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Faculteit Revalidatiewetenschappen

master in de revalidatiewetenschappen en de kinesitherapie

Masterthesis

The influence of age on the effect of balance task difficulty in children and young adults

Pieter Beyens
Sam Van Hout

Scriptie ingediend tot het behalen van de graad van master in de revalidatiewetenschappen en de kinesitherapie, afstudeerrichting revalidatiewetenschappen en kinesitherapie bij musculoskeletale aandoeningen

PROMOTOR :
Prof. dr. Pieter MEYNS

BEGELEIDER :
Mevrouw Maud VAN DEN BOGAART

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Acknowledgement

It is with great pride, that we present this paper as the second piece of our master thesis and the final milestone of our academic education. Part two of our master thesis, combined with part one, provides a detailed impression of the development of postural control in healthy children.

Both part one and part two of our master thesis were successfully realized thanks to the great help and support from several people, to whom we are grateful.

First and foremost, we are grateful to Prof. Dr. P. Meyns and Dra. M. van den Bogaart, for their endless patience, clear guidance and useful contributions.

Further, we would like to acknowledge all the participants, without whom this study would not have been possible.

Also, we would like to thank our loved ones for their support, not only during the writing of our master thesis but throughout our entire education.

Finally, we would like to thank all the professors, practical assistants and other members of the Faculty of Rehabilitation Sciences and Physiotherapy of Hasselt University for handing over, not only the knowledge but also the passion that is required for our profession.

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List of abbreviations

AP	Anteroposterior
BB	Balance board
BMI	Body mass index
BOS	Base of support
COG	Centre of gravity
COP	Centre of pressure
ML	Mediolateral
RMS	Root mean square
SD	Standard deviation
Sign.	Significant
UNP	Unperturbed
vGRF	Vertical ground reaction force

1. Research context

This cross-sectional cohort study is conducted within the scope of biomechanical research.

The relevance of this study can be attributed to a better understanding of the development of postural control, more specifically postural control on an unstable surface.

Postural control is critical for independence in functional tasks. Therefore, it is evident that a good development of postural control is of uttermost importance. A good understanding of this process is the foundation of identifying any abnormality in the development and is necessary to initiate and/or develop an appropriate intervention.

This study was conducted within the framework of the PhD study of Dra. M. van den Bogaart, named "Biomechanical fundamentals on balance control across the lifespan".

The study design was already established by our mentor before our master thesis was initiated. The recruitment of participants was almost completed by our mentor at the time that our master thesis was initiated, hence, we had little to no role in it.

The data acquisition was predominantly executed by our mentor and supported by all students, including us, by assisting during clinical tests and with the computerized data post-processing.

The analysis and interpretation of the data and, afterwards, the academic writing were independently done by us, under the supervision of our promotor and mentor.

The study was drafted following the central format prescribed by the Faculty of Rehabilitation Sciences and Physiotherapy, Hasselt University.

2. Abstract

Background

Postural control is critical for independence in functional tasks, therefore, a good understanding of its development is important. Children show lower levels of postural control compared to adults. When investigating postural control, it is indicated to involve environmental conditions that presumably cause problems concerning postural control. A balance board challenges the postural control system similar to the natural environment and the difficulty of the balance task can be easily modified by its height. Postural control can be assessed by measuring the centre of pressure (COP) mean velocity.

Objectives

The aim of this study is to evaluate whether a difference between children and young adults exists concerning the effect of the balance task difficulty on the COP mean velocity.

Participants

For this study, sixteen healthy prepubertal children (6-9 years of age) and seventeen healthy young adults (18-24 years of age) were assessed.

Measurements

COP mean velocity was calculated, based on the COP displacement, during stance under different conditions (unperturbed standing and standing on 3 balance boards of different height).

Results

A significant interaction effect between age group and condition on COP mean velocity was found ($p < 0.0001$).

Conclusion

Age influences the effect of the difficulty of a balance task on postural control. Increases in the difficulty of a balance task cause a greater decrease in the postural control of children compared to young adults. This is probably due to age differences in sensory reorganization, whether or not because of incomplete maturation of the sensory systems.

Keywords

Postural control; Balance board; Development; COP; Children; Perturbation

3. Introduction

Postural control is critical for independence in functional tasks. The two major behavioural goals of postural control are postural orientation and postural stability (F. Horak & Macpherson, 1996). Postural orientation involves the orientation of body segments relative to each other and the environment. Postural stability is the ability to control the centre of mass (COM) with respect to the base of support (BOS) (F. Horak & Macpherson, 1996; A. Shumway-Cook, & Woollacott, M. H., 2017).

This can be visualized by the position of the centre of gravity (COG), defined as the vertical projection of the COM. (Murray, Seireg, & Scholz, 1967). When maintaining postural stability, it is necessary to keep the COG in a relatively stable position within the BOS.

These outcomes (COM & COG) are not the equivalent of the centre of pressure (COP), which is the location of the vertical ground reaction force (vGRF) vector. The location of the vGRF can be determined by calculating the weighted average of the location of all downward forces on the floor, which are subject to the position and motor control of the feet and ankles. This results in the COP moving around a relatively steady COG, as a neuromuscular response to perturbations and body sway, in order to control the COM with respect to the BOS (Winter, 2009).

Since the COP location contributes to the control of the COM with respect to the BOS, it falls within the domain of postural control, more specifically postural stability. Therefore, COP outcomes are often used to quantify postural control (Beyens & Van Hout, 2020), from which the mean velocity has been found to be the most reliable conventional COP outcome measure (R. J. Doyle, E. T. Hsiao-Wecksler, B. G. Ragan, & K. S. Rosengren, 2007; Hébert-Losier & Murray, 2020; Le Clair & Riach, 1996).

Maintaining postural control requires a complex interaction of the neural, musculoskeletal and cognitive system to obtain an appropriate sensorimotor integration (F. Horak & Macpherson, 1996; A. Shumway-Cook, & Woollacott, M. H., 2017).

Postural control relies on sensory input from multiple systems, including the somatosensory (cutaneous and proprioceptive), vestibular and visual system. These systems are interpreted in an integrated manner, in order to generate a correct representation of the body orientation and the environment (F. Horak & Macpherson, 1996; Woollacott & Shumway-Cook, 1990).

In everyday life, individuals need to maintain postural control in a dynamic environment. Therefore, postural control involves a dynamic interaction among different context- and task-specific sensorimotor strategies (F. Horak & Macpherson, 1996).

Hence, when investigating postural control, it is interesting to involve different environmental conditions, in particular those that presumably cause problems concerning postural control (Chagdes, Rietdyk, Jeffrey, Howard, & Raman, 2013).

Balance tasks can vary greatly in difficulty. They can become more difficult by constraining or altering sensory input (e.g., eyes closed or a moving room), narrowing down the BOS (e.g., unipodal stance), changing the features of the support surface (e.g., unstable support surface), or a combination of these factors (Gebel, Lehmann, & Granacher, 2020).

A popular method to challenge the postural control system is the use of a balance board, an unstable standing surface on a sphere or half-cylinder with its COM above the axis of rotation, which creates an inherently unstable situation (Chagdes et al., 2013). A balance board challenges the postural control system in a similar way as the dynamic natural environment does. The two underlying mechanisms mainly responsible for it are 1) an external perturbation and 2) a mismatch of the ankle position and the general body inclination, which makes the somatosensory input unreliable (Chagdes et al., 2013; Chumacero, Yang, & Chagdes, 2018; Gebel et al., 2020).

The difficulty of a balance board can be increased by two main factors. First, a smaller radius of the sphere or half-cylinder reduces the BOS. Second, a heightened support surface results in a higher position of the COM of the balance board, which will create a more unstable situation (Hibbeler & Yap, 2012; Physio Supplies, 2017).

