An Interactive Cognitive-Motor Training System for Children with Intellectual Disability

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Abstract. It is increasingly evident that engaging in regular physical activity is important for people's health and well-being. However, physical training is still a big challenge for individuals with cognitive disabilities since it is difficult to motivate them and provide them with sustained pleasant training experiences over time. Active Video Games and Exergames may help achieve this, especially in the younger population. This paper describes an accessible Interactive Cognitive-Motor Training system (ICMT) created to encourage physical activity in children with cognitive disabilities by combining cognitive and gross motor training. The system was developed at a low cost, on top of an open source rhythm game, which has built-in support for dance pads and large video screens. The application employs user profiling in order to deliver personalized training. Performance data are recorded for further analysis to verify the training's efficacy and if needed, to tune the intervention. A pilot study showed the effectiveness of the proposed system, which by taking advantage of the positive effects of playing videogames, appears to encourage cognitively impaired people's physical activity.

Keywords: Cognitive Impairment, Physical Activity, Video game

1 Introduction

The term Intellectual Disability (ID) refers to a disorder that evolves during the development period and includes intellectual deficits in the three areas of conceptualization, socialization and practical abilities, as reported in the Diagnostic and Statistical manual of Mental disorder DSM-5.[1] Functional aspects of ID include deficits in attention,

[1] American Psychiatric Association (2013). Diagnostic and statistical manual of mental disorders (DSM-5®). American Psychiatric Pub.

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memory, executive function and problem-solving other than linguistic and verbal comprehension. As confirmed in literature, some of these factors, especially executive functions that control and integrate other cognitive activities, have great impact on common tasks in daily life requiring attention, rapid motor planning process, and effective inhibition of irrelevant or inappropriate details [24]. Consequently, people with ID often have difficulty maintaining a physically active lifestyle. Moreover, many of them have very low levels of cardiovascular endurance, compared to typical peers [5]. Besides the inherent cognitive and physiological conditions of subjects with ID that limit their physical fitness, several other intrinsic and extrinsic aspects have been put forward as contributing factors. Among these we find barriers in the physical environment, lack of social and family support, lack of awareness of the positive health effects of physical exercise, lack of motivation to perform any motor activity, economic/logistic difficulties in fruition of physical intervention programs, and need for supervision, especially in cases of severe disability [7-9].

Nevertheless, increasing physical activity is even more important in the case of individuals with cognitive disabilities, since these persons tend to have more health concerns than their peers [1, 25]. Moreover, for people with a cognitive disability, inactivity could cause additional cognitive decline, isolation and worsening of the symptoms.

The project Carpet Diem aims at providing an Interactive Cognitive-Motor Training system (ICMT) that supports physical activity in children with a mild or moderate cognitive disability, by combining cognitive tasks and gross motor movements for a simultaneous co-training. Exploiting the positive results shown in literature, the study proposes a novel system to attempt to overcome some of the limitations observed in previous research. More specifically, a combination of motion monitoring, visual instructions and musical sources (properly adapted) has been utilized to propose a suitable system for cognitively impaired subjects. The methodology and the system are described herein. After an overview on the related work, the proposed ICMT is described in Section 3. Section 4 describes a pilot test conducted with six children with mild or moderate cognitive impairment, aimed at prompting the efficacy of the system, especially in term of motivation. Conclusions and future work end the paper.

2 Related work

In recent years, many researchers have focused on how to promote physical activity among people with ID. Most of these attempts involve encouraging a healthy lifestyle to lower their cardiovascular and diabetes risk [10, 12]. However, the main issue is to identify the best strategies for fitness intervention, since traditional techniques have been inadequate for motivating this population [9]. The best approach should be the result of a coherent, complex and coordinated series of interventions in different areas, considering the social, emotional and cognitive development of individuals as well as their areas of interest [21]. In this regard, the use of technology-enhanced interventions could be a viable option, and as such, it has been the subject of several research efforts.

