65 years old or older represent 15% of the country's population but are responsible for almost half of the health and care cost of the country.

Frequently stimulating the elderly both physically and cognitively appears to be one of the main steps in order to maintain an aging person's health [9, 10]. Hence, the idea of stimulating elderly people using video games arises.

In this paper, video games will be defined as electronic games relying on user input devices and using a visual display. Notably, video games that can be used as a form of exercise are often called "exergames." Exergames appear to be an interesting tool to help people exercise while having fun [11]. Another advantage of video games is their cognitively challenging aspect, as games can include puzzles, memory, or divided attention tasks, for example. These two aspects can easily be utilized in order to create physical and cognitive training for the elderly using video games, and it has been a subject of scientific research for many years [12, 13]. In addition, having a combined physical and cognitive training have been shown to be more efficient than physical and cognitive training done separately [14, 15]. Video games, and more generally digital tools, are a great tool for creating synergistic trainings with the physical and cognitive task intricately linked together [16, 17]. However, exergames usually call for additional accessories for physical training, as opposed to a simple mouse and keyboard or game controller setup used in conventional gaming [18, 19].

Back in the 1980s, video game companies started to explore inventive solutions to allow exergaming on traditional video game consoles. This includes pressure sensing mats or platforms like the Power Pad for the Nintendo Entertainment System (1986) or the Video Jogger for the Atari 2600 (1983) [20]. A few projects of gamified cycle ergometers were also launched such as the Puffer by Atari (canceled) or the High Cycle by Autodesk (1990). Inertial motion capture controllers also hit the shelves around 1990 with the motion sensing glove Nintendo Power Glove or Virtual Racquetball by AutoDesk, a motion sensing racquet-shaped controller that could be paired with an early generation virtual reality (VR) head-mounted displays (HMDs) for greater immersion. The early 1990s indeed saw the apparition of the first commercial HMDs like Nintendo Virtual Boy (1994), as well as the first infrared sensor controllers, like the Nintendo U-Force (1990). Not mere relics of video game history, those inventions were in fact the precursors to the exergame setups used today from cycle ergometers with screens [21] to VR headset [22] by way of infrared motion capture [23].

Stimulating training of the elderly has been the focus of several recent systematic reviews; however, they usually tend to focus on only one type of stimulation, most often either physical stimulation [24, 25] or cognitive stimulation [26, 27]. Falck et al. [25] focused on the impact of exercise training on both physical and cognitive functions in older adults. They reported significant benefits on both physical and cognitive functions. Guizelini et al. [24] more specifically studied the impact of resistance training on muscle strength and rate of force development in the elderly. This type of training appeared to improve both criteria regardless of age and training duration. Regarding cognitive stimulation, Butler et al. [27] analyzed reports of cognitive training exercise interventions on elderly people lasting more than 6 months. They concluded that healthy older adults indeed improved in the cognitive domain trained, while results for older adults with MCI (mild cognitive impairment) suggested no effect on performance. Palumbo and Paternò [26] studied the impact of serious games for the cognitive stimulation of older people, with an emphasis on the technology used to provide such stimulation. They noted that elderly people were not reluctant to use new technologies, with tablets appearing to be the most well-suited tool for this population. Nevertheless, they report that the different types of technology stimulate mostly the same cognitive functions that are also the ones most involved in aging. Some of the articles studied did find improvement in cognitive functions following the serious game training, but this was not the case for all.

As mentioned prior, our work focuses on combined physical and cognitive training. A few systematic reviews have been published regarding this type of training [15, 28]. Gavelin et al. [15] reviewed publications on combined physical and cognitive training with the objective of comparing simultaneous, sequential, and exergaming types of training for older adults. They report that combined training results in a small and significant effect on cognitive and physical functions in both healthy and MCI older adults. Regarding cognitive functions, simultaneous training appears to provide better results than sequential or cognitive training only, which in turn provides better results than physical exercise alone. Regarding physical functions, simultaneous and sequential training had comparable results as physical exercise only. Exergame training appears to provide some physical and cognitive benefits but ranked lower than the other forms of training. The authors suggest that this difference in efficacy might be due to exergaming training being usually less intensive than other forms of training. On another note, Pacheco et al. [28] studied the effectiveness of exergames for improving mobility and balance in elderly people. They found that exergames can be used in geriatric rehabilitation and keep users motivated to perform the exercises, as well as improving the balance and mobility of the participants.

The aim of our work is to provide a technology-focused review, similar to Palumbo and Paternò [26], in the realm of combined physical and cognitive stimulation. We believe that the stimulation tools, referred to as "exergames" in Gavelin et al. [15] or Pacheco et al. [28], for example, need closer inspection. Different tools may be necessary to provide resistance training or balance training coupled with cognitive exercises. Furthermore, we decided to focus on interventions using digital devices as they are an efficient way to provide a simultaneous physical and cognitive training without requiring the active involvement of a staff member. Indeed, shortages of care workers for the elderly being a global issue [6], we decided to focus on stimulation tools that have the potential to enable autonomous training.

Hence, this scoping review is aimed at exploring the use of digital stimulation tools for coupled physical and cognitive stimulation of the elderly. This scoping review aspires to provide a global and comprehensive overview of the different experimental setups used for such stimulation in academic research.

2. Definition of the Stimulation in Question

2.1. Introduction. The concepts of "physical stimulation" and "cognitive stimulation" are quite hard to define. As a matter of fact, the definition of stimuli itself remains unclear and debated among the scientific community [29]. For instance, "physical stimulation" or "body stimulation" of infants can be considered as any motor or kinesthetic exercises practiced by a caregiver on the infant's body [30], while electrical stimulus controlling hand movements via forearm electrodes could also be considered as a stimulation of the body [31]. Similarly, a "cognitive stimulation" can range from being a significant cognitive load [32] to electrical impulses through electrodes implanted in the brain [33]. Consequently, a stimulation could be considered to be any electrical response coming from the brain or muscles, or it could require a tailored definition based on a specific population's or individual's physical and cognitive abilities. As this work focuses on healthy elderly adults, this population's physical and cognitive skills were used as a frame of reference to define what would be considered "stimulating," both physically and cognitively, in this work. Nevertheless, it is important to keep in mind that physical and cognitive abilities vary greatly from person to person and their decay due to aging is no exception.

2.2. Physical Stimulation. In this review, activities were considered to be physically stimulating if they involved limb movement. As a matter of fact, the World Health Organization (WHO) describes physical activity as "any bodily movement produced by skeletal muscles that requires energy expenditure" [34]. Energy expenditure can be measured by many techniques such as calorimetry, heart rate monitoring, or self-reporting methods [35]. However, some studies on exergaming may clearly involve physical activity, like aerobic exercise, without having an interest in measuring energy expenditure [36]. Exercise recommendations for adults [37] include weekly resistance training, aerobic exercise, and balance training, all of which focus on limb movement. As a result, limb movement was chosen as a criterion for physical stimulation rather than energy expenditure measurements.

2.3. Cognitive Stimulation. In this review, playing any type of video game was considered cognitive stimulating for the target population. Video game interventions have indeed been shown to improve some cognitive abilities in elderly individuals, such as memory or task-switching. For instance, Basak et al. [38] reported that after 7 weeks of training on a strategy-based video game, elderly participants significantly improved their executive functions with a large effect size compared to nongaming controls, with better performances in task-switching, n-back test, and Raven's Advanced Progressive Matrices among others. A significant postintervention improvement in hippocampal-based memory, persistent over 4 weeks, has also been observed by Clemenson et al. [39] on elderly people who played the game Super Mario 3D. In addition, playing certain video games has been reported to cause greater improvement in various cognitive functions than passive or physically active controls, including processing speed (using TMT-A or number test) in older adults [19]. Therefore, it appears that playing video games can positively impact cognitive functions in elderly participants. As a consequence, playing video games, ones specifically designed to target certain cognitive skills or ones that have no cognitive stimulation claims, was considered to be cognitively stimulating. Our research specifically addresses interactive games demanding a conscious cognitive endeavor for the player. For example, trying to match one's movement to an exercise video [40] was not considered to be cognitively stimulating.

3. Research Question

In response to the worldwide trend of population aging and the democratization of digital technology, it is becoming increasingly apparent that digital tools can serve as essential aids for the physical and cognitive stimulation of older adults. With this review, we aim to present the state of the digital technology landscape used for the physical and cognitive stimulation of the elderly in research and its evolution since 2015. We intend to do so by addressing the research question: Since 2015, what digital tools have been used in research to stimulate healthy older adults both physically and cognitively?

We consider to be healthy older adults any adult 60 years old or above with no pathological diagnosis. Healthy aging indeed is not a disease but often comes along with some cognitive and physical decline. In contrast, pathological aging refers to individuals affected by age-related diseases, such as degenerative conditions. Consequently, these two populations have distinct needs: cognitive and physical stimulation for healthy aging is aimed at maintaining overall abilities, whereas stimulation for older adults with diseases targets reduction or recovery from pathology-specific symptoms [41]. In this review, we chose to focus on the former to gain a comprehensive view of the technological landscape, as focusing on specific conditions may exclude tools incompatible with the disease. The year 2015 was chosen as a cutoff point in order to include the introduction to the global market of affordable VR headsets, which hit the shelves around 2016 and are used today for exergame interventions with older adults. We also believed that this time frame would be long enough to highlight recent technological advances while keeping the amount of retrieved publications manageable for a single reviewer. The findings from this study will offer insights into the current state of research in this area and may inform future efforts to enhance the quality of life for older individuals through technological interventions.

4. Methods

This section discusses the methods used to conduct this scoping review. It details the keywords and databases chosen to collect publications. Then, it defines the inclusion and exclusion criteria used to identify articles relevant to our topic of research in the pool of extracted papers. Finally, the reviewing guidelines, publication sorting platform, and data analysis process are defined to conclude the section.

4.1. Data Sources and Search Strategies. This scoping review was carried out following the 2020 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [42].

