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Physical and Cognitive Stimulation Using an Exergame in Subjects with Normal Aging, Mild and Moderate Cognitive Impairment

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Abstract.
Background: The use of Serious exerGames (SeG) as enriched environments (EE), which promotes cognitive simulation with physical activity in a positive emotional context, has been proposed to represent a powerful method to slow down the decline due to neurodegenerative diseases (ND), such as Alzheimer's disease (AD). However, so far, no SeG targeting EE has been tested in ND subjects.
Objective: This study aimed at evaluating the usability and short-term training effects of X-Torp, an action SeG designed for elderly ND subjects with mild cognitive impairment (MCI) and AD.
Methods: X-Torp is a SeG played using the Microsoft® Kinect™. 10 ND subjects and 8 healthy elderly controls (HEC) were enrolled in a 1-month program with three training sessions per week. Usability was evaluated through game time, game performance, the aerobic intensity level reached, perceived emotions, and perceived usability.

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Results: All participants successfully completed the training program. ND subjects played less and had a lower game performance compared to HEC. During the sessions, ND subjects maintained a light intensity of aerobic activity, while HEC maintained a moderate intensity. Both groups experienced only positive emotions, and reported a 'moderate' to 'high' perceived competence, a 'moderate' game difficulty, and a 'high' interest in the game.
Conclusion: Usability results suggest that X-Torp represents a usable EE for healthy subjects and persons with MCI and AD. However, in order to reach moderate or high intensity of aerobic activity, X-Torp control modes should be adapted to become more physically stimulating.

Keywords: Aerobic activity, Alzheimer's disease, cognition, enriched environment, mild cognitive impairment, serious game

INTRODUCTION

Due to population aging, the number of people with neurodegenerative disease (ND) leading to dementia, a decline in mental ability that interferes with activities of daily living, is predicted to escalate in the next 50 years [1]. Dementia can result from different causes, the most common being Alzheimer's disease (AD). It is often preceded by a pre-dementia stage, known as mild cognitive impairment (MCI), characterized by a cognitive decline greater than expected for an individual's age, which, however, does not interfere notably with activities of daily living [1, 2]. Depending on the etiology and the disease's stage, dementia can be characterized by cognitive, behavioral, motor, and/or functional symptoms. The biological processes involved in ND are very heterogeneous, and include neuroinflammation, gliosis, synaptic loss, neurodegeneration, cerebral atrophy, and alterations of the blood-brain barrier permeability [3]. These molecular alterations are due, among others, to alterations in the bioenergy metabolism (linked to dysfunctions in the brain cell mitochondria), to hypoperfusion/hypoxia, and to dysfunctions of the cerebrovascular hemodynamic (mainly due to brain small vessel disease [3]). From a therapeutic point of view, much research aims to modify the course of the disease or to reduce the impact of the clinical symptoms. Social interaction, activities, and motivation can have a major impact on the disease progression. Hence, non-pharmacological approaches targeting people's lifestyle are of particular interest.

The Cognitive-Enrichment hypothesis [4] states that 'the behaviors of an individual (including cognitive activity, social engagement, exercise, and other behaviors) have a meaningful positive impact on the level of effective cognitive functioning in old age'. This hypothesis assigns a key role to cognitive stimulation, physical activity (moderate and high intensity aerobic activities [MIAA and HIAA]), social engagement, emotions, and personality. These factors are supposed to modulate neuroplasticity at any age. Hence, an improvement in cognitive functioning and a delay in cognitive decline can be achieved even if behavioral modifications are started in later life. One of the ideas of the Cognitive-Enrichment hypothesis is to conceive enriched environment (EE) to stimulate simultaneously several factors (e.g., cognition and physical activity), in order to optimize brain functioning. This is in line with recent recommendations for dementia prevention [1, 5]. Aerobic exercise, alone or in the context of EE (see [6] for a review of EE effects), seems to be a powerful activity to delay neurodegenerative processes. Evidence is available on the positive effects of HIAA (such as walking, biking, or rowing) on cognition (better memory and executive functions), neuroplasticity (in the frontal and hippocampal brain regions), and maximal cardiorespiratory fitness (also named 'maximal aerobic fitness' or 'maximal oxygen consumption', VO_2max) in healthy older adults and subjects with dementia [7–9]. Moreover, animals' studies showed positives effects of MIAA and HIAA on cerebral aerobic metabolism, which can reduce alterations in the bioenergy metabolism (e.g., increase of mitochondria functioning in the brain cells [10]). These effects are associated to improvements in cognitive functions, neuroplasticity, and reduction of neuropathological processes in animal models of ND [10, 11].

The idea to use a video game (VG) as an EE is quite recent [12, 13]. It derives from the acknowledgment that VG are intrinsically entertaining and can involve physical exercise, leading to synergistic effects on cognitive functions and neuroplasticity [8, 12, 13]. Serious games (SG) are VG (i.e., an amusement mental contest, played with a computerized technology) designed primarily to educate or train the player. VG that involve physical exercise are named exergames. The cognitive activity stimulated by VG depends on game types [14–16], and VG can enhance neuroplasticity at any age [17–19]. Action VG need the player to move an avatar to avoid projectiles and shoot to destroy targets (often played in first or third person), and seem to improve several perceptual and cognitive abilities, such as visuo-spatial and selective attention [20–23], processing speed [24], and working memory [25]. Moreover, puzzle VG or problem solving based mini-games are widespread and seem to improve executive functions and processing speed in older adults [26]. They can even produce brain structural changes in young people [27].

Exergames (e.g., 'Wii™Sport') generally use motion capture devices such as the Wii™ and the Kinect™. Initial studies on elderly people show positive effects of exergames on emotions (e.g., better quality of life and reduced depressive symptoms), physical fitness (e.g., improvement of strength, agility, and aerobic performance), executive functions, and processing speeds [13, 28]. However, most of the existing exergames induce only light intensity aerobic activity (LIAA) [29]. This is mainly due to the fact that the Wii™ and Kinect™ have limited capabilities to capture movements in depth, and, as a consequence, exergames usually imply stationary movements involving mainly the upper limbs [29]. Cybercycle with Expresso® HD bike system (virtual races played with a stationary bike) specifically targets aerobic training. Cybercycle training at HIAA, in healthy elderly people (and in some subjects with MCI), improve executive functions and enhance neuroplasticity more than cycling alone at same HIAA [12].

The cognitive decline associated to ND questions the usability of the VG designed for 'healthy players' [8, 30, 31]. Furthermore, very few SG usable in subjects with dementia do exist, and they mainly target cognition [32, 33]. Recently, the serious exergame (SeG) 'X-Torp' (Ben-Sadoun, unpublished data), was developed to offer an EE including cognitive, emotional, and physical stimulation for subjects with mild and moderate cognitive impairment due to ND, such as MCI and AD. However, no usability or efficacy study has been conducted, so far.