It is well known that children show lower levels of postural control when comparing various COP outcomes during different balance tasks (e.g. mean velocity, mean amplitude & area) (Cuisinier, Olivier, Vaugoyeau, Nougier, & Assaiante, 2011; Gouleme, Ezane, Wiener-Vacher, & Bucci, 2014). During the development, these outcomes improve, which can be attributed to changes in body morphology and refinement of motor coordination, sensory organization and sensorimotor integration (Rival, Ceyte, & Olivier, 2005; A. Shumway-Cook, & Woollacott, M. H., 2017; Verbecque et al., 2016).

Furthermore, children show lower levels of postural control during stance on an unstable surface, compared to young adults, based on various COP outcomes (R. J. Cherng, Lee, & Su, 2003; Ionescu, Morlet, Froehlich, & Ferber-Viart, 2006). Uwents, Daenen, Van Waelvelde, and Meyns (2019) confirmed these findings when comparing stance on a balance board with unperturbed standing. However, the influence of age on the effect of the height of a balance board, and therefore the difficulty of the balance task, has not yet been defined.

The aim of this study is to evaluate whether a difference between children and young adults exists concerning the effect of the balance task difficulty on the COP mean velocity.

4. Methods

This study is conducted within the framework of the PhD study of Dra. M. van den Bogaart, named "Biomechanical fundamentals of balance control across the lifespan". The next three sections (4.1 Subjects; 4.2 Materials; 4.3 Procedures) were based on the primary study and modified within the scope of this study. The last two sections (4.4 Data analysis; 4.5 Statistical analysis) were appended to the primary study and apply specifically to this study.

The protocol was approved by the ethics committee of Hasselt University in 2018 (CME2018/064).

4.1 Subjects

To understand the difference in postural control between children and young adults, two age groups were compared to each other: prepubertal children (6-9 years of age) and young adults (18-24 years of age). Participants were recruited by contacting the social networks of the researchers by handing out flyers. These flyers were also distributed in the region of Hasselt (Limburg (Belgium)) and Limburg (the Netherlands). Furthermore, schools and youth movements were contacted for the recruitment of children.

Exclusion criteria were: 1) inability to speak and understand Dutch; 2) inability to maintain independent unsupported stance for 60 seconds; 3) current diagnosis of neurological or sensory disorders; 4) recurrent dizziness; 5) obesity; 6) history of orthopaedic disorders; 7) surgical operation of the lower extremity during last two years; 8) use of drugs affecting the central nervous system or known to affect postural control. Eligibility was checked using a questionnaire prior to participation (Appendix 1).

Each adult participant or minor's parent gave written informed consent prior to the testing.

4.2 Materials

The balance board consisted of a wooden board, acting as a standing surface, mounted on a half-cylinder, which creates a unidimensional instability in the sagittal plane (figure 1). Three balance boards, with varying heights of the standing surface above the point of contact (BB1 = 15 cm; BB2 = 17 cm; BB3 = 19 cm), were included to manipulate the difficulty of the balance tasks (Hibbeler & Yap, 2012; Physio Supplies, 2017). The other properties remained constant over the different balance boards. These included a radius of the half-cylinder of 24 cm and an area of the standing surface of 48 cm by 48 cm.

A force plate was used (AMTI BP600900-2K-CTT), with an F_X and F_Z sensitivity of 0.38 ɥV/[V*lb] (Advanced Mechanical Technology Inc. (n.d.)). If the trial required the use of a balance board, this was placed on top of the force plate.

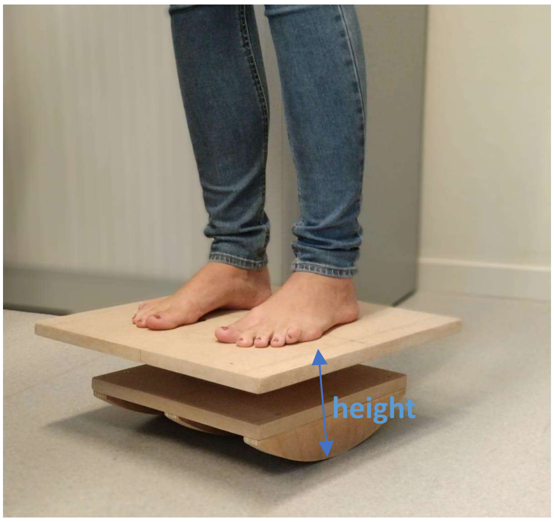


Figure 1. Uniaxial balance board, creating instability in the sagittal plane

4.3 Procedures

A measurement of one participant consisted of four trials, including unperturbed standing and perturbed standing on the three different balance boards in a randomized order. Each measurement was repeated three times. In between these measurements, the participants were instructed to sit for two minutes. In total, twelve trials were performed by each participant.

Participants were instructed to stand barefoot, with both feet parallel and hip-width apart, and with their arms along their body. Also, they were told to look at a marked spot on the wall right in front of them, which was located at eye level.

The duration of a trial was sixteen seconds, starting from the moment the above-described position was achieved by the participant.

To limit the influence of learning effects, participants were allowed only one practice trial, standing on BB1 for sixteen seconds, and were not allowed to stand on the balance boards in between trials.

Safety was ensured by a researcher who helped with stepping on and off the balance board and provided support during the measurements if necessary to avoid a fall.

Height and weight were measured before testing, using a standardized measuring tape and scale.

4.4 Data analysis

COP data were obtained in the sagittal plane since more sway occurs in the anteroposterior (AP) direction compared to the mediolateral (ML) direction (A. Shumway-Cook, & Woollacott, M. H., 2017). The sampling frequency of the COP data was 100 Hz. COP displacement in the AP direction was registered and filtered by a Butterworth 2nd order high-pass filter with a cut-off of 10Hz. Afterwards, the COP velocity was determined by calculating the derivate of the COP displacement by time. While the COP moves in a sinusoidal manner around a relatively stable point of balance (= 0 cm of displacement), the COP mean velocity would be 0 m/s, considering the velocity in the anterior direction to be positive and the velocity in the posterior direction to be negative. Therefore, the COP mean velocity was calculated using the root mean square (RMS) of the COP velocity (figure 2). Finally, the results of the three trials of each condition were averaged for each participant. These results were normalized by height, in order to correct for a possible covariance effect.

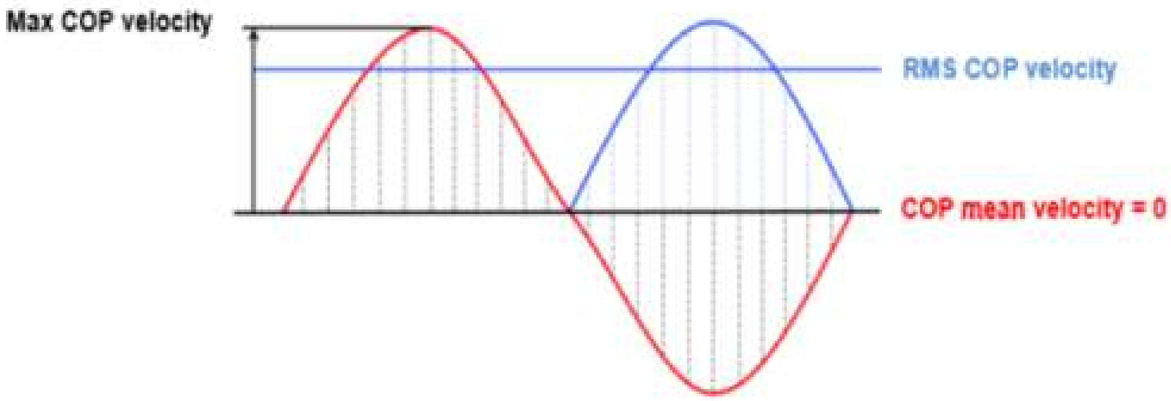


Figure 2. RMS of COP mean velocity
Averaging a sinusoidal function results in zero, therefore, the root mean square values were used. Independent variable = time & dependent variable = COP velocity; RMS: root mean square; COP: center of pressure

A trial was registered as a fall if a stepping response or an intervention by a researcher was required in order to maintain stance. In such a case, the trial was stopped and the data were excluded from the analysis. Afterwards, the COP mean velocity was calculated based on the results of the remaining trials.