The database search was done by one individual reviewer using the three following databases: MEDLINE (PubMed), Web of Science (WOS), and ScienceDirect. The databases were first searched on the 23rd of March 2023 and the reports extracted and sorted between March and April 2023. It was then updated on the 15th of December 2023 by searching the same databases with the same keywords. No language filters were used. A date filter was used, excluding all documents published prior to 2015. The keyword used were the following: (exergame OR exercise program OR exercise training OR physical activity OR workout OR motor activity OR cognitive training OR brain game OR cognitive exercise OR cognitive stimulation) AND (VR OR augmented reality OR video game OR videogame OR video gaming OR videogaming OR computer game OR computer gaming OR immersive OR semi-immersive OR digital OR computerized) AND (elderly OR old OR older OR community-dwelling OR older adults OR senior) NOT adolescent NOT adolescents NOT children NOT child NOT surgeon NOT athletes NOT exoskeleton NOT robot NOT review NOT case study.

A search was conducted for the keywords within the titles or abstracts of the papers. These keywords are organized into three pools of words, connected by "AND" connectors.

The first pool of words (exergame OR exercise program OR exercise training OR physical activity OR workout OR motor activity OR cognitive training OR brain game OR cognitive exercise OR cognitive stimulation) corresponds to the description of the intervention targeted. Here, stimulation programs include physical and cognitive activity. The connector "OR" was chosen between the words related to physical activity and the ones related to cognitive activity. The inclusion criteria detailed in Section 4.2 indeed state that both physical and cognitive stimulation must be performed in order to meet the criteria. However, due to the varied possible interpretations of the terms "physical stimulation" and "cognitive stimulation" (see Section 2), the mention of only one of the two activities was considered enough to be worth examining further.

The second pool of words (VR OR augmented reality OR video game OR videogame OR video gaming OR videogaming OR computer game OR computer gaming OR immersive OR semi-immersive OR digital OR computerized) corresponds to the description of the digital tools targeted in this review. Specific device names, such as "head-mounted display" or" Kinect", were not included in the keywords in order to limit the bias on what the reviewer might think are appropriate tools for this type of intervention.

The third pool of words (elderly OR old OR older OR community-dwelling OR older adults OR senior) corresponds to the description of the target population.

A pool of excluded keywords was also added to discard studies meeting an exclusion criterion. Protocols using robots will be excluded as they are commonly used as social assistance to the elderly [43]. This remarkably increases the pool of publications to be screened with only few eligible papers. We also considered that the tracking and measuring technology used by a robot could be used without one. Therefore, we hypothesize that our objective to do a state of the art on digital tools for physical and cognitive stimulation of the elderly would not be hindered by the exclusion of robots. We acknowledge that relevant papers may have been excluded due to this criterion.

4.2. Inclusion/Exclusion Criteria. The publications selected in this review had to fit the inclusion and exclusion criteria described here:

- Participants targeted should be 60 years old or older and healthy (no physical injury or medical diagnosis used as inclusion criteria, when evaluated MMSE (Mini-Mental State Examination) score should include scores strictly higher than 24, which corresponds to no cognitive impairment.
- The paper has to be empirical (at least one participant of the target population must follow the intervention for at least one session).
- The intervention should provide both a cognitive and physical stimulation (see 2).
- The intervention should have stimulation or training as a goal, not assessment.
- Reviews, perspective articles, and case reports are excluded.
- The paper must be written in English.
- The full paper must be available (abstracts only studies are excluded).
- The paper must be published in a peer-reviewed venue.

4.3. Data Extraction. The papers were systematically gathered from the databases based on the defined keywords. Duplicates were then identified using the automated duplicate identification tool from the CADIMA platform [44]. Every potential duplicate was verified and deleted manually. Papers were then screened based on their titles and abstracts on the CADIMA platform. Every document that was not meeting the inclusion criteria was excluded from the list of articles. The remaining articles were then screened based on their full text. Every document that was not meeting the inclusion criteria was excluded from the list of articles. From the selected full texts were extracted those parameters: number of participants (recruited and analyzed), number of sessions, frequency of sessions, time span of the intervention, duration of sessions, technological tool used, and outcomes measured (see Supporting file 1).

4.4. Data Analysis. Most of the data presented in Section 5 was directly extracted from the publications and was not further analyzed. Only means and medians for number of participants, number of sessions, frequency of session and duration of session, number of evaluation tools, and number of evaluation tools categories were computed. The means and medians were calculated using R programming language [45].

5. Results

5.1. Study Selection. Using the keywords detailed in Section 4.2, 1579 articles were extracted from the selected databases. Of these articles, 629 articles were removed in order to eliminate duplicates and the 950 articles' titles and abstracts were screened to determine if they fit the eligibility criteria. After this first screening, 119 articles were sought for full-text retrieval. One article was not accessible, as a result, 116 full-text articles were screened another time to determine if they met the eligibility requirements. After screening, 68 articles were considered eligible and will be discussed further in the Results section. Figure 1 shows a PRISMA flowchart of the study identification process.

5.2. Types of Stimulation Tools. Various digital stimulation tools were used in the different studies of our corpus. The tools were grouped into categories based on the type of hardware they used:

- Driving simulator: pedal set and haptic steering wheel
- Ergometer: treadmills and cycle ergometers
- Inertial mocap: motion capture using inertial measurement units (IMUs) on their own, or integrated in controllers or tablets, like the Nintendo Wiimote controller or iPad tablet, for example
- Optical mocap: motion capture using optical devices like cameras and possibly infrared emitters and detectors, like the Microsoft Kinect for example
- Pressure plate: pressure-sensitive platforms, boards, or mats
- VR: HMD or cave automatic virtual environment (CAVE)

The publications using each type of digital tools are referenced in Table 1.

In 18 publications of the corpus, more than one type of stimulation tool was used in the protocol. Figure 2 is a network representation of stimulation tools being used together. The different stimulation tools are represented by nodes, the diameter of which is proportional to the stimulation tool's occurrences in the global corpus. The thickness of the edges linking nodes together represents the number of times the tools were used together; the thicker the edge, the more often the tools were used jointly.

Except the driving simulator, all tools were used at least one time in conjunction with another stimulation tool. The most frequent pairings are being inertial mocap coupled with VR or optical mocap, or VR coupled with ergometers.

In the following graphs (Figures 3(b) and 4), in the case of one study using multiple stimulation tools, that study will count as one occurrence for every tool used in the study. As a result, the sum of the number of articles sorted by stimulation tool types exceeds the number of total studies.

When sorting the corpus by year of publication, it appears that the most prolific years are the most recent with 2020, 2021, 2022, and 2023 being the top 4 years in terms of articles represented in the corpus (see Figure 3(a)). The number of articles per year does not appear to follow a linear evolution of any kind. The years with the most publications also correspond to the years with the most variety in stimulation tools used, with at least one publication for each of the six stimulation tool types identified in the corpus recorded in 2021 (see Figure 3(b)). Optical mocap and pressure plates have appeared regularly in the scientific literature since 2015 whereas a sharp increase can be noted in the last 4 years for inertial mocap and VR tools.

According to the corpus of studies, the most used tool types appear to be optical mocap devices (28 occurrences) and pressure plates (24 occurrences). Inertial mocap and VR are used more modestly (respectively, 16 and 12 occurrences); see Figure 4.

A distinction was made between articles with protocols lasting more than 1 week and protocols shorter than 1 week. As a frequency of sessions (number of sessions/week) cannot be computed for protocols shorter than 1 week, it appeared necessary to sort them in a specific category. A distinction was also made between protocols that included only one experimental condition and ones with at least two experimental conditions. The latter usually allows for a more robust protocol, especially when one group is used as a control condition. These articles will be further analyzed in Section 5.3.

In all the corpus, 46 publications had a protocol lasting more than 1 week and at least two experimental conditions. This corresponds to approximately 53% of the total publications, meaning that 47% of the protocols' robustness is debatable when it comes to study a physical and cognitive training. These articles include mostly pilot studies and proofs of concepts. Similar distributions of types of protocols can also be observed when considering types of stimulation tools individually (see Figure 4). With the exception of the "driving simulator" category which includes only one publication, the proportion of publications with less robust protocols varies between 37.5% and 62.5% of publications for the different stimulation tools.

The extracted data used to draw this section's figures and observations is available in Supporting file 2.

5.3. Data on Protocols Longer Than 1 Week With More Than One Experimental Conditions. In this section, a closer look will be given at the articles with a protocol lasting more than a week and that include at least two experimental conditions. This section could be used as a reference point for designing new controlled trials in the field. For each distribution both the mean and median were calculated as one

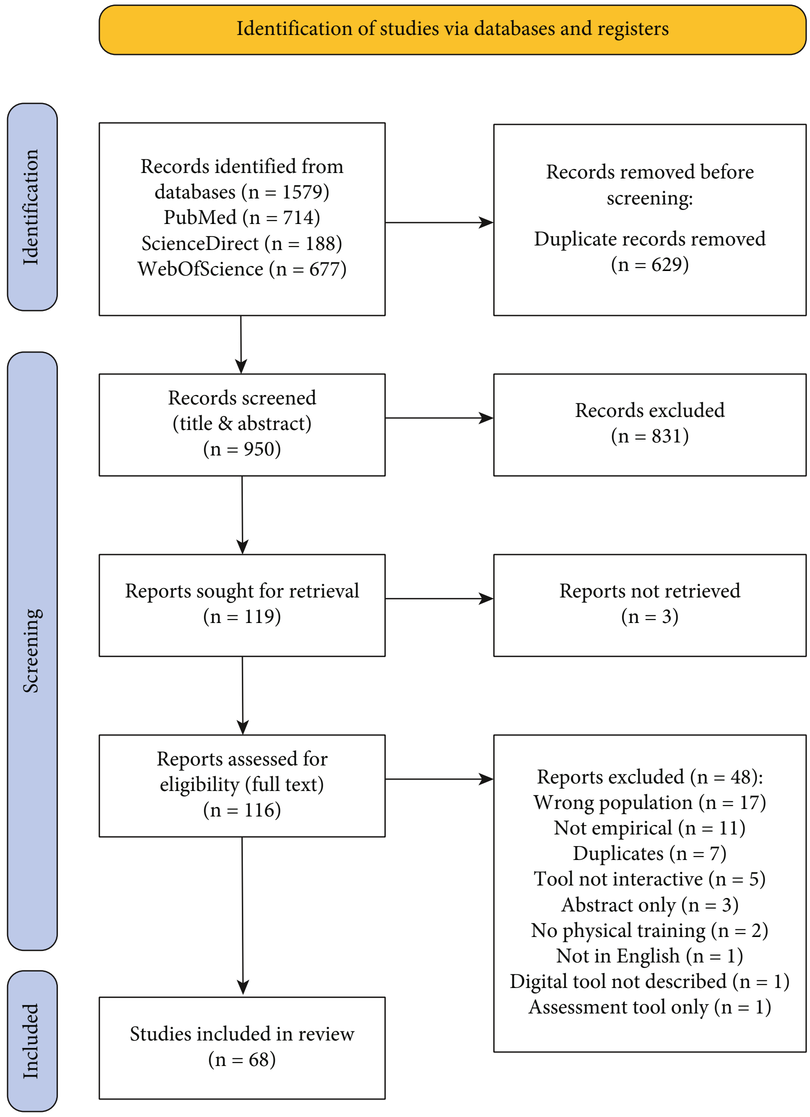

Figure 1: Flowchart of studies' identification based on the PRISMA 2020 guidelines [42].