For instance, Virtual Reality (VR) allows users to interact within computer-simulated environments and has been extensively used over the past decade in a variety of rehabilitation and educational interventions for people with cognitive impairment. Many studies confirm its positive effect in: (i) encouraging and motivating individuals [14]; (ii) adapting the treatment to allow personalization and control of the stimuli provided [13]; (iii) effectively enhancing the physical fitness of individuals. Unfortunately, often the use of VR appears to be impractical in a non-research context due to the need for special (and frequently expensive) equipment or extensive supervision, especially when disability symptoms are severe. Considering the potential and limitations of current research, it is a challenge to design fitness programs that: (i) improve subjects' motivation and participation, overcoming the limits of traditional interventions; (ii) make these alternatives reproducible in real-life contexts (home, school, gym) without entailing unaffordable expenses; (iii) propose early-age intervention in order to prevent the risk of obesity and diabetes, highly correlated to the population with cognitive disabilities [10,12].

Solutions based on ICMTs are an effective and more affordable alternative to expensive VR systems. ICMT systems require participants to interact with a computer interface via gross motor movements such as stepping, receiving immediate visual feedback from the projection screen [11, 20]. For example, the use of ICMTs has been tested positively, especially for cognitive or motor-cognitive interventions, as a way to improve physical functioning in older adults with mild cognitive impairment (due to aging) to prevent falls [3, 11, 16]. Results from literature show that continual training, through well-timed and directed stepping under cognitive load, improves step performance in real life [2]. Aside from being relatively inexpensive, such systems combine physical and cognitive training, allowing task-specific training of cognitive function while performing physical exercises. Several studies confirm the potential of this combination for reciprocal improvement in both cognitive and motor areas [11, 16, 22].

For these reasons, our study aims to provide an accessible ICMT system for children with cognitive disabilities to promote physical activity while improving cognitive skills, using a serious game as a motivational trigger. The system's expected benefits are motor coordination, visual-motor coordination, sustained attention, inhibition capacity, visual-space memory, equilibrium and processing speed. Incidentally, all these factors may also affect mood and the individual's general quality of life.

3 Methodology

To develop the proposed system, existing software (Stepmania) has been adapted according to the users' requirements as well as the specifics stated for the user interface. More specifically, the requirements for the motion monitoring, for the instructions as well as for the music characteristics have been identified. To design the Cognitive-Motor Training Programs, we took into account the suggestions proposed by [20]. In addition, the songs used were selected according to the desired training goals.

4 The Cognitive-Motor System

Our target group includes children expressing mild to moderate cognitive disabilities and without any motor impairment. Literature reports positive cognitive and behavioural effects of adequate physical activity beginning at a young age, when neural plasticity is especially active [18, 23]. Even with certain differences, similar and (in some cases) amplified benefits have also been found in children with cognitive disabilities [4, 8, 9]. The major challenge in addressing this population concerns how to motivate them and obtain cooperation when proposing cognitive-motor training programs. Lotan et al. [9] highlighted the importance of respecting individual preferences, proposing enjoyable activities, guaranteeing flexibility and allowing sharing of activities between peers and friends.

4.1 Key System Components

Carpet Diem provides a controlled environment for supported training enjoyed through dance using a rhythm video game, called Stepmania, an open source application.[2] The proposed system has five components:

1) A tutor's laptop running several software tools (as described in Section 3.4)
2) A dance pad where the children perform the exercises
3) A large-size monitor where the game is shown
4) Speakers to amplify the music (optional)
5) A Fitbit tracker, worn by the child, to record calorie consumption during playtime.

The tutor supervises the training session via a desktop application implemented in Java that allows recording and managing the users' data, controlling Stepmania execution while collecting data derived from performance of the training programs.

The child interacts via the dance pad while looking at the monitor for game instructions. We chose dance pads with high-density foam inserts for their noiselessness, ability to absorb the shock from leg joints, and low height, avoiding the risk of falls as could occur using thicker dance mats with a metal surface.