4.5 Statistical analysis

The statistical analysis was performed using JMP® Pro 15.2.0 software (SAS Institute Inc., 2019). A mixed ANOVA was used to analyze the main effect of age group, the main effect of condition and the interaction effect between age group and condition. Age group was used as between-group factor and condition as within-group factor. Age group and condition were defined as fixed effects, while participant was defined as random effect.

Prior to the analysis, violations of the assumptions of normal distribution and homoscedasticity were found, according to respectively the Shapiro-Wilk test and the Brown-Forsythe test (appendix 2). Other options were explored and transformations of data were considered. However, because of the implications of a transformation on the interpretation of results and the robustness of an ANOVA, the non-transformed data were used to run the statistical analysis (Field & Wilcox, 2017).

Afterwards, a post-hoc test would be performed to examine pairwise differences, if a significant effect would be found. Again, the assumptions of normal distribution and homoscedasticity were violated (appendix 2). Lane (n.d.) stated the TukeyHSD test to be robust against non-normal distributions. Therefore, the TukeyHSD test should be performed. Sample sizes were unequal, however, SAS JMP® automatically adjusts the TukeyHSD to a Tukey-Kramer test when analyzing unequal sample sizes (SAS Institute Inc., 2021– 2022. JMP®).

A significance level of $p < 0.05$ was set a priori.

5. Results

All the output of the statistical analysis can be found in appendix 3.

5.1 Participants

In this study, sixteen children and seventeen young adults were included. Significant differences in anthropometric properties were inevitable, hence the normalization of COP mean velocity by height. Participant's characteristics are described in table 1.

Table 1. Participant characteristics

Participant's Characteristics	Children	Young Adults
Participants	16	17
Gender (male)	10	7
Age ± SD (years)*	8,18 ± 1,16	21,91 ± 1,65
Height ± SD (cm)*	132,03 ± 8,96	174,03 ± 10,23
Weight ± SD (kg)*	27,40 ± 5,09	71,72 ± 13,84
BMI ± SD*	15,59 ± 1,52	23,55 ± 3,13

Significant differences between age groups are indicated by an asterisk (*$p < 0.05$);
SD: standard deviation; BMI: body mass index

5.2 COP outcomes

Analysis of the COP mean velocity showed a significant main effect for age group ($P < 0.0001$), a significant main effect for condition ($P < 0.0001$) and a significant interaction effect between age group and condition ($P < 0.0001$) (figure 3). The post-hoc test (tables 2-4) revealed a significantly lower COP mean velocity for the UNP condition compared to the BB1, BB2 and BB3 conditions in both the children and young adults group ($p < 0.0001$). A significantly lower COP mean velocity was also found for the BB1 condition compared to the BB3 ($p < 0.0001$) condition, only in the children group. Further, a significantly lower COP mean velocity was found for the young adults group compared to the children group in the BB1 ($p = 0.0012$), BB2 ($p < 0.0001$) and BB3 ($p < 0.0001$) conditions, but not in the UNP ($p = 0.3678$) condition.

Table 2. TukeyHSD within children group

Condition	- Condition	Difference	Std Error	t Ratio	Prob>|t|	Lower 95%	Upper 95%
UNP	BB1	0.000158	0.0000188	8.39	<.0001*	0.0001	0.000217
UNP	BB2	0.000206	0.0000188	10.93	<.0001*	0.000148	0.000265
UNP	BB3	0.000253	0.0000188	13.43	<.0001*	0.000195	0.000312
BB1	BB2	-0.000048	0.0000188	-2.54	0.1902	-0.000106	0.00001
BB1	BB3	-0.000095	0.0000188	-5.04	<.0001*	-0.000153	-0.000037
BB2	BB3	-0.000047	0.0000188	-2.49	0.2108	-0.000105	0.000011

Pairwise comparisons of COP mean velocity values between conditions within the children group. Significant differences are indicated by an asterisk (*p < 0.05). UNP: condition without a balance board; BB1: condition with the balance board of 15 cm; BB2: condition with the balance board of 17 cm; BB3: condition with the balance board of 19 cm.

Table 3. TukeyHSD within young adults group

Condition	- Condition	Difference	Std Error	t Ratio	Prob>|t|	Lower 95%	Upper 95%
UNP	BB1	0.000098	0.0000183	5.36	<.0001*	0.000041	0.000155
UNP	BB2	0.000108	0.0000183	5.89	<.0001*	0.000051	0.000164
UNP	BB3	0.000117	0.0000183	6.41	<.0001*	0.000061	0.000174
BB1	BB2	-0.00000969	0.0000183	-0.53	0.9995	-0.000066	0.000047
BB1	BB3	-0.000019	0.0000183	-1.05	0.9645	-0.000076	0.000037
BB2	BB3	-0.00000958	0.0000183	-0.52	0.9995	-0.000066	0.000047

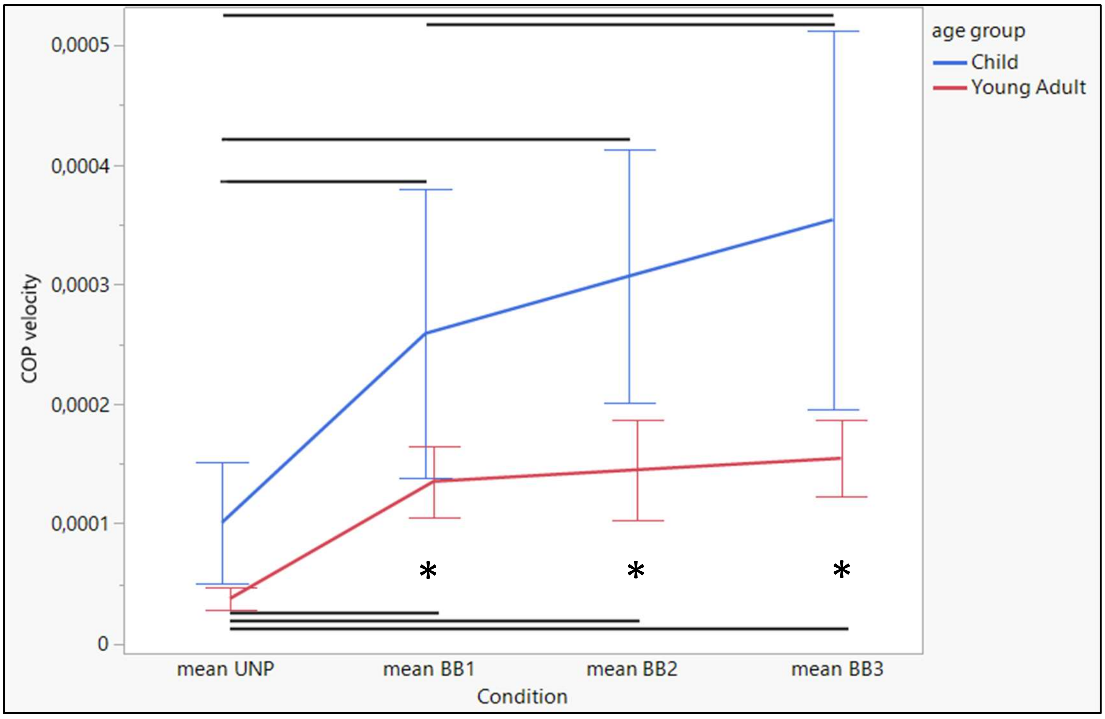
Pairwise comparisons of COP mean velocity values between conditions within the young adults group. Significant differences are indicated by an asterisk (*p < 0.05). UNP: condition without a balance board; BB1: condition with the balance board of 15 cm; BB2: condition with the balance board of 17 cm; BB3: condition with the balance board of 19 cm.