Table 1: Publications sorted according to what stimulation tools were used in their protocol.

Type of tool	Publications using said tool
Driving simulator	[46]
Ergometer	[36, 47–51]
Inertial mocap	[50–65]
Optical mocap	[53, 55, 57, 61, 66–88]
Pressure plate	[64, 68, 72, 75, 89–107]
Virtual reality	[48–51, 54, 56, 58, 61, 108–111]

indicator may be more relevant than the other, depending on the distribution.

The values computed for each type of stimulation tool are reported in Table 2, with mean values being displayed in bold and median values in italic. The first column presents the number of participants, the results of whom were analyzed, which means dropout participants are not included. The second column presents the number of sessions planned in the protocol. This does not reflect the number of sessions the participant actually attended. Some publications were excluded from this calculation as the concept of "number of session" was not relevant to their protocols, for example, when participants could train as much as they wanted. The third column reports the frequency of sessions in number of sessions per week. Similarly, some publications were excluded as no session frequency could be computed. Finally, the fourth column presents the values of session duration in minutes. When a range of duration was indicated, a mean duration of the maximum and minimum duration was computed and considered as the intervention duration. Studies were not included in the calculation if no session duration was indicated, or if participants were free to choose the duration of the session. The tool category "driving simulator" is not presented in the

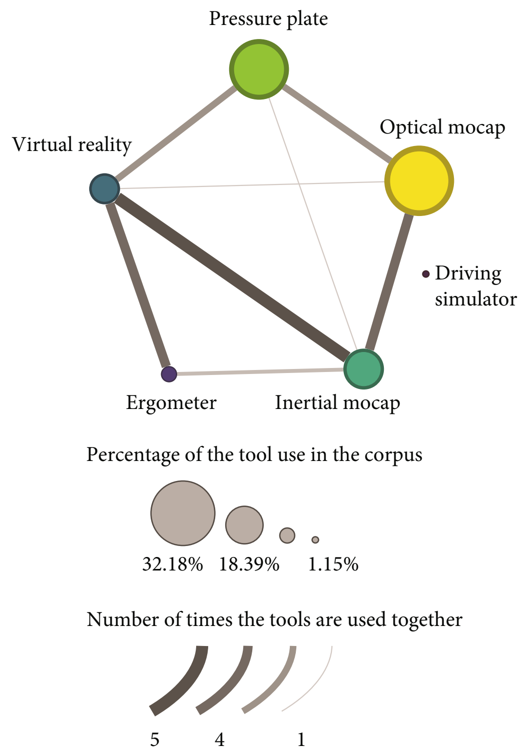

Figure 2: Network of digital stimulation tools used together in the same protocol. The diameter of the nodes is proportional to the number of times the tool was used across the corpus. The thickness and saturation in color of the edges are proportional to the number of times the two linked stimulation tools were used together in the same publication.

table as it accounts for a single article. For this study, 40 participants were recruited and had to participate in 18 sessions. The session frequency was three sessions per week, and they lasted for 40 min. Nevertheless, the data from this tool category is included in the computing of the "all tools combined" row.

5.4. Types of Evaluation Tools. More than 150 different evaluation tools were used to assess the outcomes in the different articles. In order to get a broader understanding of the types of evaluation tools chosen in the corpus, they were grouped into five categories: physical, cognitive, physiological, questionnaire, and other. The physical evaluation tools include any measurement of physical abilities and performance, such as walking distance, center of pressure displacement or number of repetitions of arm curls, or any evaluation tool monitoring physical abilities like gait analysis platforms or robotic dynamometers [112]. The cognitive evaluation tools include any measurement of cognitive abilities and performance such as verbal fluency or working memory tests [113]. The physiological evaluation tools include any measurement of physiological data, for example, heart rate, cortisol levels, or skeletal muscle mass [114]. The questionnaire evaluation tools include any set of questions filled according to the participants' own appreciation [115]. The other evaluation tools include outcomes that cannot be sorted in the previous categories, such as the number of voluntary sessions performed in an unsupervised training or participant's score in the game played [86]. Some measurements, considered variation of a main test, were grouped together for reasons of clarity. The measurements in question are digit span (grouping digit span forward and backward), Color-Word Interference Test (grouping the Stroop test and general Color-Word Interference Test), Trail Making Test (grouping both A and B conditions), Single-Leg Stance Test (SLST) (grouping both eyes open and eyes closed conditions), and custom walking test (grouping walking test of varied lengths).

Figure 5(a) displays the relationship between evaluation tools categories in the form of a network. The size of the nodes is proportional to the number of times the evaluation tool category was used in the whole corpus, and the thickness of the edges linking two nodes together is proportional to the number of times those two evaluation tool categories were used jointly in the same publication. The evaluation tool categories most used together appeared to be the three following pairing: physical-questionnaire, physical-cognitive, and cognitive-questionnaire. To get a sense of the amount of evaluation tools used in one publication, Figure 5(b) displays the number of evaluation tools used in the different protocols of the corpus. The mean number of evaluation tools used in publications is 6.10 and the median number of evaluation tools is 5. The number of evaluation tools used range from 2 to 12 in one publication. Of the multiple evaluation tools used in one publication, two specific cases arise: either all of the evaluation tools used belong to the same evaluation tool category (for example, all measurements relate to physical abilities) or the evaluation tools used spread across different categories (for example, half of the measurements focus on physical abilities while the other half focus on cognitive performance). A histogram of the number of evaluation tool categories used in the corpus is displayed on Figure 5(c). The mean number of categories evaluation tools spread across is 2.41 with a median number of categories of 2.

In order to investigate what evaluation tools tend to be used in conjunction, the tools were organized in a network, with evaluation tools being linked together when they were used in the same publication (see Figure 6). The diameter of the nodes is proportional to the number of times the evaluation tool was used across the corpus, and the thickness and saturation in color of the edges are proportional to the number of times the two linked evaluation tools were used together in the same publication. An interactive network including all the data is available at this link: . In the case of motor-cognitive dual-task evaluation tools [116], they were represented in a separate category labelled "motor-cognitive."

The evaluation tool most used is the Timed Up and Go test (TUG) with 19 occurrences across the corpus. Many measuring tests include only one or two occurrences across the corpus, as only around 18.7% of the evaluation tools are used strictly more than twice. Figure 6 illustrates what evaluation tools tend to be used together in the corpus. Some notable associations include for instance the Geriatric Depression Scale (GDS) being paired with the Fall Efficacy

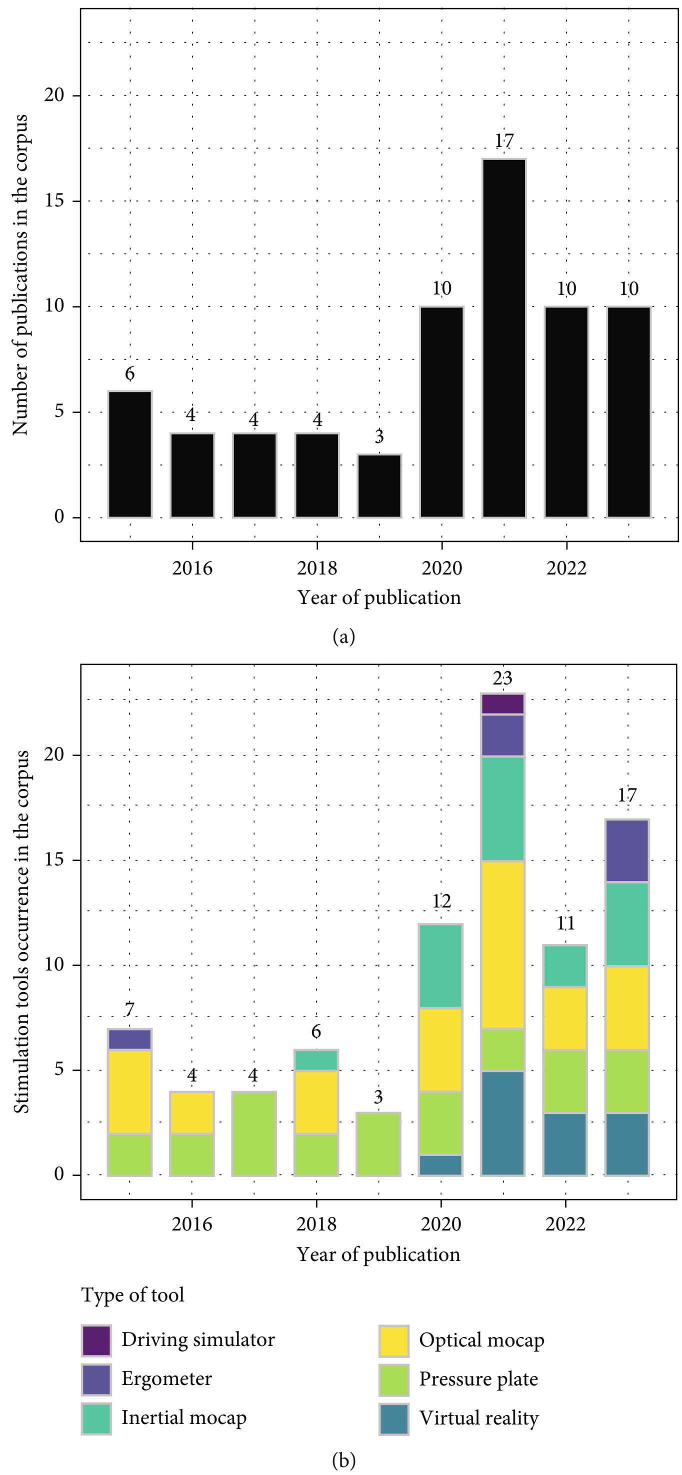

FIGURE 3: (a) Number of publications for each stimulation tool over the years. (b) Number of stimulation tool occurrence in the corpus over the years. If a publication uses several stimulation tools in its protocol, it will be counted as only one publication in Figure 3(a) but will count as one occurrence for every stimulation tool used in the protocol in Figure 3(b).

