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Effect of order of difficulty level on body movements and brain activity during balance-based exergaming

- An experimental study with healthy young adults

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Abstract

Background: Exergaming refers to exercise through videogames, and is increasingly used to train both physical and cognitive functions. Increasing the difficulty level of the game is often a natural part of gaming, and changing the difficulty level, either by increasing or decreasing the difficulty, is one of the main advantages of exergaming. However, there is limited research on whether it matters if you increase or decrease the difficulty level with regards to player's body movement and brain activity during game play.

Aim: To examine whether it matters which difficulty level you start with on player's body movements and brain activity during exergaming.

Methods: Twenty-four healthy young adults (12 men, 12 woman, mean age 24.5 ± 4 yrs) played a puzzle game at two difficulty levels, one with one puzzle piece (No Choice), and one choosing between two pieces (Choice). Puzzle pieces were chosen by mediolateral body movements to the appropriate side. Brain activity in all conditions was recorded using a 64-channel EEG system and EOG electrodes (SynAmps, RT; Compumedics Neuroscan, US), and mean spectral power was calculated for theta activity (4-7Hz) in a predefined frontal region of interest (F3,F1,Fz;F2,F4). Ground reaction forces from two Kistler force plates were recorded at 100 Hz, and used to calculate amplitude, area, velocity, and smoothness (calculated as jerk) of the centre of pressure traces (CoP). Statistical analysis consisted of independent samples t-tests and two way repeated measures ANOVAs.

Results: The group with Increasing difficulty level had on average a significantly larger CoP area, compared to the Decreasing Difficulty Group ($p=.020$). The Increasing Difficulty Group also had on average a significantly larger CoP mediolateral amplitude compared to the Decreasing Difficulty Group ($p=.035$). The same results were found on the frontal theta activity, the Increasing Difficulty Group also had on average higher frontal theta activity, compared to the Decreasing Difficulty Group ($p=.016$). There were no significant difference between the two groups on any of the other variables (CoP velocity and CoP jerk $>.05$).

Conclusion: The Increasing Difficulty Group had on average a larger CoP amplitude, CoP area and higher theta activity, compared to the Decreasing Difficulty Group. These results might point in the direction of playing with an increased difficulty level. Future research should investigate a flexible difficulty level and ask about information of previous experience with exergaming and enjoyment of the game.

Key words: Exergame, balance, brain activity, difficulty level.

Abstrakt

Bakgrunn: Exergames er trening gjennom videospill, og er brukt til å trene både fysiske og kognitive funksjoner. Å øke vanskelighetsnivået på spillet er ofte en naturlig del av spillingen, og endre vanskelighetsnivå, enten ved å øke eller senke vanskelighetsnivået, er en av hovedfordelene med exergaming. Det er derimot begrenset med forskning på om det har noe å si om man øker eller senker vanskelighetsnivået med tanke på spillerens bevegelse og hjerneaktivitet under spilling.

Hensikt: Undersøke om det har noe å si hvilket vanskelighetsnivå man starter med, og om det påvirker bevegelse og hjerneaktivitet under exergaming.

Metode: 24 unge friske mennesker (12 menn, 12 kvinner, gjennomsnittsalder 24.5 ± 4 år) spilt to vanskelighetsnivå av et pusle- balanse exergame, et med en puslespillbrikke (No Choice), og et der man skulle velge mellom to puslespillbrikker (Choice). Puslespillbrikkene ble valgt ved å bruk av mediolaterale bevegelser mot den passende siden. Hjerneaktivitet i alle kondisjonene ble målt ved bruk av en 64-kanaler EEG system og EOG elektroder (SynAmps, RT; Compumedics Neuroscan US), og gjennomsnittlig spectral power ble kalkulert for theta aktivitet (4-5Hz) i forårsdefinert region av interesse (F3,F1,Fz,F2,F4). Ground reaction force fra to Kistler kraftplater ble målt på 100 Hz, og brukt for å kalkulere amplitude, areal, hastighet og flyt (kalkulert som jerk) av centre of pressure (CoP). Statistiske analyser bestod av independent samples t-tests og two way repeated measures ANOVAs.

Resultater: Gruppen med økende vanskelighetsgrad hadde gjennomsnittlig større CoP areal, sammenlignet med gruppen med synkende vanskelighetsgrad ($p=.020$). Også for CoP mediolateral amplitude hadde den gruppen med økende vanskelighetsgrad i gjennomsnitt større mediolateral bevegelse sammenlignet med den gruppen som hadde synkende vanskelighetsgrad ($p=.035$). Det samme ble funne på frontal theta aktivering, gruppen med økende vanskelighetsgrad hadde gjennomsnittlig høyere frontal theta, sammenlignet med gruppen med synkende vanskelighetsnivå ($p=.016$). Det var ingen signifikant forskjell mellom gruppene på de andre variablene (CoP hastighet og CoP flyt) (alle p 'er $>.05$)

Konklusjon: Gruppen med økende vanskelighetsnivå hadde gjennomsnittlig større CoP amplitude, CoP areal og høyere theta aktivitet, sammenlignet med gruppen med synkende vanskelighetsnivå. Disse resultatene peker i favør av å spille med økende vanskelighetsgrad. Framtidig forskning kan se på et fleksibelt vanskelighetsnivå og spørre om informasjon om tidligere erfaring med exergaming og fornøyelse med spillet.

Stikkord: Exergame, balanse, hjerneaktivitet, vanskelighetsnivå.

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Table of Contents

Abstract	2
Abstrakt	3
Acknowledgements	4
Table of Contents	5
1. Introduction	6
2. Methods	9
2.1 Study Design	9
2.2 Participants	9
2.3 Equipment	10
2.4 Procedure.....	10
2.5 Data analysis	13
3. Results	15
3.1 Background characteristics.....	15
3.2 Game play time	17
3.3 Weight-shifting characteristics.....	18
CoP amplitude	18
CoP Area	19
CoP Velocity	20
CoP jerk.....	21
3.4 Brain activity	22
4. Discussion	23
4.1 Game play time	23
4.2 Weigh-shifting characteristics	24
4.3 Brain activity	25
4.4 Strengths and limitations	26
4.5 Future directions.....	26
5. Conclusion.....	28
6. References	29
Appendix 1	31
Appendix 2	33

1. Introduction

Video games that require physical activity in order to play, so called exergames, have during the last decade gained popularity for exercise and entertainment purposes in all age groups (1). Exergames are exercise through videogames, and can be used to train both physical and cognitive functions (2). For improvement in physical function the exergame needs to be motivating, engaging and easy to play and understand for the target group (3). Most of the games were originally designed for entertainment and enjoyment for a younger audience. However, exergames are increasingly used in training and rehabilitation for both healthy older adults and specific patient-groups (4). Exergames combine the fun of gaming with health and wellness benefits. This makes players able to undertake physical exercise in an enjoyable and interesting environment (5). Today, there are many versions of exergames, for both entertaining and exercise purposes, and it is a fast-developing field. Lately, Silverfit exergames have been more developed for a specific purpose and age group. Silverfit aims to improve elderly care with the use of technology, which may contribute to more fun activity compared to regular exercise and standard rehabilitation (6).

Several studies have researched the area of exergaming and the effect on different physical or cognitive functions. Heiden and Lajoie (7) found that balance training with an exergame appeared to provide an additional benefit to more traditional exercise programs . A review of exercise and rehabilitation delivered through exergames found that exergames is promising as an intervention to improve physical functions. However, due to large differences in both intervention protocols and outcome measures, there need to be further research to successfully establish exergames as an exercise and rehabilitation tool (2).

Adjusting level of difficulty up or down based on performance or day-to-day condition, makes it easier to find the level best suited for the player. Increasing difficulty is a natural part of any game, and changing the difficulty level is one of the main advantages of exergaming. Increasing the difficulty level can increase enjoyment and maintain motivation to exercise (8). If the game is too easy or too difficult, it could reduce the player's motivation. On the other hand, no increase in difficulty level can lead to boredom for the player (8). One study found that people prefer a cognitive challenge when playing exergames, and that the players regarded progression in the game as an important factor for game play (9).