The purpose of the present study was to assess the usability of X-Torp in subjects with ND including MCI and early AD, using a 1-month training program, which aimed to induce a MIAA. Usability was evaluated through game time, game performance, the aerobic intensity level reached, perceived emotions, and perceived usability. Usability in subjects with ND was also compared with usability in healthy elderly participants to detect possible X-Torp disease-related usability problems, which could help to find some ergonomics rules concerning the use and the design of SeG in these populations. The following hypotheses were advanced: (H1) all participants should be able to complete the game (as it was designed taking into account the target population's features), but game time and game performance should be lower in subjects with ND, due to their cognitive/physical/learning ability impairment; (H2) all participants should be able to increase the aerobic intensity level reached during the 1-month training, to reach a MIAA at the end of training program, thanks to X-Torp game controls; (H3) all participants should report mainly positive emotions, but these should be lower in subjects with ND, who often suffer from apathy; (H4) perceived competence should increase during the 1-month training in all participants, due to game experience and the clinician's help; (H5) perceived difficulty should be comparable in the two groups, and should not change during the training, mainly due to the competence increase; (H6) perceived interest should be lower in subjects with ND at the beginning of the training program compared to healthy elderly participants (again due to apathy) but should increase at the end of training program, due to a better understanding of game; and (H7) pre- and post-training effects on cognitive and physical performance are exploratory but should be different for the two group, with an increase on physical performance only for subjects with ND, due to their lower physical fitness at baseline; with a small increase on cognitive performance higher for healthy elderly participants, due to their preserved learning ability.

METHODS

Participants

Ten elderly subjects with cognitive impairment due to MCI or AD (ND group, including 3 subjects with AD, 1 with mixed AD, 4 with nonamnestic MCI, and 2 with amnestic MCI; 4 females, 6 males; age = 82.3 ± 6.4 years; height = 167.3 ± 11.2 cm; weight = 78.5 ± 17.8 kg) and 8 healthy elderly control subjects (HEC group, 5 females, 3 males; age = 71.4 ± 10.1 years; height = 167.1 ± 11.8 cm; weight = 68.5 ± 14.1 kg) volunteered to take part in this study. Participants were recruited at the Nice Memory center in France. All participants were retired, or they had not been working for the previous two years. Participants were included in the ND group if they had a diagnosis of MCI or early to moderate state of AD with late onset or mixed type of AD according to the International Classification of Diseases (ICD-10; [34]) and Peterson criteria [2]. Participants were not included if they had major visual impairments, motor deficits requiring walking aids, a history of myocardial infarction, tachycardia, and/or uncontrolled hypertension. The study was performed in compliance with the Declaration of Helsinki, and was approved by the Nice Hospital ethics committee (ID RCB: 2013-A00979-36). All participants received detailed written explanations on the study aims and procedures, and provided their informed written consent before taking part in the study.

Materials

The SeG was controlled by a desktop PC (Dell Precision M4600, Intel Core i7 2×2.2 GHz processor, 3Gbytes of RAM, AMD Fire Pro M5950 graphic card) and displayed on a high-resolution wide screen (68 cm × 121 cm). Participants interacted with the SeG thanks to a RGB-D (Red Green Blue+Depth) Kinect™ (V.1, Microsoft, U.S.A) and to customized software (Software Development Kit, Microsoft, USA).

Participants' blood pressure and resting heart rate (HRrest) before each training session were measured through a digital blood pressure monitor (Omron, M6 W, IntelliSense). Participants' heart rate (HR) was monitored continuously during the training sessions through a wearable HR monitor with a HR sensor positioned on the chest thanks to a chest belt (Polar®, RS400, Finland). A customized software (Polar® Pro Trainer 5TM, Polar, Finland) was employed to extract and process the HR data.

The 6-Minute Walk Test (6MiWT) was realized on a non-motorized treadmill (Striale ST-678 Mag-Jogger II).

X-Torp SeG

X-Torp is an action SeG played with the Kinect™ (see Supplementary Video).

The scenario mode (SM) combines action game dynamics, with exploration of open environments and mini-games. It includes an experience point system, which reflects the progression speed in the SM. To complete the SM, the player must collect enough experience points and money by destroying other ships in the sea and by accomplishing all the missions on the islands. The player controls a submarine in real time with his/her stationary movements involving (unlike most of the existing exergames) mainly the lower limbs (e.g., walking and running on place to move the submarine forward, using arms to turn or shoot). Hence, several actions involving lower and upper limb can be combined. When the player makes a movement to give a command, the submarine performs the action as long as the player keeps doing the movement. When the player stops, the submarine stops the action. The missions take the form of 2D mini-games inspired to (1) classical neuropsychological tests used in the clinical practice and (2) puzzle VG. During mini-games, the player uses only his/her hand, and a virtual hand follows his/her movements. The player selects an icon by positioning the virtual hand over it and keeping the hand position around one second. Hence, the player is considered as physical active when he navigates or battles on the sea, and physical inactive when he realizes mini-games in missions on the islands. Results collected in a pilot with healthy young adults suggested that X-Torp SM duration is around 2 hours.

The therapist mode (TM) contains virtual versions of classical neuropsychological tests. The only differences are that they have the X-Torp graphics, and are playable with the Kinect™. These tests were employed as a starting point to design the mini-games included in X-Torp SM, which used different items. The TM also included a physical test played in a virtual environment.

Procedure

Participants followed a 13-session training with X-Torp over five weeks, for a total of 10 hours of game stimulation. Clinical assessment was performed before starting the program. A comprehensive assessment of the physical fitness and cognitive functions (2-3 hours) was performed by a medical doctor one week before starting the game training (pre-training-tests) and one week after finishing the training (post-training-tests).

Clinical assessments

Participant's characteristics at baseline included collection of the following anthropomorphic data: gender, age, height, weight, body mass index (BMI) and education. The Apathy Inventory (AI) [35] and the Neuropsychiatric Inventory (NPI) [36] were used to assess, respectively, the presence of apathy and behavioral disturbances. The Mini-Mental State Examination [37] and the Clinical Dementia Rating

[38] measured, respectively, global cognitive level and dementia severity.

Assessments of the physical fitness and cognitive functions before and after game training

Assessment of the physical fitness included three standardized tests assessing lower limbs physical condition during balance, gait, and sit to stand transfer: the Short Physical Performance Battery (SPPB) [39]; the 10-Meter Walk Test (10MeWT) [40, 41]; and the Time Up and Go (TUG) [42]. Aerobic exercise capacity was also assessed using the 6MiWT on treadmill [43, 44]. Assessment of cognitive functions included: the MMSE; the Frontal Assessment Battery (FAB) [45]; the memory and verbal fluency task of Short Cognitive Battery (SCB Memory and SCB Fluency) [46]; two tests of executive functions (the Trial Making Test (TMT), [47]; the Digit Symbol Substitution test (DSST), [48]); and one test of memory (the Delayed Matching to Sample 48 (DMS48), [49, 50]).