Scale International (FES-I), or the triplet of physical evaluation tools TUG, SLST, and Five-Time Sit to Stand Test (FTSST).

The extracted data used to draw this section's figures and observations is available in Supporting file 3.

6. Discussion

6.1. General Observations. The biggest player in the home console pressure plate game appeared in 2007: the Nintendo Wii Balance Board (WiiBB). With more than 32 million

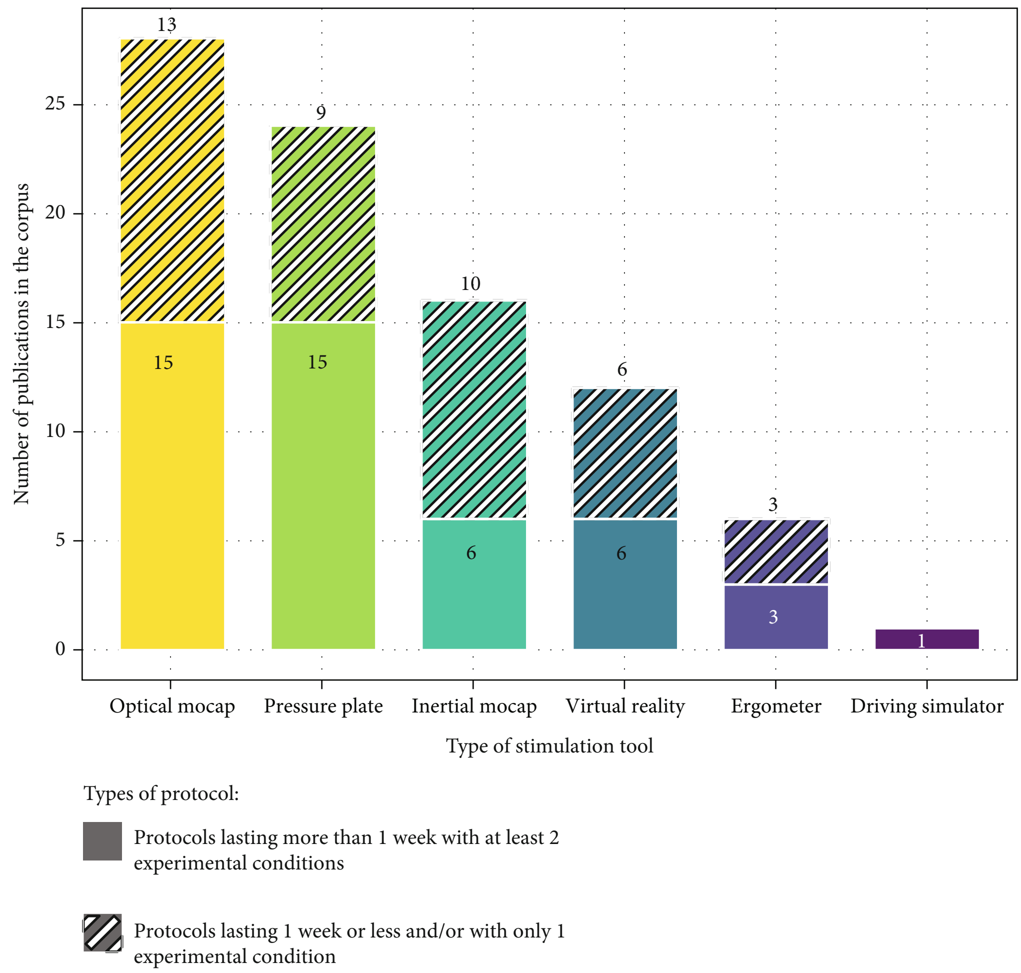

Figure 4: Number of publications for each tool with a distinction between protocols lasting more than 1 week and with more than one experimental condition (plain) and protocols shorter than 1 week and/or with only one experimental condition (hatched).

Table 2: Table of protocol values for each stimulation tool.

Values tools	No. of participants	No. of sessions	Sessions frequency (session/week)	Session duration (min)
Ergometers	*16.0*	*19.0*	*2.00*	*15.0*
	16.0	**19.0**	**2.00**	**15.0**
Inertial mocap	*40.8*	*20.4*	*1.63*	*43.0*
	40.5	**18.0**	**1.75**	**45.0**
Optical mocap	*45.7*	*25.4*	*2.20*	*28.0*
	40.0	**24.0**	**2.00**	**30.0**
Pressure plate	*47.7*	*23.8*	*1.67*	*35.0*
	43.5	**24.0**	**2.00**	**40.0**
Virtual reality	*21.2*	*13.0*	*1.50*	*18.6*
	20.0	**10.0**	**1.50**	**12.0**
All tools combined	*22.5*	*36.8*	*2.51*	*37.6*
	24.0	**34.0**	**3.00**	**35.0**

The values in italic represent the mean value extracted from the subcorpus of publication with protocols longer than 1 week with more than one experimental condition. The values in bold represent the median value extracted from the same subcorpus.

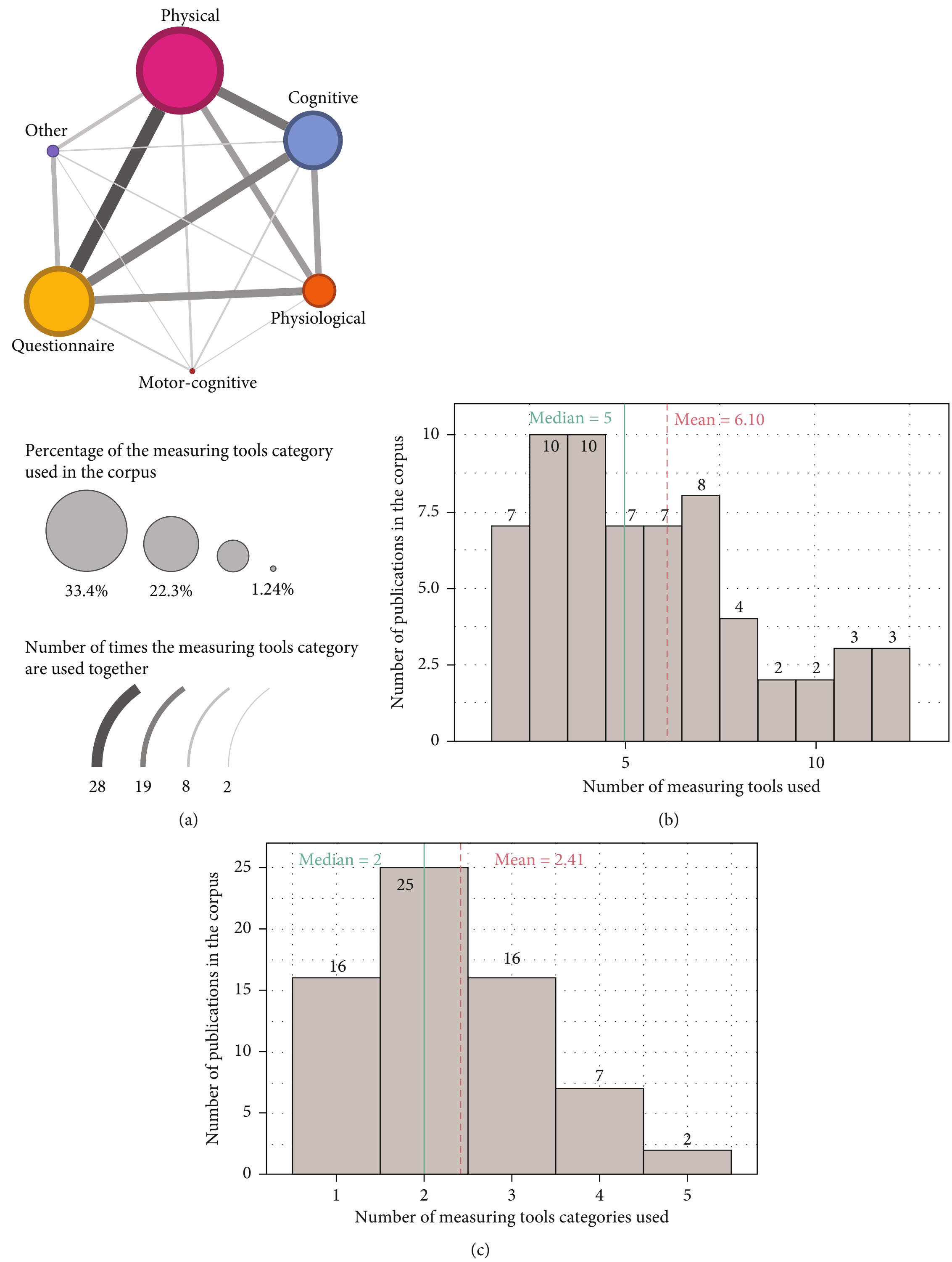

Figure 5: (a) Network of the different evaluation tool categories being used jointly. The size of the nodes is proportional to the evaluation tool category number of occurrences across the corpus, and the edges saturation and thickness is proportional to the number of times the two linked evaluation tools categories were used together in the same publication. (b) The number of evaluation tools used in the different publications of the corpus. (c) The number of evaluation tool categories used in the corpus.