Table 4. TukeyHSD within conditions

Condition	Age group	- Age group	Difference	Std Error	t Ratio	Prob>|t|	Lower 95%	Upper 95%
UNP	Children	Adults	0.000063	0.000029	2.19	0.3678	-0.000026	0.000153
BB1	Children	Adults	0.000124	0.000029	4.27	0.0012*	0.000034	0.000213
BB2	Children	Adults	0.000162	0.000029	5.59	<.0001*	0.000072	0.000252
BB3	Children	Adults	0.000199	0.000029	6.88	<.0001*	0.000109	0.000289

Pairwise comparisons of COP mean velocity values between age groups within conditions. Significant differences are indicated by an asterisk (*p < 0.05). UNP: condition without a balance board; BB1: condition with the balance board of 15 cm; BB2: condition with the balance board of 17 cm; BB3: condition with the balance board of 19 cm.

Figure 3. Interaction plot



Significant effects between conditions within an age group are indicated by a black bar. Significant effects between age groups within a condition are indicated by an asterisk (* $p < 0.05$). UNP: condition without a balance board; BB1: condition with the balance board of 15 cm; BB2: condition with the balance board of 17 cm; BB3: condition with the balance board of 19 cm.

5.3 <u>Fall registrations</u>

During the measurements, five falls were registered, one within the young adults group and four within the children group. Within the children group, two children fell once and one child fell twice.

6. Discussion

Because of the importance of postural control during everyday life, early identification of any abnormalities in its development is of uttermost importance. Therefore, the underlying mechanisms should be well understood.

To the best of our knowledge, no study cross-sectionally investigated the influence of age on the effect of balance boards of varying difficulty on COP outcomes. Therefore, an analysis of the COP mean velocity during different conditions (unperturbed and balance boards of different heights) was conducted in different age groups (children and young adults).

6.1 Interpretation of the results

Since a significant interaction effect between age group and condition was found, the significant main effects are moderately representative for the results at best (Kane, 2012, october 11). Because of the inconsistency of the main effects of condition and age group, no conclusions about the representativeness can be made (University Western Washington, n.d.). Therefore, no further attention was given to the main effects.

The significant interaction effect between age group and condition implied that the effect of the condition on the COP mean velocity depends on the age group. This finding is supported by the current literature, comparing COP outcomes during various sensory perturbations. McKay, Wu, and Angulo-Barroso (2014) found a significant interaction effect between age and sensory condition for COP mean velocity and maximal COP shift during Achilles tendon vibration. Also, R.-J. Cherng, Chen, and Su (2001) found a significant interaction effect between age and sensory condition for COP area during stance on a compliant surface. However, Cuisinier et al. (2011) did not find such interaction effect between age and sensory condition for COP area during Achilles tendon vibration. This discrepancy could be attributed to the semi-tandem position that was used in the study of Cuisinier et al. (2011).

The nature of the interaction effect was described, based on the mean differences between age groups within conditions (table 4). The effect of the condition on the COP mean velocity is larger in children, compared to young adults, with greater differences between age groups during more difficult conditions.

Interestingly, no significant differences were found between the COP mean velocities of children during unperturbed standing and adults during standing on BB1, BB2 and BB3 (appendix 4). Therefore, it appears that the postural control of children during unperturbed standing is similar to the postural control of adults during perturbed standing.

The findings concerning the nature of the interaction effect are in line with the current literature, however, none of these studies involved a balance task on a balance board. McKay et al. (2014) found an interaction effect between age and sensory condition, with larger increases in COP mean velocity in children compared to young adults when applying Achilles tendon vibration. Peterka and Black (1990) observed more evident increases in peak-to-peak sway in children compared to middle-aged adults when standing on a sway-referenced surface and hereby suggested that children are more sensitive to somatosensory perturbations, hence the possible existence of an interaction effect.

It is known that an increase in balance board height increases the difficulty of the balance task (Hibbeler & Yap, 2012; Physio Supplies, 2017) Also, it is known that children show lower levels of postural control compared to adults (Cuisinier et al., 2011; Gouleme et al., 2014). However, why children show greater decreases in postural control during balance tasks of increasing difficulty has not been explained in the current literature.
These differences in postural control between children and adults have various possible explanations, which could be attributed to the development of children, including differences in strength, attention, neuromuscular control, anthropometric properties and sensory reorganization (Schedler, Kiss, & Muehlbauer, 2019; A. Shumway-Cook, & Woollacott, M. H., 2017).

The influence of strength on postural control has been thoroughly studied by Muehlbauer, Gollhofer, and Granacher (2015). They found small correlations between maximal strength/muscle power/explosive force and reactive postural control, which stands for the recovery of postural control after an external perturbation (Sibley, Inness, Straus, Salbach, & Jaglal, 2013), for both children (respectively $r = 0.16$; $r = 0.16$; $r = 0.19$) and young adults (respectively $r = 0.24$; $r = 0.27$; $r = 0.26$). Furthermore, these correlations were not significantly different between children and young adults. Therefore, it can be concluded that strength probably plays no main role in the interaction effect between age group and condition.

The more limited attention in children (Wickens, 1974), has also been proposed as an influencing factor. The influence of this factor was minimized by the short trial length and frequent rest pauses applied in this study. However, Olivier et al. (2008) could not find any interaction effect between age and attentional conditions on postural control. Moreover, automatic postural control already improves COP outcomes at four years of age, while shifting the attention towards the postural control only limits the performance. This could be explained by the "constrained attention hypothesis" from Wulf, McNevin, and Shea (2001), which stated that a better postural control performance would be present when no attention was shifted towards postural control, because of the unconscious, fast and reflexive control processes. On the other hand, the more slow conscious control processes, which are present when the attention is shifted towards postural control, would limit postural control performance. Therefore, it can be concluded that a possible more limited attention probably plays no main role in the interaction effect between age group and condition.

The incomplete development of neuromuscular control (Kurz, Faude, Roth, Zahner, & Donath, 2018) has also been proposed as an explaining factor. To evaluate this theorem, several aspects of neuromuscular control were discussed.

First, Kurz et al. (2018) found significant differences in ankle co-activation in children (9.7 ± 0.5 years of age) compared to young adults. However, in this study, the postural control system was challenged by a single-leg stance, not by a balance board.

On the contrary, other authors found adultlike values in children of seven to ten years of age for several aspects of neuromuscular control during surface perturbations (rotations and translations). This was found to be true for the rate of motor responses (Forssberg & Nashner, 1982); the variability of postural response patterns (A. Shumway-Cook & Woollacott, 1985; A. Shumway-Cook, & Woollacott, M. H., 2017); and the torque profile, torque magnitude and velocity limits (Roncesvalles, Woollacott, & Jensen, 2001).

Since more than 75% of our population is older than seven years of age, it can be concluded that the influence of neuromuscular control on the interaction effect between age group and condition is probably limited.