X-Torp training sessions

T1

The first training session was the longest (80 minutes, see Table 1), but included regular breaks to allow participants to rest. Participants were administered the cognitive tests included in the X-Torp TM, in order to familiarize them with the mini-games embedded in the X-Torp SM missions, and to assess their performance in the game tests before starting the X-Torp SM training. These tests included an X-Torp version of: the TMT (X-Torp TMT); the DDST (X-Torp DSST); the DMS48 (X-Torp DMS48); inhibitory functions through the Go-No Go Reaction Time Test paradigm (X-Torp GNGRTT) [51] and selective visual attention through the Cancellation Test paradigm (X-Torp CT) [52]. At the beginning and the end of this session, participants were also administered the treadmill-based X-Torp 6MiWT, which following 6MiWT principles.

T2-T12

The following 11 training sessions started one week after T1 and took place three times per week over a 4-week period. During these sessions, participants were trained with the X-Torp SM, for a total of 7 hours and 40 minutes training (Table 1). After each week first session of X-Torp SM training (T2, T5, T8, and T11), participants were asked to fill in self-report questionnaires assessing perceived emotions through the Positive Affect Negative Affect Scale (PANAS) [53] and perceived usability (see Supplementary Table 1). X-Torp SM training had two specific objectives: session duration and aerobic stimulation level, which evolved from one week to the next (Table 1). Hence, the two first weeks of X-Torp SM training (weeks 2-3) were meant as a learning phase, and the two last weeks (weeks 4-5) as game physical and cognitive optimization phase. A clinician accompanied participants to allow them to achieve each session objectives using a chronometer and a HR monitor (e.g., during the optimization phase, the clinician asked participants to walk faster or to run in place to increase exercise intensity). Participants were allowed (1) to take pauses during the sessions if they were tired, (2) to stop the session if they were too tired or unwilling to continue for any reason, and (3) to continue the training for a few minutes after the end of the session to finish a task.

T13

In the last training session, participants employed the SM for 20 minutes (physical active playing).

Then, participants employed the TM for 40 minutes and repeated the X-Torp TM tests administered during T1 (except the X-Torp 6MiWT) in order to evaluate improvements in the TM tests.

In summary, from T1 to T13, participants were trained with the X-Torp SM for 8 hours and the X-Torp TM for 2 hours (Table 1).

Data analysis

Game time during X-Torp SM training: (1) The total training time, (2) the total physically inactive training time (mini-games), and (3) the total physically active training time (navigation and battles on the sea), as measured by the HR monitor (which stopped during pauses and the mini-games) were measured.

Game performance during X-Torp SM training: The total number of times the game was completed during the training program was calculated. Moreover, the progression speed on the SM during the training program was assessed by the cumulative number of experience points (Performance-1) and the cumulative amount of money (Performance-2) gained between T2 and T13 divided by the total time (in minute) spent playing. Better Performance-1 and Performance-2 indicated faster progression speed at SM.

Table 1
Summary of the X-Torp training sessions. The duration of the physical training is included in the total session duration (e.g., T2 consists of 30 training minutes including a minimum of 10 minutes of light physical activity: 30% of the mean%HRr^{peak}). W2-W3 was considered as learning period and W4-W5 as optimization period

X-Torp training program														
Weeks	W1		W2			W3			W4			W5		
X-Torp Mode	TM							SM						TM
Training session	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	
Length (minutes)	80	30	30	35	35	40	40	45	45	50	50	60	20	40
Physical training including SM X-Torp training program														
Length (minutes)		10	10	10	15	15	15	20	20	20	25	25	20	
Intensity (Mean%HRrp)		30	30	30	40	40	40	50	50	50	50	50	50	

SM, Scenario Mode; TM, Therapist Mode; mean%HRr^{peak}, mean percentage of heart rate reserve relative to the peak of HR measured during the 6MiWT; W, weeks; T, training.

The aerobic intensity level reached during X-Torp SM training: As a result of maximal cardiorespiratory fitness decline in subjects with early AD compared to healthy elderly people (expressed in HR^{peak} and $VO_2{}^{peak}$ during maximal graded exercise testing on treadmill [54, 55]), the aerobic intensity level reached was not expressed in HR reserve relative to predictive maximal HR equations, as used in other studies involving healthy elderly people (for instance, see [12]). For each training session (T2-T13), during the active playing phases, the mean established aerobic intensity level reached was expressed in terms of percentage of HR reserve relative to the peak of HR measured during the 6MiWT (mean%HRr^{peak}). It was calculated as follows:

mean%HRr^{peak} = ((meanHRexercise–*HRrest)/ HRr^{peak}*)×*100*; with: *HRr^{peak}* = *HR^{peak}–HRrest (HR^{peak} was peak of HR set during 6MiWT)*. As a result of intermittent physical activity induced by the X-Torp SM, the highest value of HR during each training session was expressed using maximal percentage of the HRr^{peak} (max%HRr^{peak}) and was calculated as follows:

max%HRr^{peak} = *((maxHRexercise–HRrest)/ HRr^{peak}*)×*100)*. Then, averages of mean%HRr^{peak}, max%HRr^{peak} and time physically active during the learning phase (Weeks 2-3) and the optimization phase (Weeks 4-5) were calculated.

Perceived emotions during X-Torp SM training: Each PANAS item was scored through the 5-point Likert ranging from 1 = 'not at all' to 5 = 'very much'. For each first training of each week (T2, T5, T8 and T11), positive (/50) and negative (/50) affect scores at the PANAS were measured by the sum of the 10 positive and 10 negative items scores. Then, the sum of Positive (/100) and Negative (/100) affects scores during the learning phase (Weeks 2-3) and the optimization phase (Weeks 4-5) were calculated.

Perceived usability during X-Torp SM training: Perceived usability questions were designed on the two dimensions of the Technology Acceptance Model of Davis (see [56] for review): 'ease of use' (3 questions for perceived competence, 3 questions for perceived difficulty) and 'perceived usefulness' (3 for questions for perceived interest, see Supplementary Table 1). Questions were assessed with a 7-point Likert self-report scale (ranging from 1 = 'not at all' to 7 = 'very much'). After each week first session (T2, T5, T8, and T11), perceived competence (/21), difficulty (/21), and interest (/21) were measured by summing the scores of the corresponding 3 items. Then, the sum of competence (/42), difficulty (/42), and interest (/42) were calculated during the learning phase (Weeks 2-3) and the optimization phase (Weeks 4-5).