WiiBB sold worldwide [117], it broke the world record of the weighing device most sold. The popularity of the WiiBB attests of a certain maturity of the technology. A similar story line can be written for optical mocap tools with the commercialization of Sony's EyeToy in 2003 followed by Microsoft's Kinect in 2010. The Kinect broke the record of the fastest-selling consumer electronic device with eight million units sold in its first 60 days [118]. As a result, both

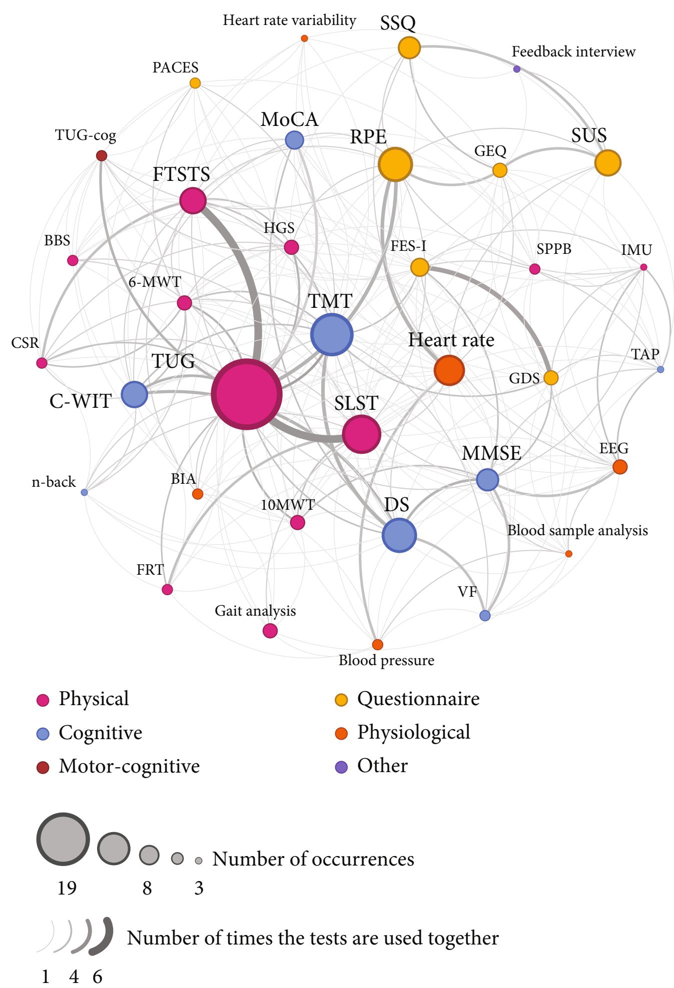

Figure 6: Network of the occurrences of outcomes in the corpus filtered to include only tests with at least three occurrences for reasons of readability. The diameter of the nodes is proportional to the number of times the outcome was used across the corpus. The thickness and saturation in color of the edges are proportional to the number of times the two linked outcomes were used together in the same publication. 6-MWT: 6-min Walk Test, 10MWT: 10-m Walk Test, BBS: Borg Balance Scale, BIA: bioelectrical impedance analysis, C-WIT: Color-Word Interference Test, CSR: Chair Sit-and-Reach test, DS: digit span, EEG: electroencephalography, FES-I: Fall Efficacy Scale International, FRT: Functional Reach Test, FTSST: Five-Time Sit to Stand Test, GDS: Geriatric Depression Scale, GEQ: Game Experience Questionnaire, HGS: hand grip strength, IMUs: inertial measurement units, LOS: limit of stability, MMSE: Mini-Mental Status Evaluation, MoCA: Montreal Cognitive Assessment, PACES: Physical Activity Enjoyment Scale, RPE: Borg Rating of Perceived Exertion, SLST: Single-Leg Stance Test, SPPB: Short Physical Performance Battery, SSQ: Simulator Sickness Questionnaire, SUS: System Usability Scale, TAP: Test of Attentional Performance, TMT: Trail Making Test, TUG: Timed Up and Go test, VF: verbal fluency test. An interactive network including all the data is available at this link: https://aombusser.github.io/InteractiveNetwork/NetworkColor/network/index.html.

technological tools have held prominent positions in the field since at least 2010. This could explain the high representation of optical mocap and pressure plate tools in the selected studies (see Figure 4). As fully developed tools, they are indeed more likely to be used in research.

To contrast, from the research on the stimulation tools state of the art, no innovation or fully fleshed ergometer coupled with cognitive stimulation seems to have found mass market appeal or global popularity. This could explain the low number of publications using ergometers in comparison to other tools; when using an ergometer for physical and cognitive stimulation, researchers would have to adapt the existing tools on the market to their need or build and develop new hardware and software. In parallel, the introduction of efficient and somewhat affordable HMDs to the market in 2016 (HTC Vive) and 2019 (Oculus Quest) probably contributed to the use of VR in research. By considering the inertia in publication dates due to the time necessary to do the experiments, write an article, and get it published, which can take from 91 to 639 days in a biomedical journal [119], the introduction of these new HMDs fit with the apparition of VR publications starting from 2020 (see Figure 3). An increase in the number of publications using inertial mocap can also be noted in 2020 and 2021. This could be explained by the popularization of Microelectrical-mechanical system (MEMS), used as captors in inertial movement units, becoming increasingly more accurate, compact, and cost-effective [120]. The addition of those two emerging technologies to the researcher's toolkit for elderly people's stimulation might explain the increase in publication in 2020 and 2021 compared to the previous years.

The higher number of publications in the corpus dating from 2020 and above can be interpreted as a growing popularity of the field; thus, the variety of digital tools could be linked to this increase in publications. The pressure of the globally aging population [5] might explain a growing popularity of physical and cognitive stimulation of the elderly as a research topic. The COVID-19 pandemic may also have played a role in the growing body of research about providing ways for the elderly to get stimulated without needing the assistance of a peer.

6.2. Stimulation Tools. In this section, the different types of stimulation tools identified in the corpus are discussed individually in dedicated subsections. In the case of publications employing more than one stimulation tool, they will be discussed in all the subsections regarding the stimulation tools that were used in the protocol.

6.2.1. Pressure Plates. Pressure plates are force plates used to quantify the pressure applied on its surface. They can be used as controllers in exergames by having participants stepping on and off the plate or swaying their center of pressure around [121]. As mentioned in Section 6.1, the WiiBB has been one of the most popular pressure plate devices. It is also the device most used in the corpus of articles selected for this review as more than half of the articles using pressure plates were equipped with WiiBB (14 articles out of 24). Other pressure plates used were Impact Dance platform (4 articles out of 24), the Dividat Senso platform (3 articles out of 24), and other custom-made or unspecified platforms (see Supporting file 3). The Dividat Senso platform provides a safe railing for frail users and comes with an exergame software. The Impact Dance platform can be plugged to a computer or gaming consoles and used as a controller. The WiiBB is compatible with the Nintendo Wii console but can also be used with a computer. Nintendo offers a wide range of exergame software through the Wii Fit game library. This variety in off-the-shelf and customizable hardware and software could be a reason for the large number of studies using pressure plates compared to other tools. As a matter of fact, the WiiBB provides affordable hardware with a great variety of exergames, which allows for an easy-to-build and inexpensive experimental setup. The safe railing provided by the Dividat Senso can improve the protocol safety for studies done on frail participants. Finally, the Impact Dance platform provides a versatile tool that can be plugged in any application, would that be a custom-made one or one made by the online community. These options provide researchers with tools that can fit the protocols' needs without requiring extensive application development or hardware modifications.

Unsurprisingly, pressure plates were the second most used technology in the corpus studies (see Figure 4). Pressure plates were also the most persistent technology over time, being the only technological tool which had at least one publication a year from 2015 to 2023.

The studies retrieved using pressure plates have very different protocols from one another. Some studies used only one experimental group training on a pressure plate as a pilot [93, 96], while others compared pressure plate training with a variety of controls, for example, active training on a cycle ergometer [92], computer training [97], or passive [94]. Other studies use optical or inertial mocap in their setups in order to enhance the user's motion tracking [68, 91] or to compare the impact of these devices on training [72, 75]. This variety in protocols makes it challenging to draw general observations; nevertheless, we will intend to summarize and highlight important results to the best of our abilities in the following paragraph.

Using a tool that can be stepped on seems relevant when it comes to studying participants' balance and gait. This is indeed a popular outcome among the articles of this section. An improvement in balance after playing exergames on a pressure plate devices was measured in multiple articles [92, 97–99, 103]. A significant improvement in limits of stability was measured in the studies by Brachman et al. [68] and Garcia-Bravo et al. [96]. Gait was monitored in Schättin et al. [106] and de Bruin et al. [93] studies, but no significant differences was observed as a result of the interventions. Other balance and gait measurements were also monitored, like gait speed [105] and center of mass displacement [72].

Several studies used EEG to monitor this effect of the intervention [89, 105, 106]. Schättin et al. [106] did not measure any difference in EEG depending on different fatty acid supplementation. A reduction of relative power of the beta brainwaves in the left prefrontal cortex during the cognitive tests was measured in the WiiBB training group in comparison to the control group in the study by Alves et al. [89]. After training on the Impact Dance platform, participants in the experimental group in the study by Schättin et al. [105] showed a significant decrease in theta brain waves' relative power compared to the control group. Cognitive functions and verbal fluency were also outcomes that appeared multiple times in the corpus of articles using pressure plates.