Skjæret-Maroni and colleagues (10) investigated whether game difficulty, for example by adding a cognitive element, affected the movement of the player during game play. They found that by increasing the level of difficulty, the quality of several movement characteristics decreased, such as smaller steps and lower step velocity. However, the participants enjoyed playing the higher difficulty levels more than the easier one. The challenge is therefore to manipulate the difficulty of the game so that it maintains motivation, without disturbing the movements made during playing. There is limited research on using decreasing difficulty levels in gaming and exercise, and which order of difficulty level is best during playing. Qin et al. (8) looked at engagement in sedentary computer games, and how the order of the difficulty level influenced the immersion of the player, which is the enjoyment of the game. They found that to maintain immersion of the game, the difficulty levels have to be increased. When the difficulty increased, the player maintained the feeling of being challenged. Furthermore, if the level of difficulty decreased, after first increasing the difficulty level, the player got a feeling of greater skill and provided the “optimal experience” for the player. They concluded that difficulty level should be flexible, start with increasing difficulty level and then increase up and down regularly (8).

Playing digital games and exergames requires the use of multiple cognitive abilities (11). It has been shown that combining physical activity and cognitive challenging tasks in exergaming can improve cognitive functions like executive functions, attentional processing and visuospatial skills (1). Cognitive changes can be inferred from brain activity as measured by electroencephalography (EEG). EEG is a neurological measurement method that uses an electronic monitoring device to measure and record electrical activity on the surface of the head. EEG is well established for assessing the functional state of the brain (12), and can be used to measure brain activity related to executive functions. Executive functions include planning, decision making and inhibition, and are associated with the functions of the prefrontal cortex (13). Frontal theta activity has been shown to be related to executive functions in both cognitive and motor control tasks, and it has been found that frontal theta activity values increase when the demands of focus and information processing get higher (14).

In their meta-analysis aiming to examine the physical and cognitive impacts of digital games in older adults, Zhang and Kaufman (11) suggested that playing digital games is effective for improving physical balance, balance confidence, functional mobility, executive functions and

processing speed. Another study on African American adolescents showed that the group playing exergames improved in executive functions more than those in the non-play control group. They also found that the group playing competitive exergames scored higher on executive functions compared to the group playing cooperative exergames (15).

Despite the multitude of studies on the effect of exergaming in general, examining the effect of difficulty level on player's body movements and brain activity using EEG measurements during exergaming is still an underexplored area of research. Therefore, the aim of the current study is to investigate whether increasing versus decreasing difficulty level, in an exergame, has a differential effect on players' movement characteristics as measured with force plates and brain activity as measured with EEG. This question will be answered by looking at game play time, weight-shifting characteristics and brain activity. As there is limited information about the feasibility of measuring EEG during game play, the question will be investigated in young, healthy adults. If this is feasible, older adults may be the next population group tested in follow-up research. This study's hypothesis is that an increasing difficulty level has a positive effect on body movements and brain activity compared to a decreasing difficulty level, because of previous research on immersion (8).

2. Methods

2.1 Study Design

The present study was an experimental study aiming to look at body movements and brain activity during balance-based exergaming. The participants played two different difficulty levels of a puzzle game, two blocks with a choice of puzzle pieces and two blocks without a choice of puzzle pieces. Each block consisted of five puzzles with the same motive. The data was collected between 19.09.16 and 28.10.16.

2.2 Participants

Twenty-four healthy young adults participated in this experimental study, 12 men and 12 women. The characteristics of the participants are presented in Table 1. To be included, participants had to be between 20-30 years old, have no known physical or mental disabilities, no injury or surgery in the lower extremity and/or the back the last six months, no known neurological disorders or balance-problems, and no known sleeping disorder. The participants were recruited from the Norwegian University of Science and Technology (NTNU) and Students welfare organization in Trondheim. Before providing written consent, the participants were informed about the study aim and the lab setting, and that they could withdraw from the study at any time. The study was evaluated by the Regional Ethical Committee for Medical and Health Research Ethics, and conducted in accordance with the Declaration of Helsinki.

Table 1. Characteristics of the participants (mean, range, Standard Error)

	Men			Women			All		
<i>N</i>	12			12			24		
	Mean	Range	SE	Mean	Range	SE	Mean	Range	SE
Age (years)	25.5	22-29	(0.6)	23.4	20-26	(0.4)	24.5	20-29	(0.4)
Total weight* (kg)	80.6	65.2-92.6	(2.4)	69.0	51.2-90.6	(3.5)	74.8	51.2-92.6	(2.4)
Body height (cm)	182.2	173.5-198	(1.9)	166.8	155.5-175	(1.7)	174.5	155.5-198	(2.0)

*Total weight: Person + EEG equipment

2.3 Equipment

A 64-channel EEG cap (Quikcap, Compumedics Neuroscan, US) (see Figure 1) sampled the EEG at 1000 HZ. A SynAmps amplifier (SynAmps, RT; Compumedics Neuroscan US) amplified the signal, and was carried in a backpack during the measurements. A Microsoft Kinect v2 camera was used to record point cloud data. The game used during the measurements was the balance-based game “Puzzle” from SilverFit (SilverFit BV, the Netherlands). A motion-sensing technology time-of-flight (ToF) camera was used to control the game. This camera could be adjusted, either up or down, to fit the height of the participants. Two Kistler force plates (40x60cm) (type 9286A, Kistler Group, Switzerland) placed next to each other, approximately 1 centimetre apart, measured ground reaction force for each foot separately. The force plates recorded data at 100 Hz. The force-plates were set up relative to the camera which controlled the game (see Figure 2). The entire data-collection was recorded with a Garmin video camera that was placed behind the participants.

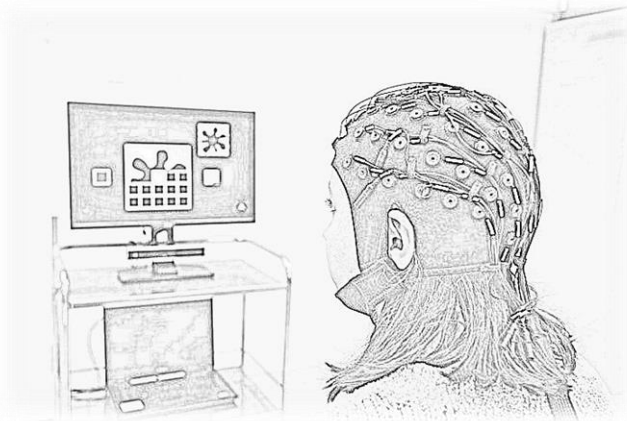


Figure 1. Illustration of the EEG-cap and the game.

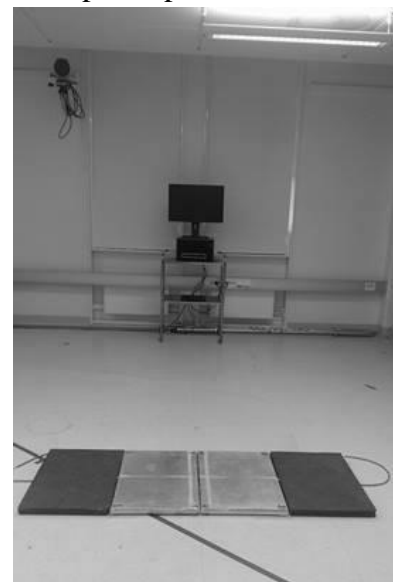


Figure 2. Picture of the lab-setting with the force plates and the screen.

2.4 Procedure

All participants were invited to the lab 2-5 days prior to testing to receive written information and to get familiar with the lab setting. At this session, they answered a questionnaire regarding physical activity (level, duration, type of exercise, see Appendix 2), the Waterloo Footedness Questionnaire (16) and height and head circumference were measured.

On the test-day, the EEG-cap was prepared before the participants entered the lab. The participants were asked to sit in a chair while being fitted with the EEG cap. A 64 channels EEG system was used, plus four electrodes for Electrooculography (EOG) recording. The

electrodes were placed according to the international 10:20 system (17). Eye electrodes were placed over, under and on the lateral side of the left eye, and one on the lateral side of the right eye.