Clinical assessments: The BMI was measured using the equation: $BMI = Weight / Height^2$. Education was measured on a 5 points scale: 1 'no education', 2 'middle school', 3 'high school', 4 'A-level', and 5 'university'. Scores at AI, NPI, MMSE and at CDR sum of boxes were calculated.

Assessment of the physical fitness (Standards tests): SPPB score, times at 10MeWT, TUG, and distance at 6MiWT were evaluated at pre- and post-training-tests. In order to set the best peak of HR during the 6MiWT, treadmill inclination was 5% and flywheel magnetic resistance was at a middle level. The bigger distance achieved in any of the two 6MiWT was kept for pre- and post-training-tests.

Assessment of the physical fitness (X-Torp TM tests): During the X-Torp 6MiWT (T1), the participant walked on a treadmill simultaneously with an avatar walking in a virtual city. The greater HR^{peak} reached in any of the two 6MiWT and the two X-Torp 6MiWT was kept as a measure of the HRr^{peak}.

Assessment of cognitive functions (Standards tests): Scores at MMSE, FAB, SCB Fluency, and SCB Memory were evaluated at pre- and post-training-tests. Times at TMT (A and B) and scores at DSST and DMS48 (only first stage on DMS48 test but in explicit memory [46, 47]) were evaluated at pre- and post-training-tests.

Assessment of cognitive functions (X-Torp TM tests): The X-Torp TMT consisted in selecting numbers in a numerical sequence (from 1 to 20, X-Torp TMT A) and alternating numbers and letters in ascending sequence (from 1 to 10 and from A to J, X-Torp TMT B) as fast as possible. The X-Torp DSST consisted in selecting the corresponding symbol in the paired list (differently from the standard DSST), following a list of digit, as fast as possible in 120 seconds (see Supplementary video for examples). The X-Torp DMS48 used alternative sets of pictures. The X-Torp CT consisted in selecting 30 target pictures among many distracter pictures as fast as possible. For the X-Torp GNGRTT, participant clicked a mouse button as fast as possible when a green sphere appeared, and did not click when a square appeared. X-Torp TMT times (A and B), X-Torp DSST score, X-Torp DMS48 score, X-Torp CT performance (score and time), and X-Torp GNGRTT performance (corrects action minus errors and mean reaction time) were evaluated at T1 and T13.

Statistical analysis

All statistical analyses were performed with STATISTICA 7.0.

Due to the relatively small sample size, clinical assessments, game time and game performance between-group comparisons (ND versus HEC) were performed using Mann-Whitney U tests with $\alpha = 0.05$.

To compare usability during the learning phase (Weeks 2-3) and the optimization phase (Weeks 4-5) of X-Torp SM training, the aerobic intensity level reached, perceived emotions, and perceived usability indexes were submitted to separate repeated-measures ANOVAs with 'Group' (ND versus HEC) as between-subject factor and 'Training phase' (Weeks 2-3 versus Weeks 4-5) as within-subject factor. *Post-hoc* corrected Fisher tests have also been reported. Differences were significant for $p < 0.05$. With the hypothesis of no statistical difference for perceived difficulty (H5), differences were not significant for $p > 0.01$ in order to reduce the risk of Type 1 error.

Concerning perceived usability, internal consistencies of the items composing each dimension were assessed using the standardized Cronbach Alpha Coefficient [57].

Assessments of the physical fitness and cognitive functions (including X-Torp TM tests) before and after X-Torp SM training were performed with repeated-measures ANOVAs with 'Group' (ND versus HEC) as between-subject factor and 'Time' (pre-training versus post-training) as within-subject factor. *Post-hoc* corrected Fisher tests have also been reported. Differences were significant for $p < 0.05$.

RESULTS

All participants completed the study. After data collection, one participant in the HEC group was excluded from the analyses because his performance at several cognitive tests was more than two standard deviations away from the mean of the HEC participants (suggesting the presence of a degenerative disease different from those addressed in the present study). Thus, the reported results refer to 17 participants, 10 ND subjects, and 7 HEC participants.

A complete list of the ANOVAs results (p and F values) are reported in Supplementary Table 2.

Clinical assessment

Anthropomorphic data, the MMSE and CDR sum of box, are reported in Table 2. Participants in the ND group were significantly older ($p = 0.02$) and had a lower education level ($p = 0.03$) compared to HEC participants, but the two groups did not differ concerning the BMI ($p = 0.14$). Furthermore, even if the difference did not reach statistical significance, ND subjects had a higher AI score compared to HEC ($p = 0.056$). No difference between ND subjects and HEC participants was found in the NPI score ($p = 0.08$). ND subjects scored lower at MMSE ($p = 0.001$) and a higher at the CDR ($p < .001$) compared to HEC participants.

Usability during X-Torp SM training

Game time and game performance

HEC participants played longer during X-Torp SM training compared to ND subjects ($p = 0.003$), due to the longer time (more than one hour) spent in the total physically active game phases ($p = 0.007$, see Table 3). No difference in the total physically inactive game phases was found ($p = 0.79$).

Table 2
Characteristics and group comparisons between ND and HEC

Participants	AD/Mixed ($n = 4$)	MCI ($n = 6$)	ND ($n = 10$)	HEC ($n = 7$)	Z-adjusted
Age (years) mean (SD)	86 (4)	81 (5)	83 (5)	70 (10)*	2.4
Study level (0–4) mean (SD)	2 (0.8)	2.5 (1.5)	2.3 (1.3)	3.6 (0.5)*	–2.24
BMI mean (SD)	28.1 (4.9)	27.7 (5)	27.8 (4.7)	25.3 (3.7)	1.47
AI (/12) mean (SD)	6 (3.9)	2.3 (3.7)	3.8 (4)	0.6 (1.5)	1.91
NPI (/60) mean (SD)	11.5 (11.7)	10.8 (13.9)	11.1 (12.4)	4.3 (7.8)	1.99
MMSE (/30) mean (SD)	20.5 (3.3)	24.7 (2.7)	23 (3.5)	28.6 (1.5)**	–3.19
CDR sum of box (/18) mean (SD)	5.5 (2.4)	1.4 (1.1)	3.1 (2.7)	0 (0)***	–3.55

Group comparisons were made using Mann–Whitney U test (*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$). ND, neurodegenerative disease; HEC, healthy elderly controls; BMI, body mass index; MMSE, Mini-Mental State Examination; CDR sum of box, Clinical Dementia Rating sum of box; NPI, Neuropsychiatric Inventory; AI, Apathy Inventory; MCI, mild cognitive impairment; AD/Mixed, Alzheimer's Disease or mixed type of AD.