As mentioned prior, Alves et al. [89] and Monteiro-Junior et al. [100, 101] observed an improvement in verbal fluency post study in the experimental group. Improvements in other various cognitive abilities were also reported such as verbal memory [97], executive functions [106], global cognition [101], and other cognitive assessment tests [75, 93]. Most papers in this section use various cognitive and/or physical assessments as outcome; however, some outliers can be noted. Bakker, Donath, and Rein [90] did not use physical or physiological measures of exertion but used questionnaires of perceived exertion. Rebsamen et al. [104] main outcome is the feasibility of a high-intensity interval training on a Dividat Senso pressure platform and its acceptance but does not report on the physical or cognitive impact of the training. Campelo and Katz [91] studied the correlation between attitude toward exercise and the predisposition to feel immersed and found indeed a moderate correlation between the two.

Pressure plates have also been for joined physical and cognitive training on varied target populations such as stroke survivors [122, 123], people suffering from Parkinson's disease [124], people diagnosed with multiple sclerosis [125], and elderly people with MCI [126]. This variety in users might be a result from the accessibility of the tool as well as its technological maturity. It is interesting to note that all the conditions mentioned have in common that they affect people both physically and cognitively.

6.2.2. Inertial Mocap. Motion capture can be defined as the process of recording the motion of a subject [127]. In the corpus, several motion capture systems were used as stimulation tools. Motion capture tools based on inertial systems will be discussed in this section (Section 6.2.2), while motion capture tools based on optical systems will be discussed in Section 6.2.3. The tools defined as inertial mocap encompass a wide variety of IMUs that can be used for motion capture. IMUs are devices combining different evaluation tools, such as accelerometers and gyroscopes, in order to monitor a body's angular rate and orientation in space. Once the delicate step of calibration has been done, the sensors can be integrated into a motion sensing controller or directly put on the player [128]. Hence, using inertial mocap to design exergames setup might be relevant as they are quite intuitive to use and appear to be preferred by the elderly over traditional controllers [129]. Over the past 10 years, inertial movement units have advances in drastic ways with sensors becoming more accurate, namely, thanks to improvement in artificial intelligence (AI) processing of the data, as well as being more wearable and with longer battery life [120]. According to Figure 4, inertial mocap is one of the most used types of tools in this corpus, with 12 studies of the corpus using this technology. Publications using inertial mocap are not as consistent over the years as pressure plate or optical mocap tools (see Figure 3); however, publications are spread out from 2017 to 2023 with an increase in number of publications in the years 2020 and 2021. This might be due to the improvement of the technology mentioned above, but the sample of inertial mocap is too small to make any robust hypothesis.

In a few papers, the inertial mocap are mostly used as a supporting tool for VR HMDs. When interacting with the virtual environment in a VR simulation, controllers with optical mocap or inertial mocap placed on the participants' feet might be necessary in order to create an immersive interactive experience [54, 56, 61].

That being said, inertial mocap allow for great freedom in movements which make them a great tool for tracking movement during whole body training, like Tai-Chi or dance training. As a result, studies using inertial mocap point to improvement in physical abilities such as upper limb dexterity [54], physical balance [56, 60], and manual grip [60]. Li et al. [57] also state that their training can be considered equivalent to light intensity exercise. However, a few negative results can be noted, with Lin et al. [59] reporting no change in motor functions and Chau et al. [54] no change in functional mobility.

Improvement in combined physical and cognitive abilities was reported by Adcock et al. [52] with increased scores in dual talk walking test after the intervention. Many studies observed improvements in cognitive and executive function [53, 54, 59], some specifying improvement particularly in working memory [56], spatial cognition [63], attention control [53], and selective attention reaction speed [58]. Moret et al. [65] reported an improvement in verbal learning and memory after the exergame training intervention, though less important than following the computerized cognitive training intervention. They also reported no improvement in information processing speed.

A few studies focus on physiological outcomes, with Zhao et al. [63] noting improvement in physical fitness post training, Li et al. [57] an effect on blood pressure, and Montilla et al. [60] an effect on VO2max, body weight, and fat mass.

Most papers reported a positive attitude [50, 55, 57, 91] and generally positive emotions [52] and satisfaction [51] toward the training program and setup. Even though Chau et al. [54] had both positive and negative comments, most stimulation tools in this category were noted to be usable [51, 52, 62], safe [50], and motivating [63]. Tammy Lin and Wu [61] more specifically highlight that female participant reported higher self-efficacy, physical activity, and perceived exertion when embodied in younger avatars compared to older avatars.

Inertial mocap is also used in joined cognitive and physical training of stroke survivors [130] and elderly with MCI [131]. Elderly people with or without MCI and stroke survivors are similar in the fact that they are affected with both physical and cognitive deficiencies. However, these deficiencies vary a lot from people to people, making these groups very heterogeneous.

6.2.3. Optical Mocap. As mentioned in the previous section, optical mocap tools are motion capture tools based on optical systems. Consequently, all the stimulation tools in this category include a camera, and most of them combined it with laser depth sensors. It is worth emphasizing that the scope of this section does not encompass hand tracking capabilities offered by some VR headsets, which rely on cameras integrated into the headset. Only tools with cameras not worn by the user were included in this category. Optical mocap tools enable game interactions without the need for controllers, addressing the challenges that elderly individuals may face in interacting with game interfaces [129]. The Kinect, which was initially a commercial success, made this type of technology easily accessible and familiar to both researchers and the general public, before losing in popularity due in part to its lack of accuracy in body tracking according to the Silicon UK newspaper [132]. In addition to its hardware availability, Microsoft offered access to the Kinect SDK (software development kit), a software development tool for Kinect, which was free for research purposes and was somewhat easy to use as it was compatible with many coding languages and offered many libraries and code samples. This allows for custom-made software specifically tailored for a research project, in addition to many off-the-shelf games available for visual tracking tools. The versatility of optical mocap tools, allowing for highly customizable or easy-to-use premade exergames, makes them great for experimental design. Other optical mocap systems are also mentioned in the corpus such as the Neo One, DIDIM, and DoveConsol systems. As a matter of fact, optical mocap tools were the most used technology in the corpus (see Figure 4) and were persistent over time with publications spreading from 2015 to 2023 (see Figure 3). The years with the highest number of optical mocap publications are 2015, 2020, and 2021. The high rate of publications in 2015 might be explained by a first wave of publication following the commercial success of the Kinect.

The Kinect is by far the most used optical mocap tool [53, 55, 57, 61, 68, 70–76, 78, 80–86]. Indeed, this device is characterized by its affordability, widespread availability, and remarkable capability to extract three-dimensional (3D) information from images, all while functioning as a conventional camera [133].

However, other tracking devices using cameras are also used in research. Borrego et al. [67] performed motion detection using an unspecified webcam and a colored ball for tracking. Béraud-Peigné et al. [66] used the Neo One technology which consisted of an optical motion capture system and a video projector. Using those two tools, a wall can be turned into an interactive interface reminiscent of a touchscreen tablet except wall sized. Hwang et al. [77] use a DoveConsol which works similarly to the Neo One but was projected on three walls, therefore increasing the sense of immersion. Park and Shin [79] used the DIDIM technology which is also similar to the Neo One described but is projected on the floor instead of a vertical wall. The Neo One, DoveConsol, and DIDIM are all hardware systems that come with a matching exergaming software. What sets apart the Kinect from some of its competitors like the Neo One and DIDIM systems is that it can be easily used with custom-made software. Among all the tools discussed in this review, the Kinect stood out as being most compatible with researchers' ambitions to develop their own exergame application. Turning to custom-made software allows to tailor the exergame application to the researchers' needs instead of dealing with commercially available game limitations.

As seen previously for other tools, balance and gait are an important point of focus and improvement in optical mocap interventions [68, 69, 72, 76, 78, 83–85]. Other physical abilities monitored after a stimulation using an optical mocap tool are strength, functional and reach, and general physical fitness [69, 71, 75, 76, 78, 82, 83].

Evolution of general cognition abilities can also be an outcome of interest [55, 76, 77, 81]. To be more precise, improvements in attention have been reported by Bapka et al. [53] and Park and Shin [79]. Ferreira et al. [73] focused on a cognitive assessment but did not report any significant changes.

Various physiological measurements were monitored in the visual tracking studies such as skeletal muscle mass and body mass index (BMI) [79], cortisol rates [55], contrast sensitivity [75], energy expenditure [74], heart rate intensity [66], and maximum respiratory pressure [79]. Questionnaires are a great tool for assessing the usability of a protocol or subjective feelings such as perceived exertion or self-assessed depression scores. They were used in several studies to assess the user experience [57, 66, 67, 70, 76, 78, 80, 82]. Participants' behavior is also a great indicator of user experience like adherence to the protocol [71] or the number of sessions performed voluntarily [86].

Optical mocap tool has been used for coupled cognitive and physical training in a wide variety of participants including people with Down syndrome [134], people diagnosed with schizophrenia [135], people suffering from Parkinson's disease [136], elderly people with MCI [137], and stroke survivors [138]. Similar to the observations made on pressure plates, this variety in users may be a consequence of the tool's popularity, maturity, and accessibility. Unlike other tools, visual tracking tools have been used on participants whose symptoms are mainly cognitive like schizophrenia. This may suggest that joined physical and cognitive training using visual tracking tools is expanding toward populations which were not considered its primary target. Thus, this could be interpreted as a popularization of this kind of training using visual tracking to a wider audience.