Small sponges were put into each electrode. To ensure good contact between the sponges and the skin surface of the scalp, the sponges were filled with electrolyte-solution. After the cap was placed and the impedance was close to, or under 10 kΩ (see Figure 3), the participants were fitted with a backpack that contained the EEG amplifier and were asked to take place on a chair behind the force plates.

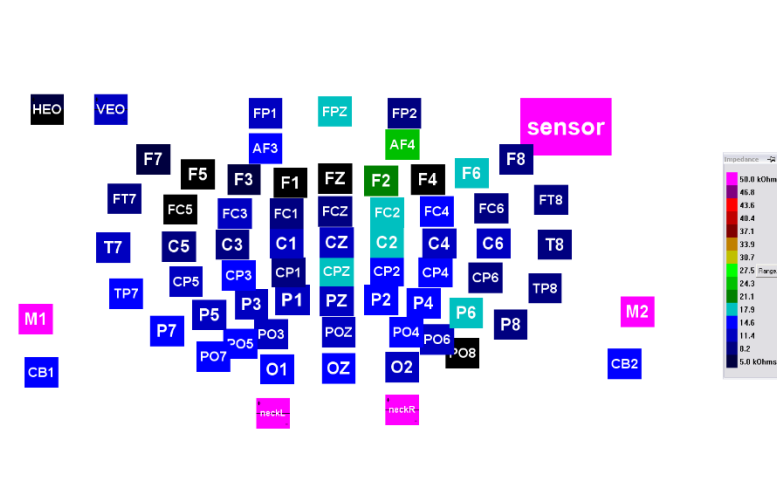


Figure 3. Example of electrode location map with impedance level indicated by colour. Darker colour indicates lower impedance. Meaning better contact between electrode and scalp.

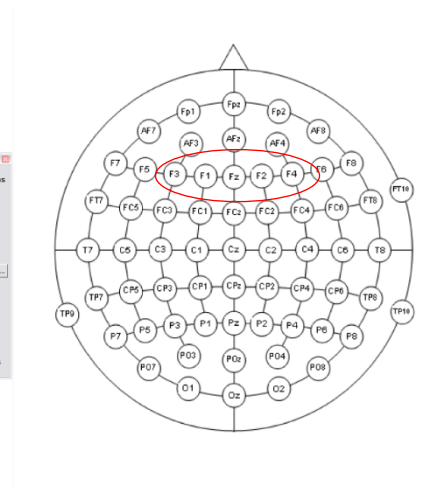


Figure 4. Overview of the electrodes. The red circle shows the five electrodes used to calculate the mean frontal theta activity.

The first condition was a three minutes relaxed seated baseline measurement. The participants were asked to be as relaxed as possible and focus on the black screen in front of them. The second condition was to stand upright on the force plates and sway from left to right in a comfortable, self selected tempo for three minutes. Both feet had to be in contact with the force plates at all times. After this condition, the participants had a two-minute seated break, before the first puzzle game started. (see Figure 6 for graphical overview of the test conditions).

The puzzle games consisted of either a No Choice game with one puzzle piece only, or a Choice game with two puzzle pieces to choose from. The puzzle consisted of five*five pieces with two different motives, one with a peacock and one with a flowerbed (see Figure 5). Half of the participants started with the No Choice condition (the Increasing Difficulty Group), the other half with the Choice condition (the Decreasing Difficulty Group). The two puzzle motives, peacock and flowers were counter balanced across participants.

There were a total of four puzzle conditions, two with choice and two without choice. Between each block of 5 trials in one condition, the participants had a two minutes' break. The puzzle was controlled by medio-lateral weight shifts. As can be seen in Figures 1 and 5, which are examples of a puzzle with Choice, the target picture is shown at the top right. There are two puzzle pieces, one at the right side and one at the left side. The participants were asked to lean to the side where they thought the correct piece was. When playing a No Choice puzzle, there was only one piece appearing on either the right side or the left side, and the participants were asked to lean to that side.



Figure 5. Picture of the game "Puzzle" from Silverfit. This is an example of the flower with Choice puzzle condition.

After the puzzles, the participants were once again asked to sit relaxed on a chair for three minutes, before the testing was finalized with a one minute left-to-right sway. The total weight of the participants with all the equipment still on, was measured before removing the EEG equipment from the participants.

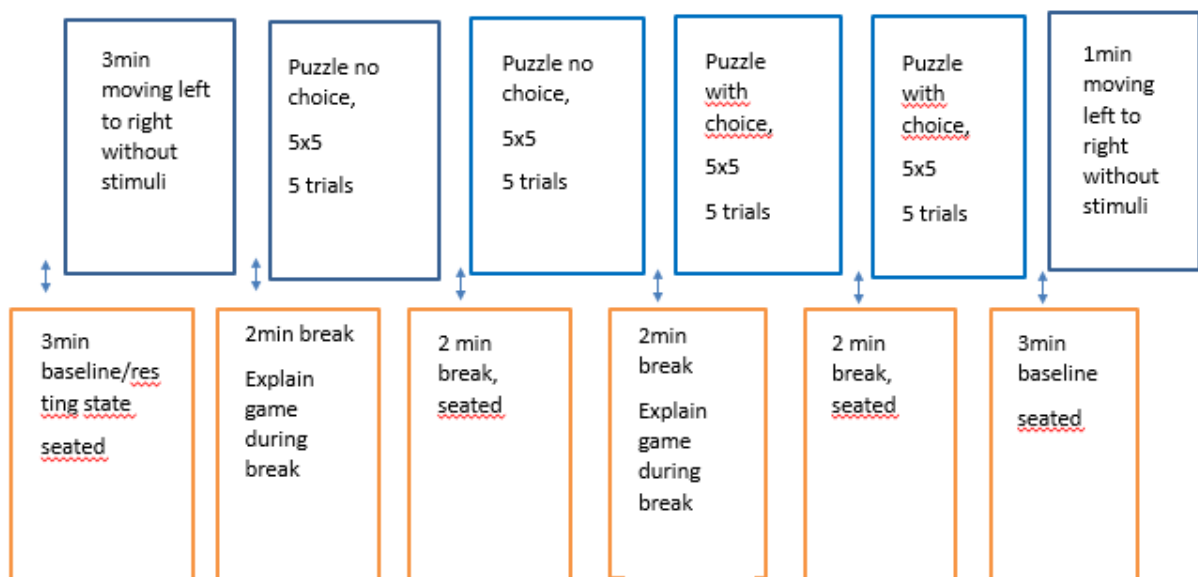


Figure 6. Schematic overview of the Protocol

2.5 Data analysis

For the present study, the game play time, force plate data and the EEG measurements from all puzzle trials were further analysed.

Game play time refers to the the total time it takes to complete one puzzle. The game play time was calculated from video annotations. Start was noted when the puzzle game started, and end was noted when the last puzzle piece started to move towards the puzzle board. The average of the ten puzzles from the No Choice condition and Choice condition, was calculated for each person.

Centre of pressure (CoP) was calculated from the ground reaction forces from both force plates. CoP is the point location of the vertical ground reaction force vector. It represents a weighted average of all the pressures over the surface of the area in contact with the ground (18). The four variables included in this study were calculated from the centre of pressure. The CoP area (cm²) was calculated by fitting an ellipse to the stabilogram that covered 95 %

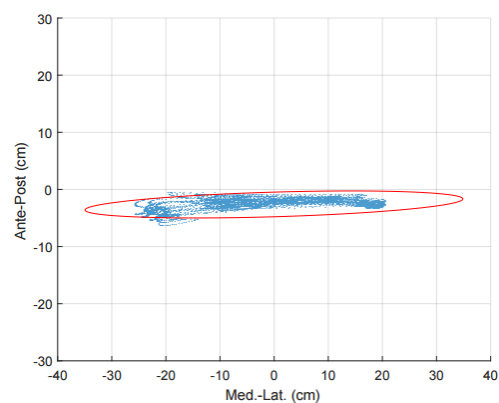


Figure 7. CoP during a puzzle game

of the CoP points (see Figure 7). CoP mediolateral amplitude (cm) was calculated by finding the average of the absolute values of all local maxima and minima per weight shift in mediolateral deviation of the CoP. The average CoP velocity (m/s) between the CoP points was calculated for the mediolateral and anterior posterior movement. CoP jerk (m/s³) was the rate of change of acceleration, the derivative of acceleration with respect to time, the second derivative of velocity, or the third derivative of position, and indicates how smooth the CoP was. The lower the jerk, the smoother the movement.