Table 3
Game play time and game performance at X-Torp SM

Participants	ND	HEC	Z-adjusted
Total playtime (hh:mm:ss) mean (SD)	06 : 59 : 54 (01 : 11 : 24)	08 : 08 : 06 (00 : 12 : 36)**	–2.98
Total playtime in aerobic exercise (hh:mm:ss) mean (SD)	02 : 59 : 36 (00 : 48 : 54)	04 : 15 : 11 (00 : 39 : 21)**	–2.69
Total playtime without aerobic exercise (hh:mm:ss) mean (SD)	03 : 56 : 18 (00 : 37 : 54)	03 : 52 : 56 (00 : 33 : 49)	0.26
Finite game (number of times). mean (SD)	2.4 (0.7)	3.8 (0.5)**	–2.94
Performance-1 (experience points/minute) mean (SD)	185.6 (74.4)	298 (29.9)**	–2.93
Performance-2 ($/minute) mean (SD)	84.2 (78.3)	230.9 (44.2)**	–3.03

Group comparisons were made using Mann–Whitney U test (*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$). ND, neurodegenerative disease; HEC, healthy elderly controls.

Concerning game performance, HEC participants completed the X-Torp Scenario more times compared to ND subjects ($p = 0.003$) and gained a higher proportion of experience-point per minute (Performance-1, $p = 0.003$) and money per minute (Performance-2, $p = 0.003$, see Table 3).

The aerobic intensity level reached

A repeated-measures ANOVA on mean%HRr^{peak} with 'Group' as between-subject factor and 'Training phase' revealed a significant main effect of 'Training phase' ($p = 0.005$) and a significant interaction between 'Training phase' and 'Group' ($p = 0.046$, see Table 4). *Post-hoc* tests revealed that mean%HRr^{peak} increased from Weeks 2-3 to Weeks 4-5 only for HEC participants (36.3% of increase, $p = 0.002$). A repeated-measures ANOVA on max%HRr^{peak} revealed only a main effect of 'Training phase', with an increase of 16.3% from Weeks 2-3 to Weeks 4-5 ($p = 0.005$). Interestingly enough, and while interaction effects are not significant, simple effects analysis suggest an increase in max%HRr^{peak} from Weeks 2-3 to Weeks 4-5 only for HEC participants ($F_{(1,6)} = 7.04$, $p = 0.04$).

A repeated-measures ANOVA on the time per training spent in physically active playing showed only main effects of 'Group' ($p = 0.001$) and 'Training phase' ($p = 0.006$). HEC participants spent more time physically active per training compared to ND subjects. However, all participants were physically active 43.4% longer from Weeks 2-3 to Weeks 4-5.

Perceived emotions and usability

The PANAS results suggested that participants reported to have experienced 'moderately' positive emotions, and to have experienced 'few' or 'not at all' negative emotions. A repeated-measures ANOVAs with 'Group' as between-subject factor and 'Training phase' as within-subject factor revealed a significant main effect of 'Group' only for the positive affects scale ($p = 0.01$, see Table 4). HEC participants experienced more positive emotions compared to ND subjects.

The internal consistency (Cronbach α) of the three items assessing perceived competence, difficulty and interest was 0.95, 0.78, and 0.88, respectively, thus suggesting that the three items of each subscale were capturing the same component.

Table 4
ND and HEC results on Aerobic stimulation, PANAS and perceived usability during learning period (Weeks 2-3) and optimization period (Weeks 4-5). Comparisons were made by employing a repeated measures ANOVA, with Group (ND versus HEC) as between-subject factor and Training phase (weeks 2-3 versus weeks 4-5) as within-subject factor

		ANOVA main effects (ND-HEC)		ANOVA main effects (pre-post-training)		ANOVA interaction effects			
						ND		HEC	
		ND	HEC	Weeks 2-3	Weeks 4-5	Weeks 2-3	Weeks 4-5	Weeks 2-3	Weeks 4-5
Aerobic stimulation (/ training)	Mean%HRrp (%), mean (SD)	32 (12)	39 (13)	32 (11)	39 (13)**	31 (11)	33 (12)	33 (9)	45 (16)μ
	Max%HRrp (%), mean (SD)	50 (17)	57 (14)	49 (15)	57 (16)**	48 (17)	53 (18)	51 (12)	63 (17)
	Average time (hh:mm:ss), mean (SD)	00 : 16 : 16 (00 : 03 : 49)	00 : 21 : 30 (00 : 03 : 52)££	00 : 15 : 15 (00 : 03 : 09)	00 : 21 : 52 (00 : 05 : 41)***	00 : 13 : 26 (00 : 02 : 56)	00 : 19 : 07 (00 : 04 : 41)	00 : 17 : 36 (00 : 02 : 43)	00 : 25 : 25 (00 : 05 : 02)
PANAS (sum of items)	Positive Affect (20–100), mean (SD)	52 (15)	74 (14)££	60 (19)	62 (18)	50 (15)	54 (17)	75 (15)	72 (16)
	Negative Affect (20–100), mean (SD)	24 (11)	22 (3)	24 (10)	22 (8)	25 (12)	23 (11)	23 (6)	20 (1)
Perceived usability (sum of items)	Competence (6–42), mean (SD)	25 (9)	33 (6)£	27 (8)	31 (8)**	24 (8)	26 (10)	31 (6)	35 (5)
	Difficulty (6–42), mean (SD)	20 (6)	17 (7)	17 (7)	19 (6)	19 (7)	21 (6)α	17 (7)	16 (6)
	Interest (6–42), mean (SD)	30 (8)	36 (7)	32 (9)	34 (7)	29 (10)	32 (7)μ	36 (7)	35 (8)

£ $p < 0.05$, ££ $p < 0.01$, £££ $p < 0.001$, main effect of Group. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, main effect of Training phase. μ $p < 0.05$, interaction between Group and Training Phase. α $p < 0.1$, main and interaction effects concerning perceived difficulty. PANAS, Positive Affect Negative Affect Scale; Mean%HRr^{peak} and Max%HRr^{peak}, mean and max percentage of heart rate reserve relative to the peak of HR measured during the 6MiWT; ND, neurodegenerative disease; HEC, healthy elderly controls.

Participants reported to be 'moderately' competent, and between 'moderately' and 'very' interested in the game. They reported that the game had a 'moderate' difficultly. A repeated-measures ANOVA with 'Group' as between-subject factor and 'Training phase' as within-subject factor revealed significant mains effects of 'Group' and 'Training phase' only for the perceived competence scale ($p = 0.045$ and $p = 0.002$, respectively, see Table 4). HEC participants perceived higher competence compared to ND subjects. However, perceived competence increased from Weeks 2-3 to Weeks 4-5 for all participants.