6.2.4. VR. The "VR" category encompasses any digital tool that enables a fully immersive and interactive experience with a 360° visual perspective. This would include CAVE setups, which are immersive environments projected on walls surrounding the participant. However, CAVEs are expensive, take up a lot of space, and can be hard to set up; this could explain in part why none of the studies selected in the corpus used this technology. VR headsets, or VR HMDs, serving as the central component of the VR interventions in this section, provide a more cost-effective and space-efficient alternative to CAVE setups. As can be seen in Figure 3, VR tools make their first appearance around 2018 in research papers of this review targeted field. This is coherent with the commercialization of cheaper and reliable VR headsets around 2016, like the Oculus Quest and the HTC Vive [139]. Despite its later appearance in the published research world, VR tools managed to be one of the most used tools in this corpus with nine publications between January 2015 and March 2023 (see Figure 4). The studies gathered in this section tend to have very different protocols, and many of them include an assessment of the acceptability and usability of the tool by the participants. This makes sense considering that VR tools are fairly new, especially for elderly people, which are usually unfamiliar with this technology. As a consequence, exploratory research and usability studies are necessary in order to define efficient and safe protocols for exergaming intervention for the elderly.

Most VR headsets come with hand controllers that are tracked in space using inertial motion units similar to the ones described in Section 6.2.2. Hence, some of the studies using VR tools chose to use only VR headsets and their matching hand controllers [108–111]. Other studies chose to swap the hand controllers for body trackers like chest trackers [58] or limb trackers [54]. Li et al. [56] chose to add foot trackers in addition to the hand controllers. Tammy Lin and Wu [61] for their part chose to supplement the HMD with visual tracking using a Kinect as well as inertial mocap in order to get an accurate body tracking. Sakhare et al. [48] and Drazich et al. [49] did not couple any motion tracking tools alongside the VR headset, opting instead to combine the VR headset with a cycle ergometer.

The physical outcome reported by the studies were improvements in balance and gait [56, 109], as well as improvements in hand grip strength [109] and upper limb dexterity [54]. Improvements in cognitive functions were also reported, including global cognitive functions [54], working memory [56], selective attention [58], and executive functions [48]. A few studies also investigated the feasibility and usability of their VR headset interventions with user experience questionnaires [54, 108, 109, 111]. Other studies used questionnaires to evaluate motivation [110] and perceived exertion [110, 111].

Even though no publications using CAVE were found in the scoping review, this publication by Gaggioli et al. [140] describes a setup for physical and cognitive training of elderly people using a cycle ergometer placed inside a CAVE. This suggests that CAVEs might be usable for training elderly people both physically and cognitively. VR experiments using HMDs have also been used on stroke survivors [141] for physical and cognitive training. Compared to other tools, the populations trained physically and cognitively using VR tools seem to be less varied. This could be due to the novelty of VR tools, meaning less time have been available for experimenting with VR HMDs on various populations.

6.2.5. Ergometers. An ergometer can be defined as an exercise machine that measures the amount of work done by a muscle or group of muscles under controlled conditions [142]. Ergometers can easily be combined with screens, projectors, or HMDs in order to provide users with a cognitive task or immersive visuals while they exercise [143]. However, ergometers did not appear to be a popular tool for the physical and cognitive stimulation of elderly people according to this scoping review. As illustrated in Figure 4, only six publications used ergometers, making them the second to last type tools in terms of occurrence in the papers retrieved. Of those six publications, half of them did not include a control group (see Figure 4) making them methodologically less robust than publications which did. This could be explained by the difficulties to set up an experiment using an ergometer instead of another tool. Currently, there is a lack of a universally accessible, affordable, and effective ergometer that combines both physical and cognitive stimulation. However, this is not the case for other types of tools, such as pressure plates or inertial sensors, which provide readily available options for hardware and software design, catering to both physical and cognitive stimulation. As a result, when choosing to use ergometers, researchers will have to invest time to develop applications for cognitive stimulation. Except in the case of uncorrelated dual tasks, having access to the user's physical performance data in real time is also necessary in order to update the cognitive stimulation application according to the physical data. This might require some hardware modifications of the ergometers or addition of inertial movement units. Another option would be to build a custom ergometer which can be quite complicated and expensive. All those reasons could contribute to explain the unpopularity of ergometers as a physical and cognitive stimulation tool in research. What can be noted is that four protocols out of six using cycle ergometers chose to pair the device with a HMD, three of those papers being published in 2023. This may suggest an up-and-coming form of immersive exergaming for the elderly.

The different articles focused on quite different categories of outcomes. Loggia et al. [47] studied cycling performance, noting an increase in cycling distance and duration when training using an exergame. Sakhare et al. [48] focused on neurological changes reporting significant improvements in cerebral flow and brain structure, specifically a reduction in pulsatility, an increase in total gray matter volume, and thickening of the superior parietal lobule. They also monitored cognitive abilities with cognitive flexibility, response inhibition, and visual memory discrimination exhibiting enhanced performance, with medium effect sizes. Barcelos et al. [36] also reported improvement in cognition, noting improvements in Stroop test performances after the intervention. Finally, Drazich et al. [49], Rojo et al. [51], and Høeg et al. [50] studied mainly the user experience reporting good acceptability [49], usability [49, 51], and enjoyment of their training programs [50].

Only cycle ergometers were selected as part of our corpus, but many protocols using treadmills have been implemented on elderly participants. For example, Szturm et al. [144] tested the validity as an assessment tool of a treadmill dual-task setup in which participants used head movement to control virtual objects on a screen while walking. V-TIME by Mirelman et al. [145] is also a great example of a treadmill training program coupled with screen displays for elderly people in order to reduce the risk of falls. Other studies from the selected corpus also used cycle ergometers or treadmills, but without coupling them with cognitive training, they were used as purely physical training tools [73, 92, 94].

Ergometers have been used for cognitive and physical training for a variety of populations. Cycle ergometers have been used for patients diagnosed with Alzheimer's disease [146], cancer survivors [143], and elderly with MCI [147, 148]. Treadmills have been used for coupled physical and cognitive training for patients diagnosed with Parkinson's disease [149] and stroke survivors [150]. All the populations mentioned here have also been trained on other tools as was seen above. This tends to confirm the position of ergometers as viable tools for coupled physical and cognitive training.

6.2.6. Driving Simulators. Driving is a cognitively demanding task that can become harder with the cognitive decline linked to aging [151]. As a result, driving simulators appear to have the potential to efficiently stimulate cognition in older adults. The physical stimulation aspect of training on a driving simulator can be considered questionable. However, according to the definition described in Section 4.2 and considering that most driving simulators include haptic feedback in the steering wheel which provides some resistance to steering, driving simulators were considered to be physically stimulating in this work.

Only one article in the corpus used the driving simulator tool. Nobari et al. [46] compared the cognitive performances of 40 participants, 20 of whom were trained on the computer driving simulator Ferrari Challenge Racing Wheel 3 times a week for 6 weeks and 20 of whom were passive controls. A significant difference in cognitive status and dual-task performance was measured in the experimental group compared to the control group using the TUG test.

This study by Haeger et al. [152] did not appear in the scoping research of publications but would fit most of the inclusion criteria. Participants trained on a driving simulator including pedals, a steering wheel, and a gear shift. After training, Haeger et al. [152] measured significant improvements in divided visual attention in the intervention group compared to the control group; however, no other cognitive domains nor motor skill benefits were observed. More studies on driving simulator training on the elderly would be needed to draw clearer conclusions from this type of training. As elderly people tend to progressively lose their ability to drive, driving simulators might not be an obvious choice for motor and cognitive training. It is however used as an assessment tool in some papers [153].

6.3. General Discussion and Critical Analysis. Overall, while a few hardware devices were constructed from the ground up, the vast majority were either commercially available or adapted from commercially available devices. This allows for easy reproducibility of the experiment or variations of previous studies.

Regarding software, some authors chose to create custom applications and games in order to tailor them to their experimental needs. This would allow, in theory, for easy access to the software data and applications well suited for elderly people as they were specifically created for them [154]. However developing a custom software is a challenging task that require expertise and long intensive work [155], not necessarily compatible with the "publish or perish" culture in the academic world [156]. This may result in custom applications experiencing technical issues or providing suboptimal user experiences, which goes against the original idea of making the software more accessible to the elderly. Few publications in the corpus tested for the participant's familiarity with technology, using questionnaires like the IT Familiarity Questionnaire [157]. We believe it would have been relevant to monitor familiarity, especially when evaluating the usability and attractivity of a device or intervention [158, 159]. Similarly, many publications in the corpus did not detail the process of onboarding and acclimatization to the stimulation device. This information could be quite valuable when trying to conduct similar experiments or when analyzing the results, as the first few sessions might in fact correspond to an acclimatization period.

6.4. Evaluation Tools. The nature of tests and tools used to measure the outcome of every protocol was not expected to be relevant in this review; however, the great variety in outcomes chosen seemed of notable interest. The evaluation tools used in the protocols are indeed quite different from paper to paper. As mentioned in Section 5.4, a large portion of the evaluation tools are only used once or twice, and the most used evaluation tool was a physical measurement used in 19 publications. This suggests a wide pool of outcome monitoring methods with no clear front-runner which makes it hard to conduct meta-analyses or comparisons between publications. Moreover, publications tended to use around six evaluation tools on average spread across approximately two evaluation tool categories (see Figure 5). This is coherent with the popularity of the physical cognitive pairing in evaluation tool's categories. As the target population is stimulated both physically and cognitively, it is relevant to use both physical and cognitive evaluation tools in order to monitor the outcome of the intervention. The two other most frequent evaluation tool category pairings are physical-questionnaire and cognitive-questionnaire. While the "physical" and "cognitive" categories attest for an objective measurement of physical or cognitive abilities, the "questionnaire" category highlights the participant's perception and subjective opinion of the outcome. This is also a very relevant pairing as both objective and subjective data are essential to tailor the physical and cognitive stimulation to the desired audience as best as possible.