EEG was recorded with a band-pass filter of 1-100 Hz. It was then pre-processed using EEGLab (19) in Matlab (MathWorks Inc., MA). First, non-stereotyped artefacts were removed from the signal manually after visual inspection. Thereafter an independent component analysis (ICA) removed stereotypical artefacts such as eye-blinks. Power spectral density for theta frequencies (4-7 Hz) in the frontal electrodes (F3, F1, FZ, F2, F4) was analysed and referred to as frontal theta activity (see Figure 6). The mean of theta activity band in these electrodes was used for further analysis. One person was excluded from analysis because of a sleeping disorder, and a second person was excluded after the cleaning of the data due to too much noise on the signal.

The statistical analysis were done in SPSS (IBM SPSS Statistics 24). Descriptive analyses were performed on participants' characteristics of the two groups with either increasing difficulty level or decreasing difficulty level. First, a paired-samples t-test was conducted to check for significant differences between the two different puzzle motives, flowers and peacock. As there were no significant differences between the two different puzzle motives, these data were pooled and all further statistical tests compared the Increasing Difficulty Group with the Decreasing Difficulty Group in the two conditions, No Choice and Choice. Shapiro-Wilk tests were used to check whether the data was normally distributed, in addition to visual inspection of the histograms. The game time measures were not normally distributed. Therefore, non-parametric independent samples t-test (Mann-Whitney U-test) were used to test for differences between the two groups on these variables.

The remaining data were normally distributed, and CoP area, amplitude, velocity, jerk and frontal theta activity were all analysed with a two-way repeated measures ANOVA on Condition (No Choice, Choice) * Group (Increasing Difficulty, Decreasing Difficulty). Due to technical problems with the force plates, two participants had missing force plate measurements, and were therefore not included in these statistical analyses. Analysis were done both on all 10 trials and on trials 3-10 to check whether the same results were found after removing the acute learning effect in the first two trials.

Significance level was set at $p < .05$.

3. Results

The results are presented in four parts. First, background characteristics of the participants are described for the two groups that are to be compared in this study, named Increasing Difficulty Group (who started with No Choice) and Decreasing Difficulty Group (who started with Choice). Second, game play time is compared between the two groups. Then, CoP amplitude, CoP area, CoP velocity and CoP jerk are compared between Increasing and Decreasing Difficulty Group. Lastly, the EEG signal from frontal midline electrodes in the bandwidth from 4-7 Hz (theta activity) are compared between the same two groups.

3.1 Background characteristics

Background characteristics of the participants in the two groups, Increasing and Decreasing Difficulty Group are presented in Table 2. An independent t-test indicated that there were no significant differences between the two groups on any of these variables.

Table 2. Background characteristics (mean, range and standard error) of the two groups.

	Increasing Difficulty Group			Decreasing Difficulty Group		
	Mean	Range	SE	Mean	Range	SE
<i>N</i>	12 (6 M, 6 F)			12 (6 M, 6 F)		
Age (years)	24.17	20-29	.66	24.8	22-29	0.59
Total weight (kg)	74.97	52.2-92.6	3.12	74.6	51.2-92.4	3.82
Body height (cm)	176.6	160-198	2.9	172.48	155.5-188	2.85
Frequency*	5.00	3-7	.369	4.75	3-7	.411
Strenuous**	3.17	3-4	.112	2.83	2-4	.167
Duration***	2.83	2-4	.207	2.58	1-4	.229

***Frequency:** How often are you physically active per week?

(1= Less than once a week. 2= 1-2 times a week. 3= 2-3 times a week. 4= 3-4 times a week. 5 = 4-5 times a week. 6= 5-6 times a week 7= 6 or more)

****Strenuous:** How strenuous is the activity?

(1= Not strenuous. 2= Somewhat strenuous. 3= Quite strenuous. 4= Very strenuous)

*****Duration:** How long lasts the activity in mean?

(1= 0-30 min. 2= 31-60 min. 3= 61-90 min. 4= 91-180 min. 5= 181 min +)

Figure 8 shows an overview over current and former balance training of the participants. This data was collected in one of the questionnaires answered at the info session prior to the testing. This was the following open question: “Do you exercise or did you exercise in a sport or a hobby that requires balance?”

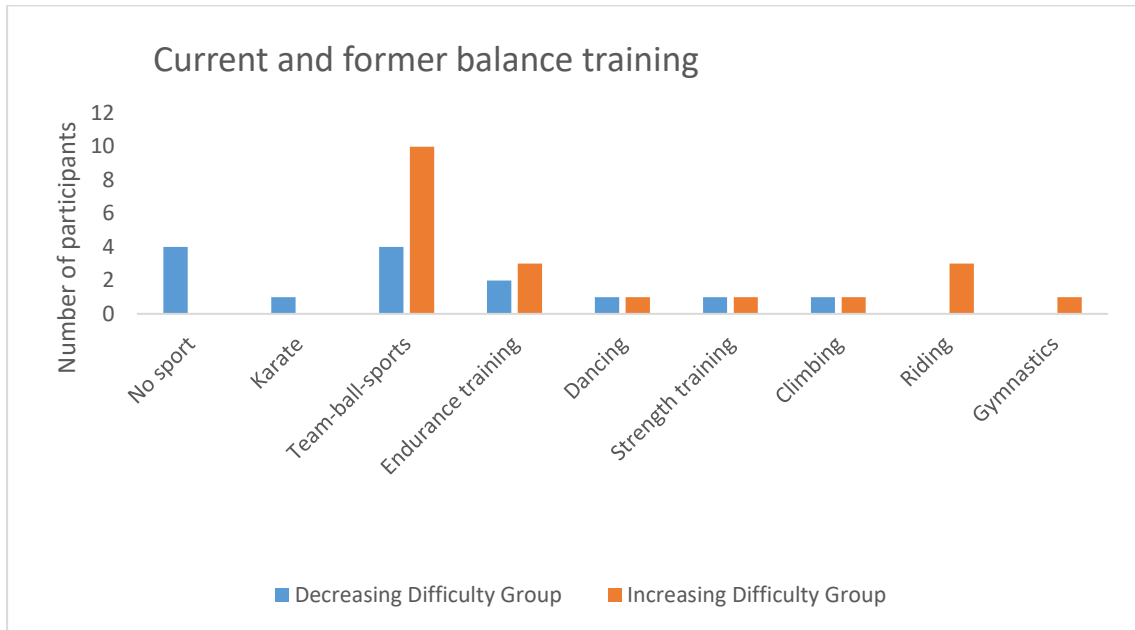


Figure 8. Current and former balance training for the Increasing and the Decreasing Difficulty Group.

The Increasing Difficulty Group had more varied current and former balance training, compared to the Decreasing Difficulty Group. Four participants in the Decreasing Difficulty Group indicated that they had no current or former balance training information.

3.2 Game play time

Game play time refers to the total time it takes to complete one puzzle. For each trial, the mean of the 5 puzzles was calculated per subject. Figure 9a shows the mean game play time across the ten puzzle trials for the Choice puzzle condition, for the two groups Increasing and Decreasing Difficulty Group, while and Figure 9b shows the mean game play time for the No Choice puzzle condition in the same two groups. As can be seen in the Figures, the first trial played, either this was No Choice or Choice, had a longer game play time compared to all other trials. There was also a difference in mean time spent playing the puzzle game between the two groups.