Another possible contributing factor to the difference in postural control between children and young adults is the difference in anthropometric properties. Children are, of course, shorter than adults. This difference in height has an impact on the COM height. A higher COM position results in greater COM displacements, and therefore greater COG displacements. This creates a more challenging situation for the postural control system (Ojie, Saatchi, & Saatchi, 2020). This effect was minimized by the normalization by height.

However, children differ proportionally from adults, with a relatively higher position of the COM. The combination of the higher position of the COM and the shorter height results in a faster sway rate in children until the age of seven (Lebiedowska & Syczewska, 2000; A. Shumway-Cook, & Woollacott, M. H., 2017).

Therefore, anthropometric properties could play a role in the difference in postural control, even when normalized by height. However, since more than 75% of our population is older than seven years of age, the influence of anthropometric properties on the interaction effect between age group and condition is probably limited.

Finally, sensory reorganization could also play a role in the difference in postural control between children and young adults. Sensory reorganization during somatosensory perturbations reaches mature values in children between 8 to 15 years of age (Beyens & Van Hout, 2020). This means that, when standing on a balance board, young adults downgrade their reliance on the somatosensory system more compared to children. Therefore, it can be concluded that sensory reorganization explains, at least partly, the difference in postural control between children and young adults. An important sidenote is the uncertainty of whether the difference in sensory reorganization is attributed to the non-mature higher cognitive process of sensory reorganization itself or the non-mature function of the sensory systems.

Moreover, we hypothesized that the difference in sensory reorganization might play a role in the influence of age on the effect of balance board height on the COP mean velocity. During stance on balance boards of increasing height, adults will downgrade the reliance on somatosensory information more compared to children. This could lead to an increasing difference in COP mean velocity between children and young adults during balance tasks of increasing difficulty.

After taking all this information into account, the interaction effect between age group and condition could probably be explained by differences in sensory reorganization. Also, anthropometric properties and neuromuscular control possibly contribute to this interaction.

When interpreting these findings, it is important to realize that these cannot be generalized to children younger than seven years of age, since other factors might play a greater role in that age category.

Further, it is important to differentiate between postural control in the AP and ML direction. According to Hong, James, and Newell (2008), the postural control matures in the AP direction well before it does in the ML direction. The findings of this study only apply to postural control in the AP direction and are therefore not generalizable to the ML direction.

Another important consideration is the broad distribution of COP mean velocity in children. This means that large variability in maturation is present.

6.2 Limitations

As with every study, this study has its limitations, listed below.

1) Falls were excluded and the COP mean velocity was calculated based on the remaining trials. However, since the fall probably occurred in a trial with high COP displacements and therefore high COP velocities, this could cause an overestimation of the performance of the participant. Since more falls occurred in the children group compared to the young adults group (4 VS 1), this could influence the results.

2) A mixed ANOVA was employed, however, the assumptions of normality and homoscedasticity of residuals were violated. As post-hoc test, the TukeyHSD was employed, again the assumptions of normality and homoscedasticity were violated. Both choices have been justified. Nevertheless, this could still have an impact on the reliability and has to be taken into account when interpreting the results.

3) The COP outcome measures have not been thoroughly studied in the current literature and the evidence was conflicting. Based on the limited evidence, the mean velocity has been found to be the most reliable conventional COP outcome measure (R. Doyle, E. Hsiao-Wecksler, B. Ragan, & K. Rosengren, 2007; Hébert-Losier & Murray, 2020; Le Clair & Riach, 1996). However, this was argued by Santos, Delisle, Larivière, Plamondon, and Imbeau (2008), who found the COP area to be the most reliable conventional COP outcome measure. Furthermore, no literature was available about the best COP outcome measure for the differentiation between children and adults regarding postural control.

4) The COP mean velocity was corrected for height differences by a fraction (COP mean velocity (m/s)/height (cm)). The rationale behind this correction was that larger people have larger feet,

hence a larger BOS and larger limits of stability. However, no further evidence for this approach was found. The validity of these adjusted COP mean velocity values is still questionable.

5) Foot placement on the balance board has not been standardized, which could influence the working forces and axes of the ankle.

6) The balance boards were manually replaced and the position on the force plate was visually checked. This could possibly cause the movement to deviate from the sagittal plane.

6.3 <u>Strengths</u>

1) The statistical analysis and the interpretation of the results were performed by two researchers. Whenever there was doubt, a third researcher was consulted.

2) During the statistical analysis, when there was doubt concerning the most appropriate approach, all possibilities were performed. Afterwards, the best option was discussed.

3) After the analysis, the findings were extensively compared to the current literature.

4) To the best of our knowledge, the effect of balance board height on postural control in children and adults has not been studied yet. This study could have an important contribution to the decision-making process of therapists when considering the difficulty of a balance task.

5) Since this study was conducted within the framework of the PhD study of Dra. M. van den Bogaart, named "Biomechanical fundamentals of balance control across the lifespan", the a priori calculation of required sample size for an adequate power (= 0.80) was already conducted, based on the COM acceleration. A post-hoc test to compute the achieved power was conducted afterwards, using G*Power (Faul, Erdfelder, Buchner, & Lang, 2009). Given the employed sample sizes, a power of 1.00 was achieved (appendix 5).

6.4 <u>Recommendations for future research</u>

After conducting this study, some gaps in the current literature became clear.

First, more research should be conducted concerning the reliability, validity and responsiveness of COP outcome measures for postural control, especially to compare children and young adults.

Furthermore, it would be interesting for future studies to include other age groups, so the evolution of the interaction between age and difficulty of balance tasks could be described more precisely.

Finally, future studies could also consider the ML postural control, because of the difference in the maturation of postural control in the AP and ML directions.

6.5 Implications for clinical practice

Clinicians should be aware of the fact that when they increase the difficulty of a balance task, this has a greater impact on the postural control of children compared to young adults. They should consider this when choosing an appropriate balance task in rehabilitation.

7. Conclusion

In conclusion, it can be stated that a difference between children and young adults exists concerning the effect of the balance board height on the COP mean velocity. Hence, age influences the effect of the difficulty of a balance task on postural control in children and young adults.

More specifically, an increase in the difficulty of a balance task causes a greater decrease in the postural control of children compared to young adults. This is probably due to age differences in sensory reorganization.

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Appendices

Appendix 1. Questionnaire screening (Dutch)

Beste deelnemer,

Hieronder vindt u een korte vragenlijst om enkele gegevens van u vast te leggen. Deze gegevens zullen enkel in het kader van het onderzoek gebruikt worden. U wordt verwacht het bolletje in te kleuren dat een passend antwoord geeft op de vraag. Bij vragen, kan u deze altijd stellen aan de onderzoeker via mail (maud.vandenbogaart@uhasselt.be) of telefonisch (+32(0)11 26 93 28).

Deelnemer nummer: ………………………………………………..

Geslacht

- o Man
- o Vrouw

Geboortedatum: ………. / ………. / ……….

Nationaliteit: ………………………………………………..

Moedertaal: ………………………………………………..

Neemt u deel aan of heeft u deelgenomen aan sportactiviteiten?

- o Nee
- o Ja → welke?
  - ……………………………………………
    - Aantal uren per week? …………..
    - Aantal jaren van deelname? …………..
    - Aantal jaren gestopt? …………..
  - ……………………………………………
    - Aantal uren per week? …………..
    - Aantal jaren van deelname? …………..
    - Aantal jaren gestopt? …………..
  - ……………………………………………
    - Aantal uren per week? …………..
    - Aantal jaren van deelname? …………..
    - Aantal jaren gestopt? …………..