Although not statistically significant, ND subjects tented to have a higher perceived difficulty score compared to HEC ($p = 0.105$). A repeated-measures ANOVA revealed a significant interaction between 'Group' and 'Training phase' for the difficulty scale ($p = 0.05$, explained by an increase in perceived difficulty from Weeks 2-3 to Weeks 4-5 only for ND subjects, $p = 0.03$ and by a higher perceived difficulty in Weeks 4-5 compared to HEC participants, $p = 0.02$, see Table 4).

Finally, a repeated-measures ANOVA revealed a significant interaction between 'Group' and 'Training phase' for the perceived interest scale ($p = 0.05$). *Post-hoc* analysis revealed an increase in perceived interest from Weeks 2-3 to Weeks 4-5 only for ND subjects ($p = 0.05$, see Table 4).

X-Torp SM training effects

The repeated-measures ANOVA with 'Group' as between-subject factor and 'Time' as within-subject factor revealed a significant main effect of 'Group' for all the standard physical fitness tests (SPPB, 10MeWT, TUG, 6MiWT) and most of the standard and X-Torp cognitive functions tests (MMSE, FAB, SCB Fluency, TMT A, TMT B, DSST, DMS48, X-Torp TMT A, X-Torp TMT B, X-Torp DSST, and X-Torp DMS48, see Table 5). ND subjects showed lower performance compared to HEC participants in both tests of physical fitness and of cognitive functions.

Also, a main effect of 'Time' was found for the SPPB, TMT B, X-Torp TMT A, X-Torp TMT B, X-Torp DSST, X-Torp DMS48, and X-Torp CT (Time), with higher performance at post-training-tests compared to pre-training-tests of 7.3%, 13.8%, 20.3%, 17.1%, 30.6%, 6.9%, and 24.2%, respectively.

Interestingly enough, and while interaction effects are not significant, simple effects analysis suggest a higher TMT A performance for HEC participants ($F_{(1,6)} = 40.79$, $p < 0.001$) and a higher TMT B performance only for HEC participants ($F_{(1,6)} = 8.3$, $p = 0.03$) at post-training-tests compared to pre-training-tests.

The interaction between 'Time' and 'Group' was significant only for the 6MiWT ($p = 0.04$) and the X-Torp DMS48 ($p = 0.03$, see Table 5). *Post-hoc* analysis revealed that this interaction was due to an effect of 'Time' only for the ND subjects (performance at post-training-tests compared to pre-training-tests of 23.2% for the 6MiWT, $p = 0.02$ and 15.3% for the X-Torp DMS48, $p = 0.003$). However, performance of ND subjects in the post-training-tests was still lower compared to that of HEC participants (6MiWT, $p = 0.009$; X-Torp DMS48, $p = 0.02$).

The repeated-measures ANOVA revealed no significant effects for the SCB Memory, X-Torp CT (score) and X-Torp GNGRTT (score and reaction time).

DISCUSSION

The present study tested the usability and effects of X-Torp, a Serious exerGame (SeG) targeting cognitive functions and physical activity, in ND subjects (MCI and AD) compared to HEC participants.

Results on game time and game performance show that ND subjects played less time. HEC participants were able to adhere to the training program in terms of training attendance, duration, and goals. A similar adhesion level was found by Maillot et al. [13] with 97.5% training attendance rate. ND subjects were generally tired after 30-40 minutes of training, and needed to stop earlier or to take breaks. In addition, 3 ND subjects missed one training session. This result suggests that the maximal duration of the SeG training sessions must be shorter in people with mild to moderate cognitive impairment. ND subjects gained fewer experience points/minute and money/minute compared to HEC participants. As hypothesized (H1), ND subjects progressed on the SM at a slower pace than HEC participants. These results are not surprising but raise a question: what cognitive factors can explain game performance differences between ND subjects and HEC participants? X-Torp combines action games, mini-games, and exergaming in order to stimulate several cognitive functions, especially executive functions, memory, and attention [12–15, 20–28]. It is thus difficult to explore the relationship between performance at the X-Torp SM and cognitive impairments.

Table 5
ND and HEC results on physical and cognitive performance before (Pre-training) and after (Post-training) the training program. Comparisons were made by employing a repeated measure ANOVA, with Group (ND versus HEC) as between-subject factor and 'Time' (pre-training versus post-training) as within-subject factor