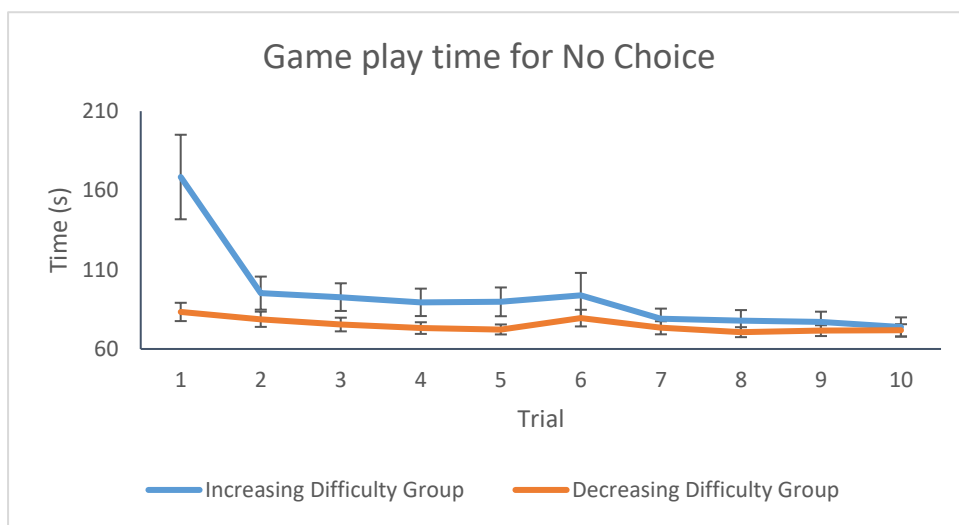


Figure 9 a) Mean game play time (s) with Standard Error bars on the No Choice condition, for Increasing Difficulty Group and Decreasing Difficulty Group across ten trials.

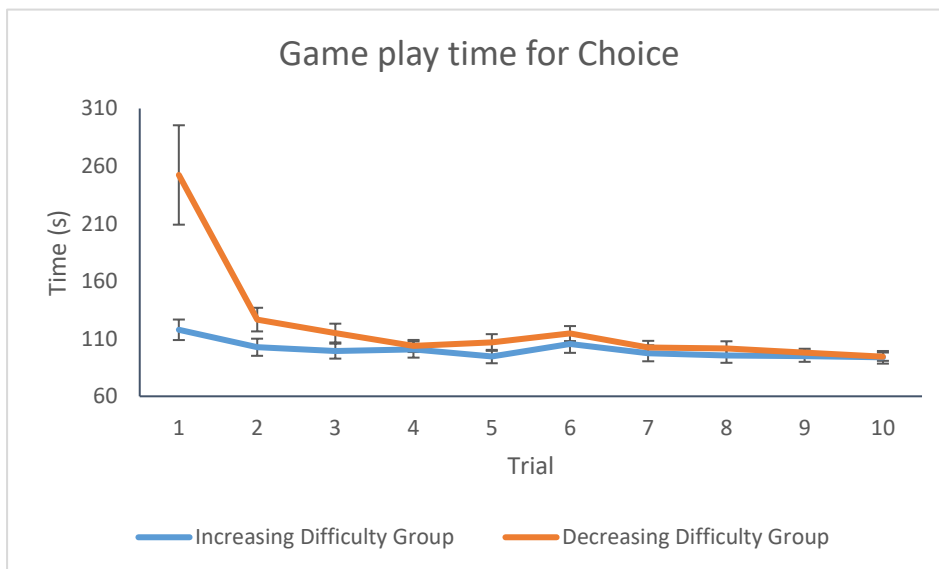


Figure 9 b) Mean game play time (s) with Standard Error bars on the Choice condition, for Increasing Difficulty Group and Decreasing Difficulty Group across ten trials.

Non-parametric independent samples t-test (Mann-Whitney U-test) indicated that on the Choice puzzle condition, the Increasing Difficulty Group used significantly shorter time compared to the Decreasing Difficulty Group ($Z = 101$ $p=.031$), while the group that had Increasing Difficulty used significantly more time on the No Choice puzzle condition compared to the Decreasing Difficulty Group ($Z = 33$ $p=.042$). In other words, both groups played the second puzzle level the fastest. When looking at trial 3-10 only, there were no longer significant differences between the two groups in game play time. (No Choice $Z = 47$, $p = .242$; Choice $Z = 89$, $p=.157$), indicating that the two first trials were responsible for the overall difference in the game play time.

3.3 Weight-shifting characteristics

Four different variables from the force plate are analysed in this study to describe the movement of the participants. All the variables are calculated from the CoP points, namely the amplitude, the area, the velocity, and the jerk.

CoP amplitude

CoP amplitude is the mean of the maximum absolute mediolateral movement for each weight shift. Figure 10 shows the CoP amplitude for the No Choice and Choice puzzle condition, for both groups, Increasing and Decreasing Difficulty Groups. On both the No Choice and the Choice condition, the Increasing Difficulty Group had larger mediolateral movement (Mean No Choice=39.34 cm and Mean Choice=42.48 cm, respectively) compared to the Decreasing Difficulty Group (Mean No Choice=37.32 cm and Mean Choice=42.48 cm, respectively).

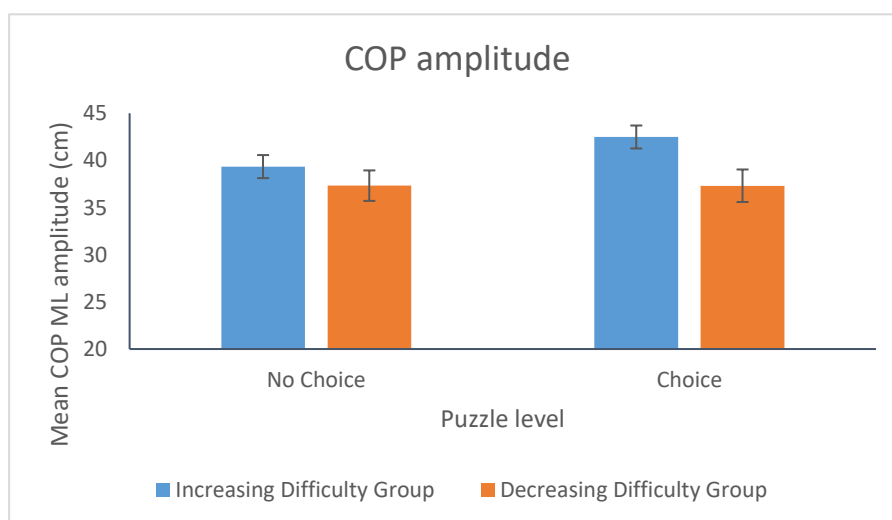


Figure 10. Mean CoP mediolateral amplitude of the No Choice and Choice condition for the Increasing and Decreasing Difficulty Groups. ($\pm SE$)

As can be seen in Figure 10 as well, the difference between the Increasing Difficulty Group and Decreasing Difficulty Group in CoP mediolateral amplitude seems to be larger in the Choice puzzle condition compared to the no Choice puzzle level. A 2-way repeated measures ANOVA on Puzzle condition (2) * Difficulty level (2) on the average mediolateral amplitude showed a significant main effect of difficulty level, $F(1,9)=6.171$, $p=.035$, indicating that the Increasing Difficulty Group on average had a larger amplitude than the Decreasing Difficulty Group (see Figure 10). There was no significant effect of Puzzle condition ($p=.092$), nor a significant interaction between Puzzle condition and Difficulty level ($p=.084$).

Removing the first two trials from the analyses did not change these results.

CoP Area

CoP area is the area that the CoP points cover during exergaming. Figure 11 shows the area for the Choice and No Choice puzzle condition for both groups. For both puzzle levels, the Increasing Difficulty Group had a larger area (Mean No Choice= 300.81 cm^2 and Mean Choice= 246.83 cm^2 , respectively) compared to the Decreasing Difficulty Group (Mean No Choice= 185.16 cm^2 and Mean Choice= 216.32 cm^2 , respectively).