Neemt u frequent medicatie?

- o Nee
- o Ja → welke?
  - ……………………………………………
  - ……………………………………………
  - ……………………………………………

Ervaart u soms problemen met uw…

- evenwicht
- zicht
- gehoor
- gevoel
- geen van bovenstaande

Ervaart u soms symptomen van…

- duizeligheid
- licht gevoel in het hoofd
- geen van bovenstaande

Heeft u afgelopen 2 jaar een operatie ondergaan aan uw benen?

- Nee
- Ja → welke?
    - ………………………………………………
    - ………………………………………………
    - ………………………………………………

Kruis aan indien een van onderstaande beperkingen/aandoeningen voor u van toepassing zijn:

- Orthopedische aandoening vb. artrose, prothese, overbelastingsletsel…
    - Welke? ………………………………………
- Neurologische aandoening vb. ziekte van Duchenne, MS, ALS, beroerte, epilepsie…
    - Welke? ………………………………………
- Cognitieve beperking vb. leerstoornis…
    - Welke? ………………………………………
- Ontwikkelingsstoornissen vb. autisme, ADHD…
    - Welke? ………………………………………
- Geen van bovenstaande

Andere opmerkingen voor onderzoekers:

……
……
……

Alvast bedankt voor het invullen van deze vragenlijst. Gelieve uw handtekening en de datum van vandaag onderaan deze pagina te plaatsen. Vervolgens mag u deze vragenlijst terugsturen aan de onderzoeker.

Ik bevestig dat hogergenoemde antwoorden correct en volledig zijn.
Handtekening deelnemer (en/of voogd) en datum ………. / ………. / ……….

Overige Metingen

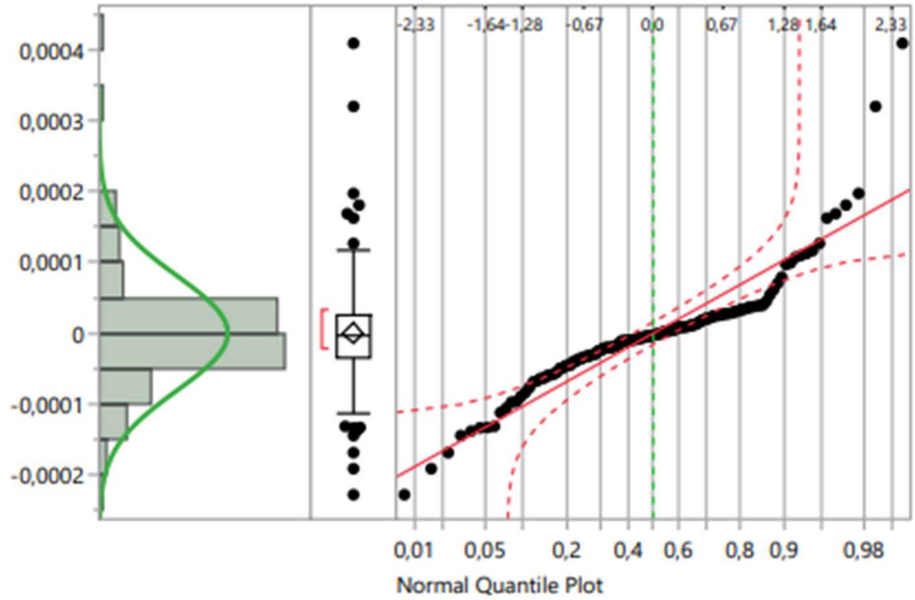
Deelnemer nummer: ……..
Gewicht: …….. kg
Lengte: ……..cm
Score mini-mental state examination: ……..

Appendix 2: JMP® output: assumptions

2.1 Normality of residuals

Distributions

Residual Normalized data



Compare Distributions

Show	Distribution		AICc	BIC	-2*LogLikelihood
☑	Normal	—	-2109,743	-2104,071	-2113,836

Quantiles

100.0%	maximum	0,0004092981
99.5%		0,0004092981
97.5%		0,0001918669
90.0%		0,0000917293
75.0%	quartile	0,0000266742
50.0%	median	-2,911905e-6
25.0%	quartile	-0,000033716
10.0%		-0,000087757
2.5%		-0,000160923
0.5%		-0,000228088
0.0%	minimum	-0,000228088

Summary Statistics

Mean	2,895e-20
Std Dev	8,0915e-5
Std Err Mean	7,0428e-6
Upper 95% Mean	1,3932e-5
Lower 95% Mean	-0,000014
N	132

Distributions

Residual Normalized data

Fitted Normal Distribution

Parameter		Estimate	Std Error	Lower 95%	Upper 95%
Location	μ	2,895e-20	7,0428e-6	-1,38e-5	0,0000138
Dispersion	σ	8,0915e-5	0,0005568	1,124e-10	0,0000821

Measures

-2*LogLikelihood	-2113,836
AICc	-2109,743
BIC	-2104,071

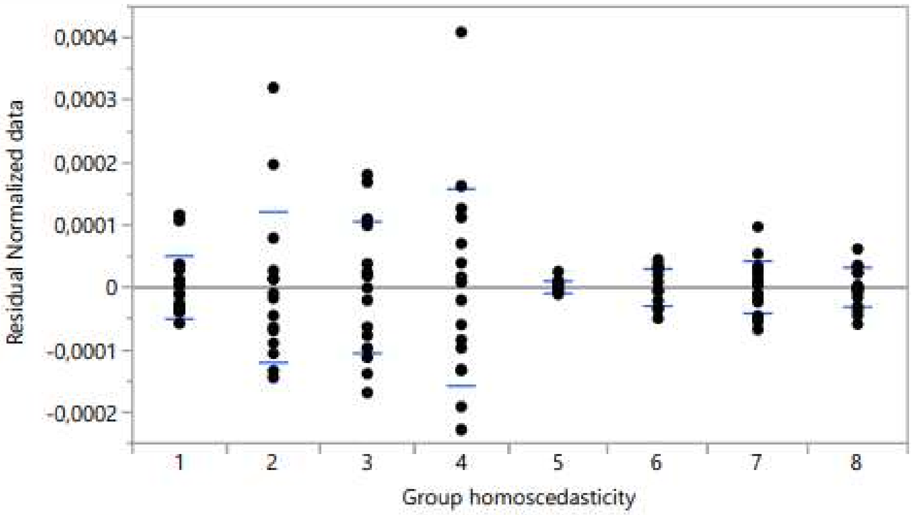
Goodness-of-Fit Test

	W	Prob<W
Shapiro-Wilk	0,8774402	<,0001*

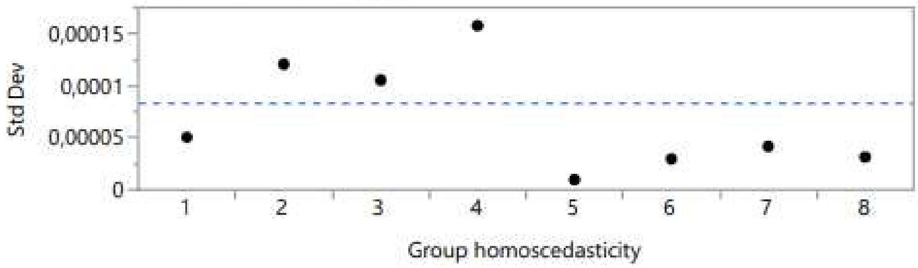
	A2	Simulated p-Value
Anderson-Darling	4,5104616	<,0001*