[2] https://www.stepmania.com/

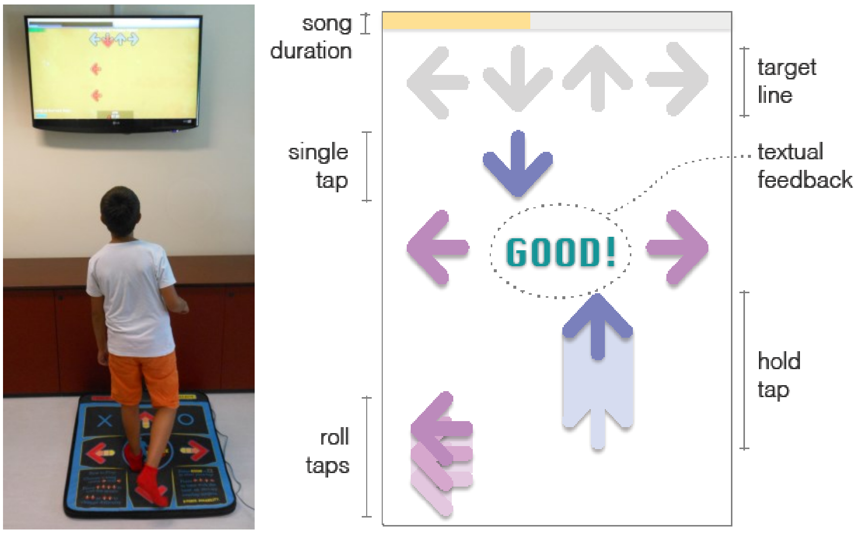

Fig. 1. (a) A room equipped with the training system, (b) Game Screen, detail of elements

4.2 Technical overview of the system

The system conceptual model is depicted in Fig. 2. It includes two main components: the Stepmania Software and the Carpet Diem application.

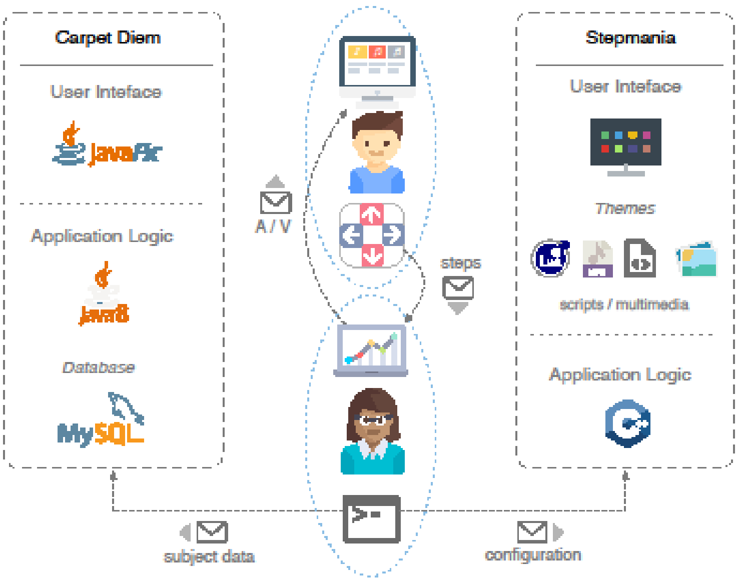

Fig. 2. System Conceptual Model

Stepmania software: an open source video game-engine, whose core source code is released under the MIT License. The application logic is made on C++ and the user interface operations are implemented through Lua[3] scripts managing different multimedia files. The game-engine is the result of an ongoing community effort, which has been involving many developers all over the world for more than 10 years. It offers several customizable options, but more advanced custom features may prove difficult to implement, since there is no official and complete documentation. Stepmania represented a good starting point to develop our project, but is greatly lacking in usability aspects, so it would have been impossible for us to use it as it is. Therefore, starting from the Stepmania source code and from a theme available online (*Moonlight* theme), we created a set of customized UIs (graphics, fonts, text strings, etc.) and automated scripts, representing the Carpet Diem theme of the game. Our main goal was to provide an accessible and usable theme, both for therapists and for children with ID. To this end, the original Stepmania environment was modified by:

- Removing all the interface elements that were a potential source of confusion and error for the therapist who controls the system
- Removing interface elements that were unnecessary and could disturb the subject participating in the training
- Removing game-modalities that are not consistent with the current training program.