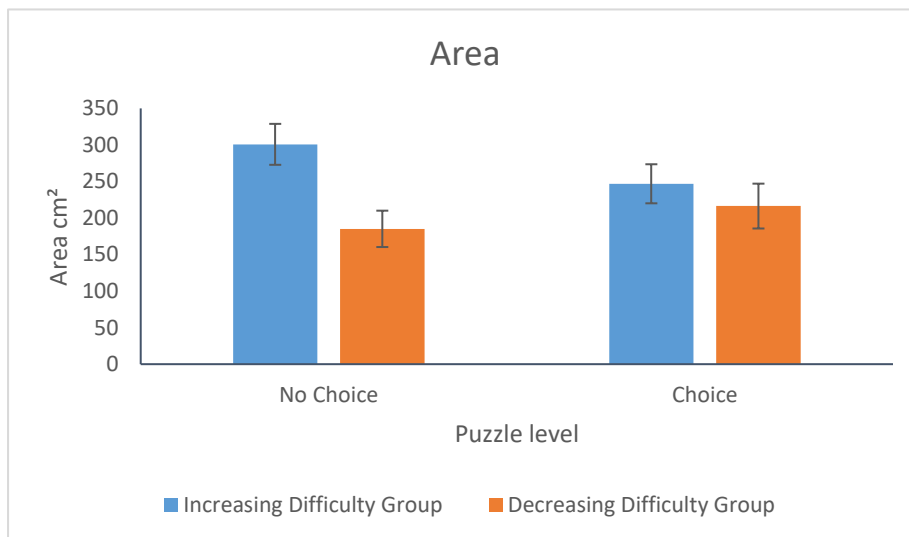


Figure 11. CoP Area of the No Choice and Choice condition for the Increasing and Decreasing Difficulty Groups. ($\pm SE$)

A 2-way repeated measures ANOVA on Puzzle condition (2) * Difficulty level (2) showed a significant main effect of Difficulty level, $F(1,9)=8.033$, $p=.020$, indicating that the Increasing Difficulty Group on average had larger CoP areas than the Decreasing Difficulty

Group. There was no significant main effect of Puzzle condition ($p=.630$), nor a significant interaction between Puzzle condition and Difficulty level ($p=.109$).

When removing the first two trials there were no significant main effects or interaction (all $p's >.05$), indicating that the larger area in the Increasing Difficulty Group was caused by larger area in the first two trials.

CoP Velocity

CoP velocity is the average velocity of the mediolateral movement of the CoP. As shown in figure 12, there is no difference between the two groups on the No Choice puzzle condition (Mean Increasing Difficulty Group=.19 m/s and Mean Decreasing Difficulty Group=.19 m/s). In the Choice puzzle condition, the group with the Increasing Difficulty Group had a larger velocity ($M=.20$ m/s) compared to the group with the Decreasing Difficulty ($M=.16$ m/s). A 2-way repeated measures ANOVA on Puzzle condition (2) * Difficulty level (2) showed no significant main effect of Difficulty level ($p=.503$), nor Puzzle condition ($p=.187$). However, there was a significant interaction between Puzzle condition and Difficulty level, $F(1,9)=18.868$, $p=.002$, indicating that the Decreasing Difficulty Group plays the second puzzle condition faster than the first, whereas the Increasing Difficulty Group maintains the same CoP velocity across both puzzle conditions.

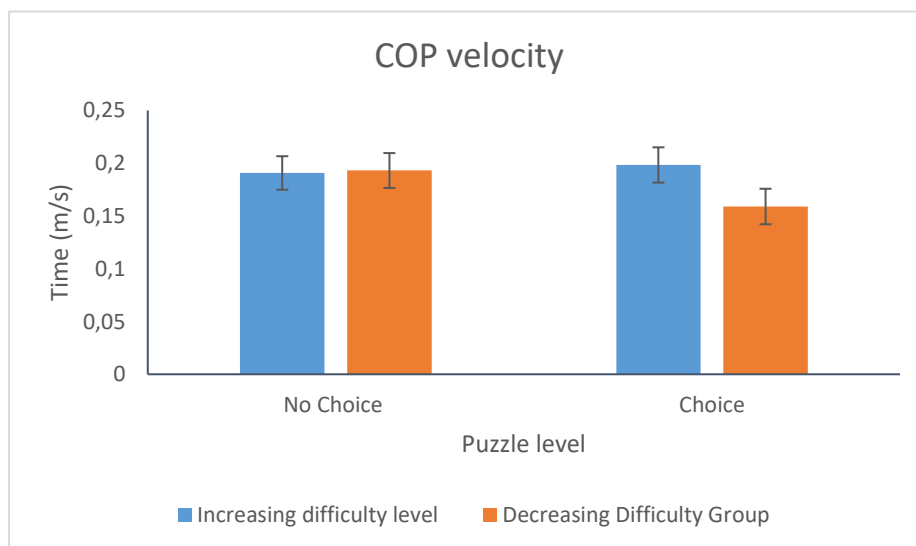


Figure 12. Average CoP Velocity ($\pm SE$) of the No choice and Choice condition for the Increasing and Decreasing Difficulty Groups.

When the same analysis was done without the two first trials, the interaction remained significant, whereas the two main effects remained non significant.

CoP jerk

CoP jerk is the smoothness of the movement, where lower values indicate smoother movements. As can be seen in Figure 13 the smoothness is almost the same for both groups in both puzzle conditions. (Mean No Choice Increasing= $.180 \text{ m/s}^3$ and Mean No Choice Decreasing= $.178 \text{ m/s}^3$ and mean Choice Increasing= $.184 \text{ m/s}^3$ and Mean Choice Decreasing= $.184 \text{ m/s}^3$).

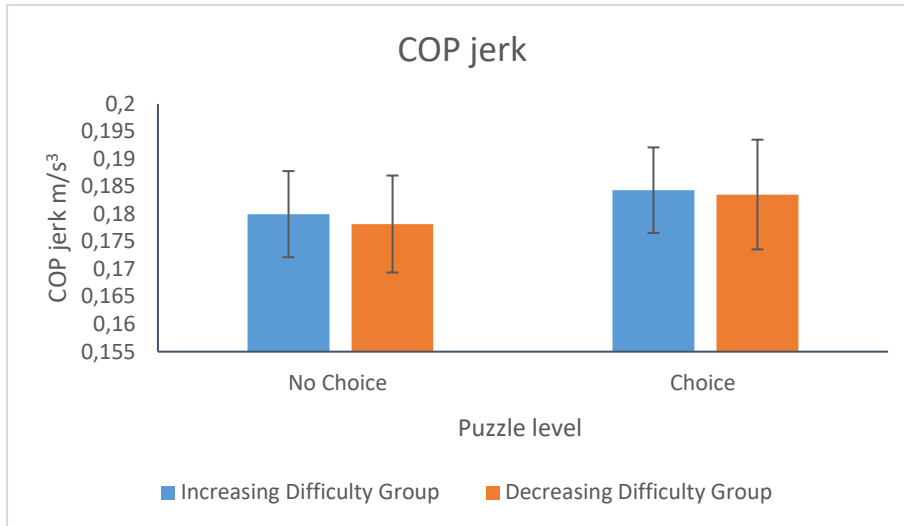


Figure 13. CoP Jerk of the No Choice and Choice condition for Increasing and Decreasing Difficulty Groups. ($\pm SE$)

A 2-way repeated measures ANOVA on Puzzle condition (2) * Difficulty level (2) showed no significant main effect of Puzzle condition ($p=.122$), Difficulty level ($p=.917$), nor a significant interaction between Puzzle condition and Difficulty level ($p=.779$).

Removing the first two trials did not change these results (all p-values $>.14$).

3.4 Brain activity

Mean frontal theta activity is the mean power in the 5-7 Hz frequency band of the five frontal electrodes, F3, F1, FZ, F2 and F4. Table 3 shows the power spectral density of the theta frequencies on No Choice and Choice condition in the two groups.