		ANOVA main effects (ND-HEC)		ANOVA main effects (pre-post-training)		ANOVA interaction effects			
						ND		HEC	
		ND	HEC	Weeks 2-3	Weeks 4-5	Weeks 2-3	Weeks 4-5	Weeks 2-3	Weeks 4-5
Physical Assessments	SPPB (/12) mean (SD)	7.9 (1.7)	10.9 (0.9)£££	8.9 (2.1)	9.6 (2)*	7.6 (1.7)	8.2 (1.6)	10.6 (1)	11.3 (0.8)
	10MeWT (s) mean (SD)	9.9 (1.7)	7.1 (1.4)££	8.9 (2.4)	8.4 (1.8)	10.3 (2)	9.5 (1.3)	7.2 (1.6)	6.9 (1.3)
	TUG (s) mean (SD)	13.9 (2.8)	9 (2)££	12 (3.5)	11.2 (3.5)	14.5 (2.2)	13.2 (3.3)	9.1 (2.1)	8.9 (2.1)
	6MiWT (m) mean (SD)	178.5 (66.8)	318.7 (79.6)££	235.1 (108.3)	252.8 (96.2)	157.5 (51.2)	194.1 (76.8)µ	323.7 (84.2)	313.7 (81)
	X-Torp 6MiWT (m) mean (SD)	191.9 (61.1)	319.3 (68.1)	255.6 (90.7)		191.9 (61.1)		319.3 (68.1)	
Standard Cognitive Assessments	MMSE (/30) mean (SD)	23.5 (3)	28.7 (1.4)£££	25.4 (4.1)	25.8 (3.2)	23 (3.5)	23.9 (2.5)	28.9 (1.5)	28.6 (1.5)
	FAB (/18) mean (SD)	14.7 (2.3)	17.1 (1)£	15.4 (2.5)	15.9 (2)	14.1 (2.4)	15.3 (2.2)	17.3 (0.8)	16.9 (1.2)
	SCB Fluency (items) mean (SD)	11.6 (3)	21.3 (5.1)£££	15.6 (6.2)	15.5 (6.5)	11.2 (2.7)	11.9 (3.4)	22 (3.2)	20.6 (6.7)
	SCB Memory (/10) mean (SD)	8.8 (1.5)	9.9 (0.5)	9.4 (1.1)	9.1 (1.4)	9 (1.3)	8.6 (1.6)	10 (0)	9.7 (0.8)
	TMT A (s) mean (SD)	64.9 (22.5)	33.4 (9.1)££	55.2 (23.3)	48.6 (24.9)	68.3 (21.2)	61.5 (24.4)	36.4 (8.3)	30.3 (9.5)
	TMT B (s) mean (SD)	213.6 (83.8)	85.9 (33.1)££	172.9 (94.1)	149.1 (92.1)*	223.2 (90.3)	204 (80.4)	101 (33.3)	70.7 (27.1)
	DSST (items) mean (SD)	37.5 (17)	61.3 (10.6)££	46.2 (17.7)	48.4 (20.2)	35.6 (14.1)	39.4 (20)	61.3 (9.3)	61.3 (12.5)
	DMS48 (/48) mean (SD)	38.7 (6.4)	47.4 (1.1)££	42.7 (6.9)	41.8 (6.4)	39.2 (7.1)	38.1 (6)	47.7 (0.5)	47 (1.4)
X-Torp Cognitive Assessments	X-Torp TMT A (s) mean (SD)	76.6 (32.2)	45.9 (11.1)££	70.3 (31.4)	56 (26)*	84.8 (34.4)	68.8 (27.7)	51.6 (13)	40.1 (4.6)
	X-Torp TMT B (s) mean (SD)	167.4 (62.6)	63.1 (23.4)£££	133.2 (72)	110.4 (72)**	181.8 (55.8)	153.1 (69)	70.7 (26.7)	55.4 (18.4)
	X-Torp DSST (items) mean (SD)	15.5 (8)	35.6 (9.3)£££	20.6 (12.4)	26.9 (13.4)***	12.9 (7)	18.1 (8.4)	31.7 (9.6)	39.6 (7.8)
	X-Torp DMS48 (/48) mean (SD)	37.4 (6.6)	46.5 (1.7)££	40.4 (7.8)	43.2 (4.9)*	34.7 (7.5)	40 (4.9)µ	46 (1.5)	46.4 (1.9)
	X-Torp CT (/30) mean (SD)	29.3 (0.6)	29.9 (0.4)	29.4 (0.9)	29.7 (1)	29.1 (1.1)	29.4 (1.4)	29.7 (0.5)	30 (0)
	X-Torp CT (s) mean (SD)	117.3 (40.2)	82.1 (37)	114.8 (49.5)	87 (28.5)**	131.3 (47.2)	103.4 (28.5)	96 (48.4)	65.3 (13.5)
	X-Torp GNGRTT (/40) mean (SD)	38.1 (2.4)	38 (2.6)	37.6 (3)	38.5 (1.6)	37.5 (2.8)	38.7 (1.8)	37.7 (3.4)	38.3 (1.6)
	X-Torp GNGRTT (ms) mean (SD)	759.2 (252.3)	708.7 (109.3)	745.3 (107.1)	722.6 (88.5)	765 (87.3)	753.3 (77.7)	725.5 (129)	691.8 (94.5)

£ $p < 0.05$, ££ $p < 0.01$, £££ $p < 0.001$, main effect of Group. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, main effect of Training phase. µ $p < 0.05$, interaction between Group and Training Phase. SPPB, Short Physical Performance Battery; 10MeWT, 10 Meters Walking Test; TUG, Time Up and Go; 6MiWT, 6 Minutes Walking Test; MMSE, Mini-Mental State Examination; FAB, Frontal Assessment Battery; SCB Fluency, Short Cognitive Battery semantic verbal Fluency; SCB memory, Short Cognitive Battery memory; TMT A, Trail Making Test A; TMT B, Trail Making Test B; DSST, Digit Symbol Substitution Test; DMS 48, Delayed Matching to Sample 48 explicit working memory; CT, Cancellation Test; GNGRTT, Go-NoGo Reaction Time Test; ND, neurodegenerative disease; HEC, healthy elderly controls.

Results of the aerobic intensity level reached show that HEC participants followed better the training program goals compared to ND subjects. Accordingly, the mean%HRr^{peak} increased from the first two weeks to the last two weeks only for HC participants (45% of the HRr^{peak} during weeks 4-5). Maillot and colleagues [13] reached an aerobic intensity level at 41.5% of the HR reserve (relative to the equation which estimate maximal HR) for the exergames 'Wii Sports' and 'Mario & Sonic at the Olympic Games'. Taylor et al. [29] also reached, in similar exergames, an aerobic intensity level at 3 MET (Metabolic Equivalent of Task) only for boxing games and 1.5 to 2.5 MET for other games (tennis, golf, tai chi). In the present study, mean%HRr^{peak} method was used to account for probable maximal cardiorespiratory fitness decline in people with early dementia [54, 55] and could overestimate the aerobic intensity level in HEC participants. Hence, it is difficult to conclude that X-Torp, which is played primarily with stationary movements of the lower limbs, physically stimulate more than other exergames. Results show that the max%HRr^{peak} increased from the first two weeks to the last two weeks reaching in the HEC participants 60% of the HRr^{peak}. Physically active phases (navigation and battles) lasted from two to five minutes and were alternated to physically inactive phases (missions). The max%HRr^{peak} values suggest that X-Torp SM training may be even more physically intense in HEC participants if the physically active phases were lasting longer or permanently. Taken together, the results of the HRr^{peak} suggest that X-Torp SM training seems to induce a LIAA in ND subjects (<40% of the HR reserve) [58] and a MIAA in the HEC participants (40% to 59% of the HR reserve) [58]. The stimulation induced in ND subjects may not sufficient to induce an improvement bioenergetics functions, mainly aerobic metabolism functioning, maximal cardiorespiratory fitness (VO_2max), and thus to favor cognitive improvements, neuroplasticity, or to slow down neuropathological processes involved to ND through physical training [8]. Indeed, evidence collected so far suggests that bioenergetics functions, mainly aerobic metabolism functioning and aerobic fitness, are associated with cognitive functioning [59, 60], and could play a major in the early development of neuropathology [8, 61, 62]. In elderly healthy subjects or elderly subjects with MCI or AD, aerobic exercise training becomes efficient if the aerobic intensity level exceeds 50% of the HR reserve [7, 8, 63–66]. The poor increase of aerobic stimulation in ND subjects between the first two weeks to the last two weeks could be explained by their inability to run in place, contrary to HEC participants. However, no study on aerobic stimulation during walk versus run in place, and on gait apraxia during these movements exists to confirm this hypothesis. Hence, these results suggest that X-Torp and the exergames using these control modes are not an appropriate strategy to induce MIAA and HIAA in subjects with dementia, thus rejecting hypothesis H2. In order to induce MIAA and HIAA in subjects with dementia, X-Torp should be interfaced with a treadmill (as done for the X-Torp 6MiWT) or an exercise bike. For instance, in cybercycle study [12], elderly participants have been trained at 60% of the HR reserve.