2.2 Homoscedasticity of residuals

Oneway Analysis of Residual Normalized data By Group homoscedasticity



Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
1	16	0,0000506	0,0000380	0,0000354
2	16	0,0001208	0,0000848	0,0000837
3	16	0,0001055	0,0000848	0,0000848
4	16	0,0001578	0,0001182	0,0001182
5	17	0,0000098	0,0000077	0,0000075
6	17	0,0000298	0,0000261	0,0000259
7	17	0,0000419	0,0000316	0,0000310
8	17	0,0000316	0,0000243	0,0000242

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	3,5400	7	124	0,0017*
Brown-Forsythe	8,5575	7	124	<,0001*
Levene	8,9497	7	124	<,0001*
Bartlett	18,3293	7	.	<,0001*

Welch's Test

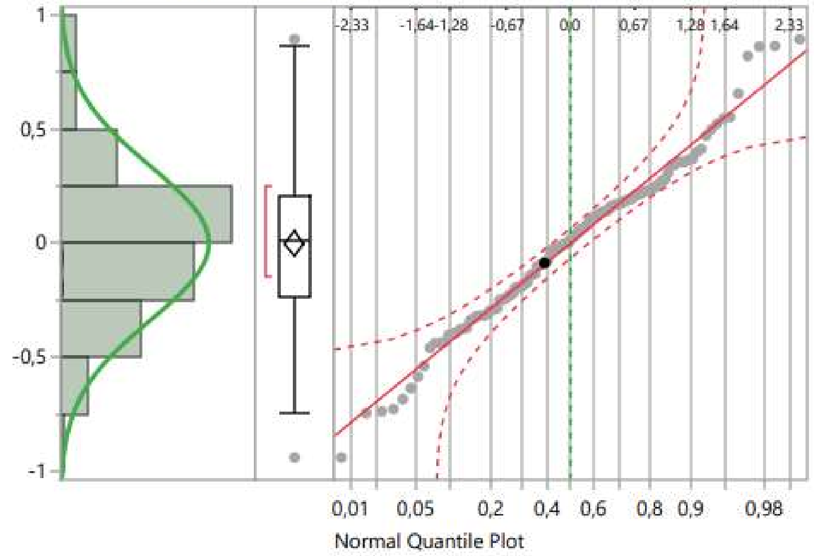
Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
0,0000	7	49,018	1,0000

2.3 Normality of residual log [normalized data]

Distributions

Residual Log[Normalized data]



Compare Distributions

Show	Distribution		AICc	BIC	-2*LogLikelihood
☑	Normal		90,59868	96,27126	86,505656

Quantiles

100.0%	maximum	0,8942204332
99.5%		0,8942204332
97.5%		0,8481423954
90.0%		0,3679791187
75.0%	quartile	0,2077344552
50.0%	median	0,0144647899
25.0%	quartile	-0,237130615
10.0%		-0,399249046
2.5%		-0,733166609
0.5%		-0,938747578
0.0%	minimum	-0,938747578

Summary Statistics

Mean	-4,04e-15
Std Dev	0,3370656
Std Err Mean	0,0293378
Upper 95% Mean	0,0580372
Lower 95% Mean	-0,058037
N	132

Distributions

Residual Log[Normalized data]

Fitted Normal Distribution

Parameter		Estimate	Std Error	Lower 95%	Upper 95%
Location	μ	-4,04e-15	0,0293378	-0,057501	0,057501
Dispersion	σ	0,3370656	0,0359366	0,2735034	0,3420061

Measures

-2*LogLikelihood	86,505656
AICc	90,59868
BIC	96,27126

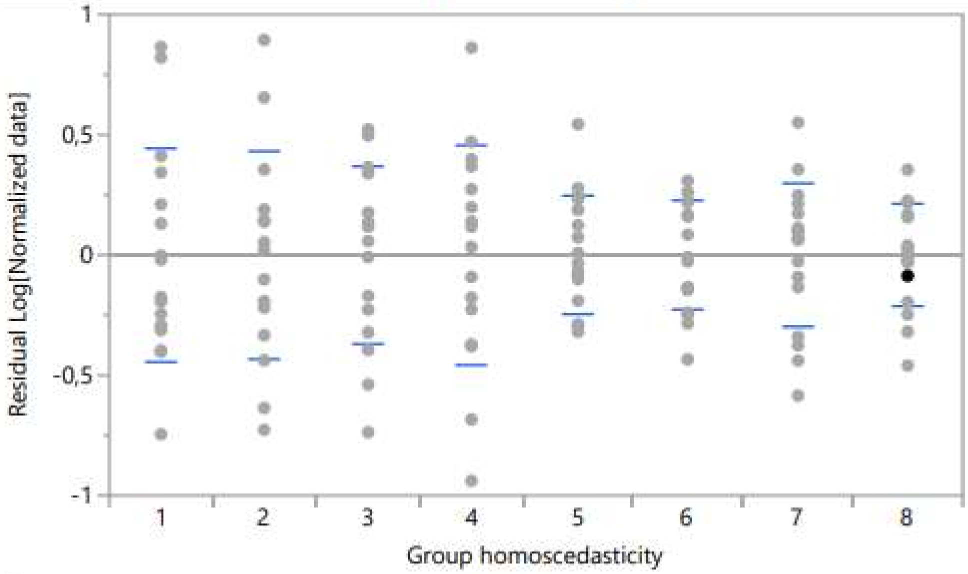
Goodness-of-Fit Test

	W	Prob<W
Shapiro-Wilk	0,9877663	0,2914

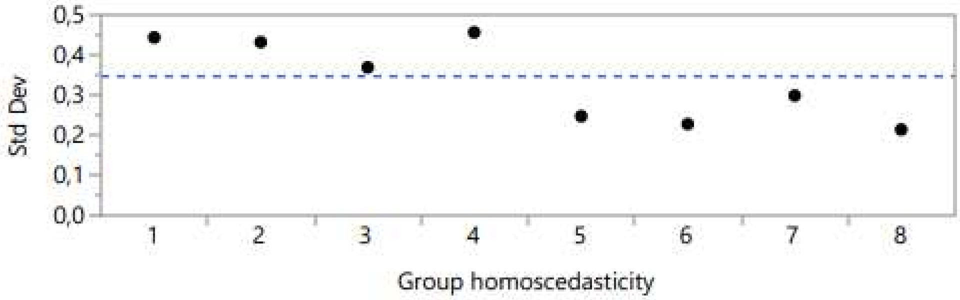
	A2	Simulated p-Value
Anderson-Darling	0,4740619	0,2544

2.4 Homoscedasticity of residual log [normalized data]

Oneway Analysis of Residual Log[Normalized data] By Group homoscedasticity



Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
1	16	0,4437868	0,3478671	0,3450390
2	16	0,4321328	0,3306479	0,3279656
3	16	0,3689395	0,2995765	0,2923735
4	16	0,4567081	0,3582334	0,3539763
5	17	0,2469707	0,1994311	0,1974648
6	17	0,2272769	0,1956110	0,1950407
7	17	0,2984949	0,2338922	0,2224375
8	17	0,2135407	0,1608916	0,1605594

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	2,2656	7	124	0,0333*
Brown-Forsythe	2,0735	7	124	0,0512
Levene	2,4474	7	124	0,0220*
Bartlett	2,8369	7	.	0,0059*