Although a wide range of evaluation tools were utilized, the predominant ones were commonly used standardized tests, with the occasional inclusion of walking tests featuring nonstandard distances or duration, as well as some bespoke questionnaires. As a result, most of the evaluation tools used in the corpus have an established validity and are highly reliable. This includes for instance the 35 most used evaluation tools displayed on Figure 6 such as the TUG test, MoCA, Borg RPE, or heart rate monitoring. These evaluation tools were indeed reported as having a high intratester and intertester reliability as attested by the reported intraclass correlation coefficient (ICC) and Cronbach's alpha coefficient. Namely, the TUG test has been reported to have an ICC of 0.96 [160] and an alpha of 0.74 [161], the MoCA an ICC of 0.92 [162] and an alpha of 0.85 [163], the Borg RPE an ICC up to 0.96 [164] and alpha 0.77 [165], and heart rate monitoring an ICC of 0.99 [166] and an alpha up to 0.9 [167]. These tools' validity has also been confirmed, with the TUG test showing strong concurrent validity with balance and mobility measures [168], the MoCA with the MMSE [162], the Borg RPE with facial RPE [169], and heart rate monitoring with ECG [170]. The variety in evaluation tools may indeed not result from eccentric choices in evaluation tools but from this type of stimulation being at the intersection of various fields of study. Most evaluation tools mentioned in the corpus can indeed be found in senior physical or cognitive fitness test protocols [171, 172], Velayudhan et al. [173] or are common questionnaires or biomarkers [174, 175].

6.5. Common Limitations in the Corpus. Most limitations reported were not stimulation tool specific. First, as is illustrated on Figure 4, nearly half of the papers analyzed only include one experimental and/or last less than 1 week. These publications provide great insight as pilot and exploratory studies but do not supply exploitable data. Many publications also mentioned their small sample size as the main limitation of their experiment. Only few studies included follow-up testing sometime after the postintervention assessment [48, 53, 64, 65, 95]; this provides precious information regarding the lasting effect of the training in question and would be valuable to add to full-scale studies. Another common limitation that was not frequently mentioned was the wide range in age of the participants considered "older adults." As a result, studies may be comparing individuals with an age difference up to 26 years [52]. Making sure to test for possible correlations between the observed results and age, or setting age categories, may be solutions to limit this potential bias. A dozen of studies included in this review had dropout rates higher than 20%. Explanations for attrition are hard to get; however, technical issues during the intervention have been identified by their authors as a possible cause of dropout [52, 75].

7. Recommendations for Future Works

7.1. Recommendations on Protocol. In terms of protocol characteristics for studies involving multiple experimental conditions, the data from this corpus suggests that sessions lasting approximately 30 min, occurring three times a week, would be advisable. To reduce the diversity in evaluation tools employed, it would be advantageous to concentrate on popular evaluation tools referenced in Figure 6. Furthermore, employing consistent outcome measures could facilitate comparisons between various physical and cognitive training approaches. Similarly, developing standardized protocols could help to draw clearer conclusions when comparing different studies. As mentioned prior in Section 6.5, we recommend to particularly watch out for technical issues which might induce important dropout rates. We also suggest to pay attention to the age range of participants as the term "older adults" can encompass a wide variety of people.

7.2. Recommendations on Hardware Selection. Training in balance and gait was a prevalent aspect across all the stimulation tools, but it seemed to be particularly well suited for pressure plate setups. Pressure plates allow indeed for feet pressure tracking, which can be of great help when monitoring a balance exercise. The utilization of pressure plate balance training can be combined with inertial mocap or optical mocap devices to seamlessly integrate upper limb training and monitoring. In fact, inertial mocap or optical mocap tools appear to be the optimal choice not only for upper limb training but also for comprehensive full-body exercise. Optical mocap can be limited for tracking body parts that are not directly facing the optical mocap camera; however, coupling it with inertial mocap can alleviate this problem. Even for protocols needing only inertial mocap, the addition of an optical mocap device might be helpful to increase the accuracy of tracking with minimal additional equipment.

Multiplayer training, in competitive and collaboration modes, appear to be preferred to solo play in studies that investigated this option. This could be interesting to further investigate in future studies. In addition, optical mocap seemed to be the stimulation tool best suited for multiplayer play, as it allows for multiple players to play at the same time, whereas other tools might necessitate more equipment to do so or be limited to sequential play. VR interventions using HMD appeared to focus mainly on relatively light exercise that only moderately raises participant's heart rate. This choice of training probably results from a desire to reduce the risk of falls, discomfort while wearing the HMD, and the risk of cybersickness. In order to provide a visual immersive endurance training, we recommend to pair the VR HMD with a cycle ergometer. This would allow for efficient endurance training while limiting the risk of falls and discomfort by having the user seating. According to this corpus data, we hypothesize that a trend in pairing cycle ergometers with VR HMD might be emerging. The increase in inertial mocap use in recent publications could also be a sign of a rise in popularity of the tool, with advances in technology making them more accurate and affordable than a couple of years prior.

7.3. Recommendations on Software Selection. Regarding the software used for the training, off-the-shelf solutions using commercially available games appeared to be acceptable and usable by an elderly population. Nevertheless, they are usually not made to target older adults meaning that the content might not be best suited for this population and is usually not customizable. Every type of stimulation tool mentioned in this review was used at least once with a custom software made by the authors, the driving simulators being the only exception. This highlights the possibility to use commercially available devices with software created to meet the specific need of the study. Thus, when studying full-scale physical and cognitive training of the elderly, we would recommend using the chosen hardware coupled with custom-made games. A less resource-intensive alternative being to use off-the-shelf software tailored to the elderly or applications providing a large choice in customizable options.

8. Limitations

The scoping review has a significant limitation in that the reviewing process was conducted by a single reviewer, thereby increasing the potential for selection bias. Another limitation pertains to the choice of keywords, as they do not explicitly mention specific tools by name. This could lead to the exclusion of relevant articles that refer to digital tools using their commercial names, such as" Kinect," without explicitly describing them. The choice to exclude the term "robot" from the keywords chosen to explore the databases might also have biased the types of stimulation tools identified by excluding relevant devices.

9. Conclusion

This review allowed to identify six types of stimulation tools used for the simultaneous physical and cognitive training of the elderly. Those types of tools can be described as optical motion capture, pressure plates, inertial motion capture, VR, ergometers, and driving simulators. The experimental protocols encountered were very heterogeneous, making it hard to contrast and compare studies. A great variety in evaluation tools was also noted and grouped into five categories. Physical tests, cognitive tests, and questionnaires were the most popular evaluation categories, followed by physiological tests and other tests, the latter category including all the miscellaneous evaluations that could not be classified in other categories. Although coherent with the multidisciplinary nature of the physical and cognitive stimulation interventions considered in this review, the diversity in evaluation tools used complicates the matter of comparing the outcomes of different studies. Setting experimental guidelines regarding both protocols and evaluation tools might be necessary in order to improve physical and cognitive training of the elderly in the future. Promising stimulation tools such as VR and ergometers could also benefit from further experimentation to perfect experimental protocols and help popularize these tools in the research community regarding the targeted intervention.

Nomenclature

10MWT	10-m Walk Test
6-MWT	6-min Walk Test
AI	Artificial intelligence
BBS	Borg Balance Scale
BIA	Bioelectrical impedance analysis
BMI	Body mass index
C-WIT	Color-Word Interference Test
CAVE	Cave automatic virtual environment
CSR	Chair Sit-and-Reach test
DS	Digit span
EEG	Electroencephalography
FES-I	Fall Efficacy Scale International
FRT	Functional Reach Test
FTSST	Five-Time Sit to Stand Test
GDS	Geriatric Depression Scale
GEQ	Game Experience Questionnaire
HGS	Hand grip strength
HMD	Head-mounted display
IMUs	Inertial measurement units
LOS	Limit of stability
MCI	Mild cognitive impairment
MEMS	Microelectrical-mechanical system
MMSE	Mini-Mental State Examination
MoCA	Montreal Cognitive Assessment
mocap	Motion capture
MSC	Motion sensing controllers
PACES	Physical Activity Enjoyment Scale
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RPE	Borg Rating of Perceived Exertion
SDK	Software development kit
SLST	Single-Leg Stance Test
SPPB	Short Physical Performance Battery
SSQ	Simulator Sickness Questionnaire
SUS	System Usability Scale
TAP	Test of Attentional Performance
TMT	Trail Making Test
TUG	Timed Up and Go test
VF	Verbal fluency test
VR	Virtual reality
WHO	World Health Organization
WiiBB	Wii Balance Board.

Data Availability Statement

All of the data collected in this article is available in the Supporting data or on the online platform of the Open Science Framework (OSF) at the following link: https://osf.io/w7g6q/.

Ethics Statement

Ethics statement is not applicable.

Disclosure

This review has been carried out as a part of A. Busser PhD thesis work.

Conflicts of Interest

A. Busser receives a salary from HRV Simulation as a research engineer of the company. One of the publications selected in this scoping review [47] uses in its protocol a cycle ergometer commercialized by HRV Simulation. We declare that HRV Simulation had no influence on the methodology nor the discussion of this paper.

Author Contributions

A. Busser wrote the main manuscript text and prepared the figures. A. Busser, S. Fleury, and A. Kadri collaborated on organizing the ideas and the discussion of the manuscript. All authors reviewed the manuscript.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.

Supporting 1. Data 1 is a table presenting all the data about the sessions and participants gathered from the papers of the corpus. The data gathered include the number of participants pre and postintervention, the number of sessions planned in the intervention, the time span over which the sessions were done, the frequency of sessions (number of sessions per week), and the duration of the sessions. In this table, every row corresponds to a paper in the corpus. Values reported as "?" correspond to data that was not available in the article, and values reported as "NA" correspond to data that is not relevant considering the protocol of the article.

Supporting 2. Data 2 is a table presenting the different stimulation tools used in the papers of the corpus. One column reports the type of stimulation tool identified, based on the tools categories defined in this article. The other column reports the tools' brand name in order to identify them more specifically. In the case of one article using several tools, the article will have a different entry of each different tool. Thus, every row corresponds to a paper, with some papers appearing more than once if multiple stimulation tools were used in the protocol.

Supporting 3. Data 3 is a table presenting the different evaluation tests used in the papers of the corpus. One column reports the conventional name of the test or measurement done. The other column reports the evaluation test category based on the categories defined in this article. In this table, one paper will be represented by as many rows as they were tests done in its protocol. Thus, every paper is represented by a few rows, each focusing on one specific test.

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