Table 3. Mean power spectral density ($10 \cdot \log(\mu \cdot V^2)$)

	No Choice		Choice	
	Mean	SE	Mean	SE
Increasing Difficulty Group	42.029	.709	42.670	.671
Decreasing Difficulty Group	40.896	.581	40.339	.564

Frontal mean includes five channels: F3, F1, FZ, F2, F4. SE=Standard Error.

A 2-way repeated measures ANOVA on Puzzle condition (2) * Difficulty level (2) on frontal theta activity showed a significant main effect of Difficulty level, $F(1,9)=8.721$, $p=.016$, confirming that there is a significant difference between the two groups, with the Increasing Difficulty Group on average displaying higher theta activity than the Decreasing Difficulty Group. A significant interaction was found between Puzzle condition and Difficulty level, $F(1,9)=5.859$, $p=.039$, indicating that the Increasing Difficulty Group had slightly more frontal theta activity in the Choice compared to the No Choice condition, whereas the Decreasing Difficulty Group had slightly less frontal theta activity in the Choice compared to No choice condition. There was no significant main effect of Puzzle condition ($p=.833$).

4. Discussion

The aim of this study was to investigate whether increasing versus decreasing difficulty level had a differential effect on players' movement characteristics as measured with force plates and brain activity as measured with EEG. The results showed differences between the Increasing and Decreasing Difficulty Group in some of the variables investigated in this study. The Increasing Difficulty Group had a larger area and a larger mediolateral movement compared to the Decreasing Difficulty Group on the CoP amplitude and the CoP area. The same effect was found in the frontal theta activity, in predefined frontal area of interest (F3,F1,Fz,F2,F4), with the Increasing Difficulty Group showing significantly more frontal theta activity compared to the Decreasing Difficulty Group.

The discussion below consists of five parts. First, there is a part for each game play, brain and movement characteristic, discussed with respect to the aim of this study and relevant literature. The two last parts discuss the strengths and limitations of the study and directions for future research.

4.1 Game play time

The present study found that during an exergaming session, there was a significant difference in both No Choice and Choice puzzle condition between the Increasing and Decreasing Difficulty Group on game play time. The condition the participants played first was played faster than the second condition. When removing the first two trials, this significant difference was gone, indicating that the difference in game play time was caused by the difference during the first two trials. The participants used more time on the first two trials compared to later trials, irrespective of the condition played. One assumption can be that the participants learned the task itself in the early trials, and that the improvements in time reflect this learning process. Game play time decreases with more trials played. Trial 6 (the new puzzle motive) shows a slight increase in game play time again, but as this is not much, it may point to transfer of learning from one puzzle motive to next. This can be supported by Vereijken and colleague's research (20), they found that the steepest learning curves are found early in the learning.

4.2 Weigh-shifting characteristics

In this study, the mediolateral movement was on average larger for the Increasing Difficulty Group compared to the Decreasing Difficulty Group. More movement in the mediolateral direction arguably challenges balance control more compared to a smaller movement, because a larger sway magnitude is related to greater postural unsteadiness (21). The more you lean to either side, the more unstable you get, and this might challenge balance control more than if you do not lean as far as you can.

For CoP area, the Increasing Difficulty Group on average moved over a larger area of the force plate compared to the Decreasing Difficulty Group. The reason for these results may be related to the results from the mediolateral movement. Larger mediolateral movement might give a larger CoP movement area on the force plate. Another reason could be different movement techniques. The participants had a few different methods to solve the weight-shifting movements, and some of these techniques had more movement in both mediolateral and anteroposterior direction. One way of solving the mediolateral movement was by leaning forward with the hands on the knees while doing the weight-shift, this might make a bigger area compared to the participants standing straight up while leaning to the side. One interesting result here, is that the significant difference is gone when the two first trials were removed. This indicates that during the first two trials, many of the participants moved more, especially in the anteroposterior direction, compared to later trials. In contrast, most participants moved over smaller areas during later trials, which caused the difference found between analyses on trials 1-10 versus trials 3-10.

CoP velocity showed that the Decreasing Difficulty Group played the second condition faster than the first. The Increasing Difficulty Group played maintained the same CoP velocity across both puzzle conditions. They learned the movement and the game when playing the Choice condition. When they played the easier one after playing with Choice, the velocity got higher. The Increasing Difficulty Group who started with the No Choice condition played at the same velocity. They started with the easy one and could transfer the same velocity even though the difficulty level got higher.

CoP jerk showed no significant difference between the groups on either No Choice condition or Choice condition. The reason why there might be a difference between the groups on the other two variables on the force plate and the game play time, and not on CoP Jerk, might be that the participants stood relatively still in the middle of the force plate to decide which

puzzle piece they should choose before moving to either side. The game play time and the CoP area are likely more influenced by this than the jerk, which measures characteristics of the mediolateral movements and not the time spent playing the game.

The effect of different exercise background on former and current balance, might be part of the explanation for the differences we found between the two groups in some of the force plate variables. The results on current and former balance training indicated that in the Increasing Difficulty Group, the participants may have participated or currently participate more and/or in a larger variety of sports or exercises that challenged balance than participants in the Decreasing Difficulty Group. In the Decreasing Difficulty Group, four participants did not have any current or former balance training, and the remainder seemed to have less varied experience. This could have contributed to the Increasing Difficulty Group challenging their balance more than the Decreasing Difficulty Group. This can be supported by an intervention study looking at the long-term effects of an exercise programme on balance. The participants underwent an exercise intervention, and the differences between those participants who continued to exercise and those who discontinued were investigated. They found significant improvements from baseline to follow up in balance tests like timed up and go and different sway characteristics. The control group was unchanged in the same tests from baseline to follow up (22). This shows that doing exercise and sport can contribute to better balance, and in this case, might challenge the balance more during the exergame.

4.3 Brain activity

The results from the brain activity analyses show that the Increasing Difficulty Group on average displayed higher theta activity compared to the Decreasing Difficulty Group, which supports our hypothesis. This is in line with Gevins et al (23) who investigated changes in cortical activity during memory tasks in healthy younger adults. They found that theta signals increased with both increasing difficulty and with practice.

In addition, Baumeister and colleagues (24) found that frontal theta activity demonstrated differences due to skill level during a golf putting performance. Their results showed significant better performance in expert golfers, which was associated with higher frontal theta activity. This might also have been the case in the current study, where participants with more experience from previous exergames or balance training may have higher or different EEG results compared to those who never or almost never played an exergame before.

4.4 Strengths and limitations

To the best of our knowledge, this is the first study looking at both movement characteristics and brain activity while playing an exergame, and it shows that it is possible to measure EEG during weight-shifting movements. Another strength of this study was that the sessions were conducted in a laboratory. This made it possible for us to control the environment to a high degree and, together with detailed protocols, decide how to collect the data.

One limitation of this study is that the weight-shift movement might be unnatural or unexpected, especially for people who played exergames before. Some of the participants may have expected more challenge or more movement when they were invited to play an exergame. The weight-shifting movement might be too easy or boring, compared to for example Wii Fit sport where you should use your whole body to make movement on the screen. As can be seen in the background characteristics from the results, the participants who participated in this study were all very active. The results from the questionnaire about physical activity indicate that the participants were active on average at least four to five times a week. The minimum answered on the question on frequency was at least three to four times a week. This is higher than for the general population, which might make it difficult to generalize the results to other groups.

4.5 Future directions

Healthy young adults were included in this study to see if it is possible to measure EEG during a videogame that requires movement to play. The weight-shift movement was chosen because the movement was not so big, and it should influence the EEG signal as little as possible. This study found that, after pre-processing and cleaning the data, the EEG measurement had good enough quality to analyse it. This passive EEG system made it possible to record EEG while playing exergames doing standing weight shifts. It might be possible to go a step further and measure with even more movement and a game more suitable for younger adults. For more advanced games it would be recommended to use an active EEG system. These systems amplify the EEG at the scalp and thereby potentially decrease the influence of ambient electrical noise (25). Another possibility for future research is to measure the same movement, but on healthy older adults. This weight-shift movement might be challenging enough for older adults. During the session, there should be taken more caution compared to the session with healthy young adults. Some support, like a chair or a

person standing behind the participant, might be of good help if they lose their balance and to prevent falls.