Moreover, we designed ex novo the game programs as described in Section 3.3.

Carpet Diem: a desktop Rich Client Application built using the JavaFX 8 graphic user interface framework. We developed this application with two main goals: (i) Supervising Stepmania execution; (ii) Gathering and managing user information and collecting data from play sessions.

These goals are achieved through three key components:

a. The database access layer
b. The graphic user interface (GUI)
c. The Stepmania 5 Controller

The data access layer consists of a set of Java classes specialized in the management of a local MySQL database. Through this component, Carpet Diem manages the connection to the database and the business logic application to read and write data. Through the Controller component, the application performs two separate tasks as autonomous processor threads:

- A Starter thread that triggers the execution of Stepmania configured with the user data selected via the GUI, including the associated theme.
- A Controller thread that checks the presence of player data in order to update the database. Moreover, it can also terminate the execution of Stepmania. This thread runs in the background, but leaves a trace of its activity in the GUI, so the user can easily monitor the application. At a predefined time interval, the Controller checks whether the data file size has changed (in which case the results are read from the file and the database is updated).

[3] https://www.lua.org/

Fig. 3 shows a screenshot of the Carpet Diem User Interfaces during the starting phases.

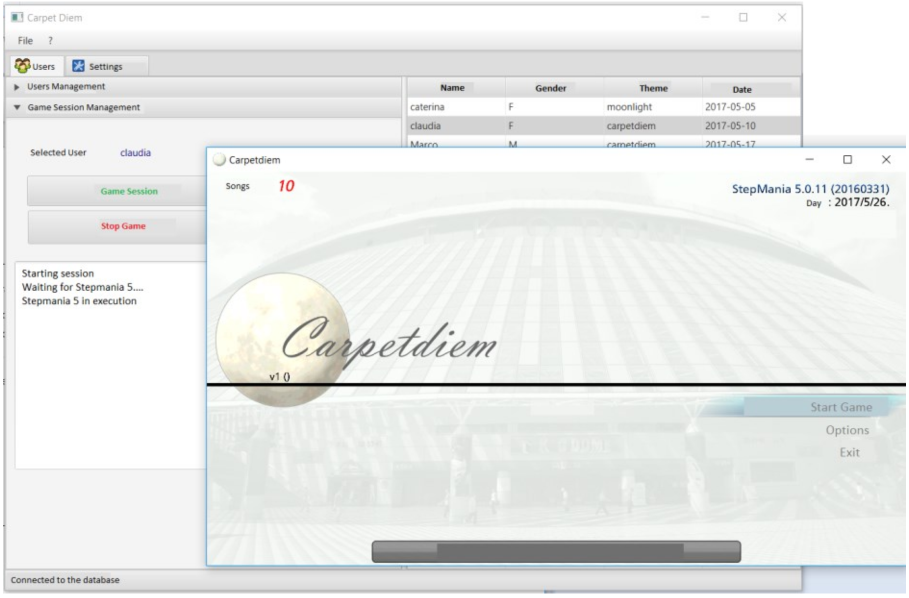

Fig. 3**.** Carpet Diem application, screenshot

4.3 Design of Cognitive-Motor Training Programs

Stanish [20] summarized eight suggestions for motivating and engaging people with cognitive disabilities in performing physical activities:

a) Include activities of different intensities
b) Include strategies to motivate users and positively reinforce task completion
c) Include fun activities and social interaction
d) Involve participants in activity selection and decision-making
e) Select age-appropriate activities
f) Prefer inclusive environments considering participants' preferences
g) Tune each activity to individual skills
h) Consider setting goals and monitoring progress over time.

We attempted to apply all these suggestions as described in the following.

Music, especially for children and adolescents, can motivate the subject to participate in and enjoy training interventions. We used Stepmania, which encourages physical activity via music, offering a base for motivation and engagement (**b, c**).

The system enables one to define the user profile and assign the training path according to personal needs (age, intensity) and preferences (**a, e, f, g**), in order to provide simple interaction for ensuring participants' satisfaction.

The system provides automatic monitoring over time, recording users' performance data (**h**).