Participants reported to have experienced positive emotions and almost no negative emotion during the training (PANAS), similarly to previous findings on SG in subjects with MCI and AD [33]. HEC participants reported higher positive emotions (from 'moderately' to 'high') compared to ND subjects (from 'few' to 'moderately'). These results suggest that X-Torp represented an emotionally positive experience, not stressful, thus confirming hypothesis H3. The Cognitive-Enrichment hypothesis [4] advanced that experiencing positive emotions is a protective factor against brain dysfunctions. Consistent with this theory, Kühn and colleagues [19] showed a maximal effect of a VG on neuroplasticity in young adults during the first month of training, when positive emotions (e.g., the willingness to keep playing) seemed stronger. They concluded that the playful power of VG could partially trigger neuroplasticity induced by cognitive challenges. In our study, perceived competence was different between ND subjects and HEC participants, who reported respectively 'moderately' and 'high' competence. Perceived competence increased from the first two weeks to the last two weeks of X-Torp SM training in both groups, suggesting that participants developed game experience, confirming hypothesis H4. Counter-intuitively, perceived difficulty tended to be higher in ND subjects compared to HEC participants. They reported that the game was slightly more difficult in the last two training weeks, thus rejecting hypothesis H5. This may be explained by the fact that training sessions became progressively longer and, thus, more tiring. Also, despite a better competence, ND subjects could have developed a better understanding of the game challenges, and thus could evaluate the task difficulty more objectively. Participants reported a 'medium' to 'high' interest for X-Torp. Perceived interest was lower for ND subjects at the beginning of the training program compared to HEC participants, but increased at the end of training program, which confirming hypothesis H6. This increase may be explained by their better understanding on game, together with an increase in perceived competence and difficulty, which made the game more motivating. Moreover, many ND subjects (and their caregivers) expressed the desire to continue the training after the end of the trial. Interest did not increase for HEC participants, most probably due to the fact that the SM was too short for them and became repetitive. Taken together with game performance, these results also suggest that X-Torp should propose a longer SM in order to play more than 1 month, especially for healthy participants.

Finally, another explanation concerning usability differences between ND subjects and HEC participants, is that HEC participants were younger and more educated than ND subjects, and thus were more likely to have gained experience with computerized technologies (e.g., possible higher socioeconomic status and younger age at the beginning of the VG commercialization). Future studies should employ a better-matched control sample, to disentangle the effects of these variables.

Results of the pre- and post-training-tests show a significant post-training improvement in the SPPB. This small improvement may be explained by the fact that X-Torp control modes required participants to stand up, walk and run in place, and squat down, similarly to SPPB components. Consistent with previous findings [13], this study also showed an improvement in the post-training 6MiWT (+36.6 meters), but only for ND subjects. However, the X-Torp 6MiWT performance (at T1) seems similar to the post-training 6MiWT. During X-Torp 6MiWT, ND subjects did not seem to use the virtual avatar to increase their motivation. Hence, the observed improvement may not be ascribed to the training. Taken together, it is difficult to conclude that ND subjects were physically better after the training with X-Torp, which can be explained by their incapacity to follow a MIAA with X-Torp control modes, thus rejecting partially hypothesis H7. Results of the pre- and post-training-tests show a significant post-training improvement in the TMT A and TMT B only for HEC participants. In a similar population, Maillot et al. [13] showed a training effect in executive functions using several tests including the TMT but also the DSST. Cybercycle training study [12] showed an increase in executive functions using several tests. The poorer cognitive training effects for HEC participant compared to these exergames studies may be explained by the 1-month training program. However, as showed by Nouchi et al. [26] in 4 weeks of training using the puzzles game 'Brain Age', cognitive improvements in short term training seem possible. Results show also better performance at post-training-tests in all participants in the X-Torp TMT A, X-Torp TMT B, X-Torp DSST and X-Torp CT (time). Taken together with standard cognitive tests results, improvements in the X-Torp TM tests did not translate into improvements in the corresponding standard tests, except for TMT in HEC participants. The differences in X-Torp TM pre-post-training-tests sessions and no differences in standards pre-post-training-tests in ND subjects may be explained by their greater difficulty to transfer their cognitive improvement to task different from those trained (X-Torp TM Tests to standards tests), already affected by aging [4]. More likely, this suggests that the improvement in the X-Torp TM tests may be mainly due to a better control of the Kinect™ control modes. Accordingly, Basak et al. [17] observed an increase of cerebellum volume after VG training in novice elderly players. These authors attributed this result to improvements of visuomotor coordination, induced by a better control of the mouse cursor. X-Torp CT results could reinforce this hypothesis. Failing to find impairments in selective visual attention in the ND subjects is against the expectations [52], and suggests that the X-Torp CT was not well designed. The classical CT requires finding target symbols among distractors. The Kinect™ control modes imposed to position symbols at a certain distance, to avoid interferences in the target selection. This constraint reduced the task difficulty, and thus reduced the recruitment of attentional resources. Hence, X-Torp CT improvements may be due solely to a better control of the Kinect™ control modes, confirming that changes in performance in the X-Torp TM tests should be interpreted with caution. It is noteworthy that training program aimed at testing usability, and was anyway too short and not intense enough to expect large improvements in the targeted cognitive functions.

Finally, the presence of a clinician during the whole training could be a critical factor in determining usability and in facilitating training adherence and training effects, especially for ND subjects. The presence of a clinician enriched the game with a social component, which may further contribute to trigger neuroplasticity [4]. A feasibility study should be conducted in order to evaluate the impact of the clinician on VG usability and performance in elderly subjects, to assess objectively the role played by the game social dimension.

In conclusion, this feasibility study indicates that the SeG X-Torp represents a usable tool, not stressful, proposing a usable EE combining cognitive, physical, and positive emotional stimulation for people with mild and moderate cognitive impairment due to ND and in elderly healthy people. ND subjects progressed on the SM at a slower pace than HEC participants and have less capacity training, suggesting that the maximal duration of the training session for subjects with dementia should be shorter compared to healthy elderly people. Game difficulty seems well calibrated in functions of subject's competence, reminding the importance of designing SG or SeG in function of the cognitive or physical player's characteristics, as suggested by Bastien and Scapin [67] through the 'compatibility' ergonomic criteria. However, the Kinect™ control modes, using stationary movements, do not seem adequate to induce sufficient aerobic stimulation, thus clearly limiting the potential effectiveness of X-Torp. These control modes should be adapted to become more physically stimulating in subjects with dementia. Future efficacy studies should test training effects in a longer training period with a longer X-Torp SM, more participants and a randomized controlled trial design, in order to test the effectiveness of this SeG as EE in populations with dementia.

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SUPPLEMENTARY MATERIAL

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