This study provided no information on enjoyment or previous experience with exergames. Previous research showed that prior videogame experience was found to significantly influence the learning outcomes. Orvis and colleagues (26) studied twenty-six adults playing a videogame. They investigated whether prior videogame experience influenced learning outcomes, and the results suggested that prior videogame experience has an important influence on performance and motivation of the game. For further research, it would be relevant to have a questionnaire that asks questions about enjoyment and previous experience with exergaming. Especially if the research population is older adults, previous experience may influence the results to a higher degree than with younger adults, as younger adults generally may have more experience with technology compared to older adults.

Also, it would be interesting to investigate the effect of a flexible difficulty level. A previous study on game immersion found that the best way to set up the game difficulty was with first increasing difficulty level and then alternating between decrease and increase (8). This was studied with respect to the players' enjoyment, and the participants had more enjoyment when the game started with an increasing difficulty compared to a decreasing difficulty. When the difficulty decreased after the first increase, this led to a feeling of achievement. One way to examine this could be by first increasing the difficulty level and then have a decrease of the difficulty level. This, together with a questionnaire that say something about the enjoyment of the game, could be a suggestion to further research.

5. Conclusion

This study investigated the effect of order of difficulty level on body movements and brain activity during balance-based exergaming. The Increasing Difficulty Group had on average a larger CoP amplitude, CoP area and higher frontal theta activity, compared to the Decreasing Difficulty Group. These results support the hypothesis and indicates that playing with an increasing difficulty level was favourable with respect to the area, mediolateral movement characteristics and the frontal theta activity. Because of the limitations of the study, more research is needed.

Since this study found that it was feasible to measure EEG while playing a weigh-shifting exergame in healthy, young adults, future research should include older adults to be the next population group testes in follow up-research. For investigating the order of difficulty level, a flexible difficulty level would be interesting to measure, and information of previous experience with exergaming and enjoyment of the game should also be included.

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Appendix 1

Forespørsel om deltagelse i forskningsprosjektet

“Brain activity and body movements during balance-based exergaming”

Bakgrunn og hensikt

Dette er en forespørsel til deg om å delta i en forskningsstudie ved Institutt for Nevromedisin ved NTNU. Hensikten med studien er å kartlegge bevegelsene og hjerneaktiviteten i ulike deler av hjernen under spilling av et balansebasert treningsspill hos unge, friske mennesker.

Hva innebærer studien?

Studien innebærer at du skal stå på en kraftplate og styre et spill ved å bevege deg fra side til side. Mens du spiller spillet vil du ha på deg en EEG-hette som måler hjerneaktiviteten din under forsøket. Denne hetten vil være koblet til en boks via en ledning og skal sitte på hodet under hele forsøket. Boksen vil være i en sekk som festes på ryggen. Klargjøring av hetten gjøres ved å tilføre vann-basert væske til små svamper slik at elektrodene får best mulig kontakt med huden din, her må det påberegnes litt tid. Det vil også bli festet overflateelektroder ved øynene, som skal måle øye-bevegelse. Før spillet starter vil det gjøres en “baseline”-måling hvor din oppgave er å sitte avslappet i en stol i 3 minutter, deretter skal du bevege deg fra side til side i 3 minutter. Etter disse målingene starter spillet og du skal spille et puslespill med fire forskjellige variasjoner. Hver variasjon utføres fem ganger, og du får 2 minutter pause mellom hver variasjon. Testingen vil også bli filmet for å dobbeltsjekke dataene, men kameraet vil bli plassert bak deltageren slik at det ikke er mulig å gjenkjenne personen. Til slutt vil det bli målt totalvekt (med utstyret på).

Mulige fordeler og ulemper

EEG systemet er et passivt system som ikke påfører smerte eller skade. Bevegelsen som styrer spillet kan oppleves som noe slitsom over tid, men er ikke ment å slite ut deg eller oppleves som vanskelig. Risikoen for uønskede hendelser (fall og/eller skader) er veldig lav. Heller ikke elektrodene rundt øynene vil ha noen påvirkning på kroppen, sett bort fra mulig irritasjon i huden som følge av klisteret som brukes for å feste disse på huden.

Hva skjer med informasjonen om deg?

Informasjonen som registreres om deg skal kun brukes slik som beskrevet i hensikten med studien. Alle opplysningene og prøvene vil bli behandlet uten navn og fødselsnummer eller andre direkte gjenkjenningende opplysninger. Det vil ikke være mulig å identifisere deg i resultatene av studien når disse publiseres.

Frivillig deltagelse

Det er frivillig å delta i studien. Du kan velge å avslutte testingen når som helst, uten å oppgi grunn. Du kan også velge å fjernes fra studien dersom du gir beskjed før du forlater testlokalet, dette fordi data ikke blir lagret med navn. Dersom du ønsker å delta undertegner du samtykkeerklæringen på siste side.

Utdypende forklaring av hva studien innebærer

Deltagerne vil være 20 friske personer, 10 kvinner og 10 menn, mellom 20-30 år. Hvis du har hatt skader/operasjon i underekstremitet og/eller rygg de siste 6 måneder, eller nevrologiske lidelser/balanseproblem, kan du dessverre ikke delta. Testingen foregår på St. Olavs Hospital ved Nevro-Øst i Bevegelseslab 2 (2.etg). Testen gjennomføres kun en gang og tar omtrent 2,5 timer fra start til slutt. Vi ønsker også å møte deg som vil delta for å informere og vise deg rundt i labben et par dager før testing. Her vil du bli bedt om å fylle ut to korte spørreskjemaer. Dette tar ikke mer enn 30 min. Det vil også bli målt høyde og hodeomkrets på dette møtet.

Dersom du velger å bli med på studien vil du bli bedt om å ha på/med klær uten refleks som ikke er for løse. For at EEG-målingen skal bli optimal er det viktig at du vasker håret kort tid før målingen, men håret må være tørt og uten produkter. Du bør også møte uthvilt og kan ikke ha inntatt alkohol de foregående 24 timene. Om du har nedsatt syn er det viktig at du har på linser eller briller under forsøket. Forsøket vil bli gjennomført uten sko.

Du vil bli orientert så raskt som mulig dersom ny informasjon blir tilgjengelig som kan påvirke din villighet til å delta i studien.

Økonomi

Studien er finansiert gjennom forskningsmidler fra NTNU.

Du vil ikke få betalt for å delta i studien.

Informasjon om utfallet av studien

Resultater fra studiet vil bli forsøkt publisert. Du kan kontakte prosjektmedarbeidere om du er interessert i å få informasjon om resultat av studien.

Samtykke til deltagelse i studien

Jeg er villig til å delta i studien

(Signert av deltager, dato)

Jeg bekrefter å ha gitt informasjon om studien

(Signert, rolle i studien, dato)

Appendix 2

Spørreskjema

Deltakernummeret: _____

Dato: _____

Kjønn: Mann Kvinne

Alder: _____

Hodeomkrets: _____

Høyde: _____

Fysisk aktivitet

Driver du eller har du drevet med en idrett eller hobby som krever eller trener balanse?

Om ja, hvilken? _____

Hvor ofte er du fysisk aktivt per uke? (kryss av)

- Mindre enn 1 gang i uka
- 1-2 ganger i uka
- 2-3 ganger i uka
- 3-4 ganger i uka
- 4-5 ganger i uka
- 5-6 ganger i uka
- 6 eller flere ganger i uka

Hvor anstrengende er aktiviteten? (Kryss av)

- Veldig lett
- Litt anstrengende
- Ganske anstrengende
- Veldig anstrengende

Hvor lenge varer aktiviteten gjennomsnittlig?

- 0-30 min
- 31-60 min
- 61-90 min

91-180 min

181 min +

Hva trener du? _____

Har du eller har du hatt...

Ja

Nei

Nervesykdommer?

Epilepsi eller lignende?

Søvnforstyrrelse?

Sykdommer som påvirker balansen?

Skader/operasjon i underekstremitet og/eller rygg de siste 6 måneder?