The Cognitive-Motor Training program consists of choreographies, i.e., steps synchronized with music tracks and guided by video instruction. Synchronism helps the player to reduce the cognitive load required to coordinate the visual component with the motor component and makes the game more fun. This element works very well in typical subjects and is the basis of the success of exergame programs, but can be a challenge for people with cognitive disabilities. For these reasons, the system implements different levels of difficulty to make the game increasingly challenging while supporting user success. Moreover, synchronism does not influence the score weight during the early training levels, but it affects the score at the advanced levels (**g**).

Song tracks were selected in collaboration with therapists in order to be suitable for the subject's age, and are quite varied in order to meet individual preferences (**e, f**). In addition, each selected track has a strong rhythm base (such as Latin American songs) in order to be easily perceived and it was elaborated in order to reduce disturbance, cut duration (all tracks are about 2 min long) and individuate the BPM (beats per minute), to associate it with the choreography. One constraint was having the BPM constant in each song to simplify the choreography's execution, helping familiarize the users with the rhythm (**a, e**). Lastly, participants were actively involved in the selection of preferred songs (**d**).

4.4 Cognitive implications in game play

Actions tracked by the dance-pad are: 1) steps in the basic four directions (DX/SX/UP/DOWN); 2) holds (steps pressed for a long time) and 3) jumps (simultaneous pressing of two directional arrows). Stepmania depicts these elements on the screen through arrows of different styles (see Fig. 1.b) in order to ask the user to perform them. Each element flows on the screen, forcing the player to pay attention, and the cognitive load required can be considerable.

People with intellectual disability often have difficulty sustaining attention, so our system implements choreographies involving only steps in four directions without holds or jumps. The flow of arrows on the screen defines each choreography, which was defined with the help of the project therapists. When each arrow flowing from the bottom of the screen arrives on a target arrow on the top of the screen, the player must step on the corresponding arrow of the dance-pad. Players receive feedback for each step performed (perfect, good, miss) and a final summary at the end of the song.

Levels of difficulty may increase if the user performs the choreography correctly. Each level results from the combination of two variables: how many steps per second players must perform on the target location (step execution time), and type of steps (variability between one step and the next). Specifically, for each track, four levels of difficulty (Beginner, Easy, Medium and Advanced) were identified to meet two main requirements: provide a progression flow by adapting times and difficulties to individual needs, and diversify the offer to satisfy different individuals' skills (**e, g**).

1. *Beginner:* the tracks were split into four sub-sections of about 30 s. Each one consists in repeating only one step many times (30 s step DX, 30 s step SX, 30 s step UP, 30 s step DOWN). The step execution time is sustained since the step is always the same one but repeated for a long time.

2. *Easy:* the tracks were split into five subsections of about 24 s. Each one consists in repeating a combination of two steps many times. Step execution time is sustained since step instructions are simple and repeated for a long time.
3. *Medium:* the tracks were split into subsections of different duration. Each one consists in a simple combination of steps. Step execution time is low, and the difficulty is mainly expressed by step variability (BPM/4).
4. *Advanced:* the tracks have been split into subsections of different durations. Each one consists in a more complex combination of steps with a sustained step execution time (BPM/2).

Cognitive demand on performing such types of choreographies mainly rely on executive functions, including planning and implementing strategies for performance, monitoring performance, using feedback to adjust future responses, vigilance, and inhibiting task-irrelevant information.

5 Pilot Test

In order to collect feedback and observe the interaction with real users, we tested the platform with six children (two male and four female) aged 7-10 years and expressing mild or moderate severity of intellectual disability due to different conditions such as Down Syndrome, George Syndrome, or other rare genetic diseases.

The test was carried out at the Institute of Neuropsychiatry IRCCS-Stella Maris Foundation in Pisa. The Institute of Neuropsychiatry takes care of children and adolescents expressing the main and most frequent pathologies of the nervous system and of the mind. It was our point of reference both for the collection of the training system requirements and for the preliminary verification of the prototype realized.

The test was organized to involve one child at a time in two phases to achieve two main goals: (i) collect preliminary feedback on the system's acceptability; (ii) evaluate sustainability over time.

A dedicated space was set up inside the room where children usually attend traditional therapy sessions. The children were not informed about the test but were simply invited by a therapist to perform the game. During the first phase of the test, the system was presented to each child, observing their responses to the proposed tasks. Some children accepted playing with the therapist without hesitation and waiting for instructions. They seemed involved in the game but did not really understand the existing connection between what was shown on the screen and the dance-pad. However, they tried to perform the task following the therapist's verbal instructions, properly prompted. Some other children needed more time to be cooperative. After some training, only a few children executed the proposed steps correctly, but all six users began to look at the screen to receive instructions, showing better accuracy in identifying the step to perform.

We realized, during this first phase, that: (i) The number of steps per second needed to be harmonized with the steps' variability; (ii) Certain step combinations (including the step *down*) were difficult to perform (compromising balance) due to the difficulty in mentally perceiving the dance-pad and its arrows' location.

These observations were valuable for improving the design of tasks and choreographies for the second phase, when we wished to observe how subjects reacted to a sustained demand for work, i.e., an intensive intervention session scheduled three times a week for 2 weeks. The dance-pad seemed to be highly motivating for all the users. Even when the tutor asked for a high frequency of usage, it was not perceived as an imposition nor as a repetitive and boring task. Despite the very good acceptance, intensive frequency intervention (three times a week) was difficult to propose at the clinic: often sessions were canceled or rescheduled due to unforeseen family and health problems. To resolve this issue, we plan to reproduce the training environment at home with the addition of an Internet connection to supervise the remote intervention. In this case, in order to calibrate the sequences' complexity and collect qualitative data, we also expect to use a video camera.

The 2-week study confirmed the importance of motivation and involvement in task execution during the play sessions. In similar studies involving older people needing cognitive-motor training to prevent risk of falling [3, 11, 16], personal awareness of the importance of training had a relevant role. In our target group, this key factor is lacking so finding alternatives to maximize user engagement is crucial. As suggested in literature, "compelling the persons to accept a physical activity condition without promoting (ensuring) their self-determination and independence could cause those persons considerable stress and anxiety" [6, 15]. In that sense, adapting stimuli to the subject's abilities and preferences could be the best approach to reducing stress, improving user cooperation and making the training program successful.

Moreover, environmental aspects enriching the game area could contribute to a positive overall experience. As an example: (i) the monitor where instructions are provided should be larger in order to improve user engagement; (ii) music has to be clear and clean (without distortions); (iii) additional stimuli such as different background colors associated with each song could enhance the emotional status of the subject without interfering with the main stimulus.

6 Conclusion and Future work

This paper describes an accessible technology-enhanced environment for cognitive-motor training of subjects with intellectual disabilities. Compared to the state of the art, our contribution (i) proposes a tool suitable for an early intervention, addressing a target population of children and teenagers with mild or moderate disability; (ii) offers a low-impact (economic and technological) system reproducible in non-research contexts.

The platform is based on Stepmania, a free and freely available interactive video game, allowing a high degree of customization and integration into more complex systems such as the cognitive-motor training system described herein. The overall aim of the system is to maximize the involvement of the target population, offering physical exercise under cognitive load, and exploiting the potential of music and videogames in terms of engagement, motivation and pleasantness.

Preliminary results achieved with six children involved in the pilot test are encouraging and provide more insight into key factors for designing cognitive-motor training programs in order to motivate children with intellectual disability and ensure a pleasant experience.

In the future, we plan to carry out a 3-month user test with an improved version, involving ten subjects aged 7-14 years expressing mild to moderate cognitive disability. A pre/post cognitive-motor assessment through standardized scales to evaluate the effects of this cognitive-motor training intervention in terms of

1) *Positive/negative influence in cognitive skills*: attention, auditory memory, spatial memory
2) *Positive/negative influence in motor skills:* balance, coordination, speed, fluidity
3) *Fitness measures* quantifiable with the calories burned stepping with the dance-pad compared to baseline condition

would enable the analysis of the system's effectiveness.

Acknowledgments. We thank the participants in the pilot test and Fondazione Pisa, which funded the project.

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