Welch's Test

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
0,0000	7	52,464	1,0000

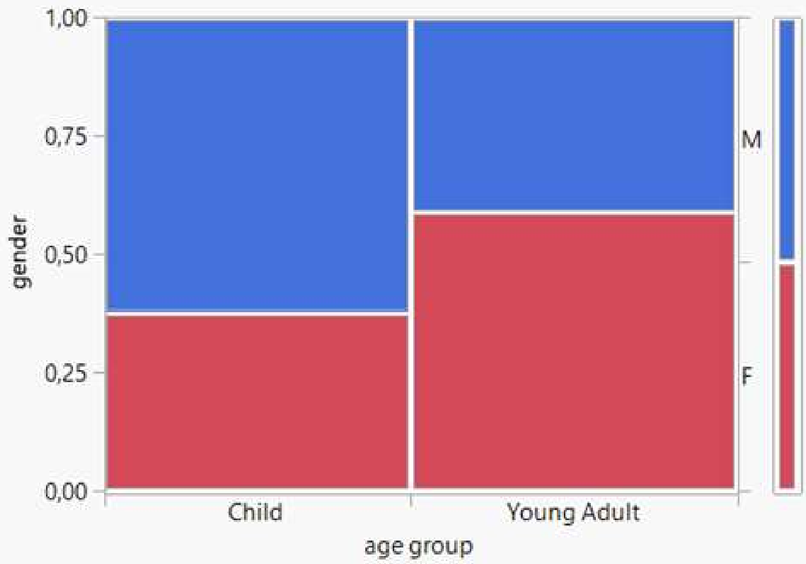
Appendix 3. JMP® output: result

3.1 Comparisons of patient characteristics

3.1.1 Gender by age group (Pearson's test)

Contingency Analysis of gender By age group Condition=mean BB1

Mosaic Plot



Contingency Table

age group	Count / Total % / Col % / Row %	F	M	Total
	Child	6	10	16
		18,18	30,30	48,48
		37,50	58,82	
		37,50	62,50	
	Young Adult	10	7	17
		30,30	21,21	51,52
		62,50	41,18	
		58,82	41,18	
	Total	16	17	33
		48,48	51,52	

Tests

N	DF	-LogLike	RSquare (U)
33	1	0,75628644	0,0331

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	1,513	0,2187
Pearson	1,500	0,2206

3.1.2 Age by age group (Rank-Sum Test)

Oneway Analysis of age By age group Condition=mean BB1

Tests that the Variances are Equal

Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Child	16	1,161858	0,944216	0,944216
Young Adult	17	1,645338	1,196128	1,135564

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	1,5331	1	31	0,2249
Brown-Forsythe	0,3194	1	31	0,5760
Levene	0,6492	1	31	0,4265
Bartlett	1,7674	1	.	0,1837
F Test 2-sided	2,0054	16	15	0,1856

Welch's Test

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
774,3476	1	28,817	<,0001*

t Test
27,8271

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Child	16	136,000	272,000	8,5000	-4,881
Young Adult	17	425,000	289,000	25,0000	4,881

2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
136	-4,88138	<,0001*

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
24,0040	1	<,0001*

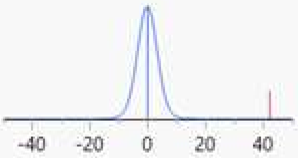
3.1.3 Height by age group (t-Test)

Pooled t Test

Young Adult-Child

Assuming equal variances

Difference	41,9982	t Ratio	12,51133
Std Err Dif	3,3568	DF	31
Upper CL Dif	48,8444	Prob > |t|	<,0001*
Lower CL Dif	35,1519	Prob > t	<,0001*
Confidence	0,95	Prob < t	1,0000



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
age group	1	14538,364	14538,4	156,5334	<,0001*
Error	31	2879,190	92,9		
C. Total	32	17417,553			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Child	16	132,031	2,4093	127,12	136,95
Young Adult	17	174,029	2,3374	169,26	178,80

Std Error uses a pooled estimate of error variance

t Test

Tests that the Variances are Equal

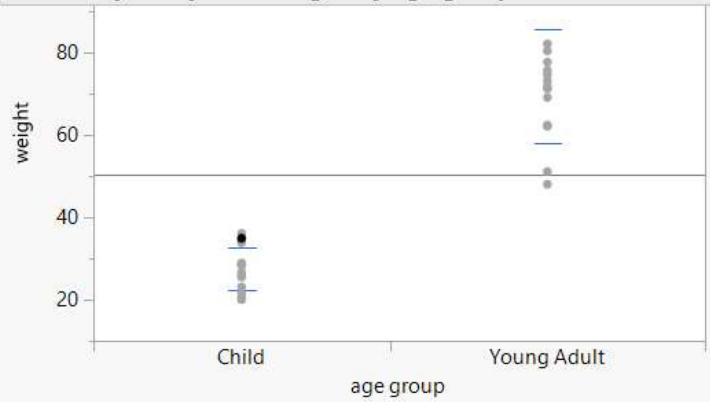
Nonparametric Comparisons For Each Pair Using Wilcoxon Method

q*	Alpha
1,95996	0,05

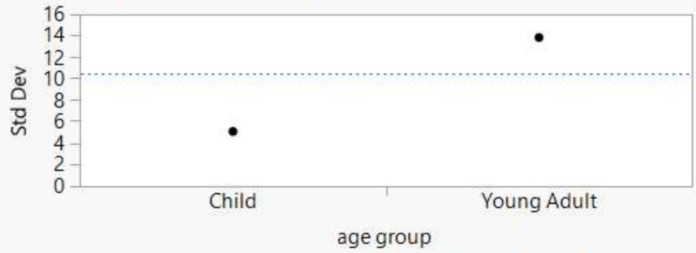
Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL	Difference Plot
Young Adult	Child	16,43934	3,368048	4,880969	<,0001*	42,20000	34,00000	49,80000	

3.1.4 Weight by age group (Welch's test)

Oneway Analysis of weight By age group Condition=mean BB1



Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Child	16	5,08960	4,02500	3,92500
Young Adult	17	13,83913	10,12457	10,11765

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	4,9284	1	31	0,0339*
Brown-Forsythe	6,6298	1	31	0,0150*
Levene	6,5512	1	31	0,0156*
Bartlett	12,7933	1	.	0,0003*
F Test 2-sided	7,3935	16	15	0,0004*

Welch's Test

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
152,4298	1	20,478	<,0001*

t Test
12,3462

3.1.5 BMI by age group (Rank-Sums Test)

Oneway Analysis of BMI By age group Condition=mean BB1

Tests that the Variances are Equal

Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
Child	16	1,523985	1,051910	0,962299
Young Adult	17	3,133237	2,532464	2,510200

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	4,8753	1	31	0,0348*
Brown-Forsythe	8,2793	1	31	0,0072*
Levene	8,5930	1	31	0,0063*
Bartlett	7,0993	1	.	0,0077*
F Test 2-sided	4,2269	16	15	0,0078*

Welch's Test

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
87,4759	1	23,473	<,0001*

t Test
9,3529

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Child	16	139,000	272,000	8,6875	-4,773
Young Adult	17	422,000	289,000	24,8235	4,773

2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
139	-4,77290	<,0001*

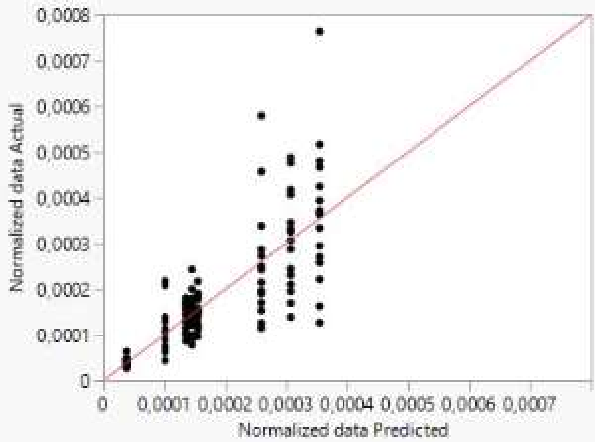
1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
22,9529	1	<,0001*

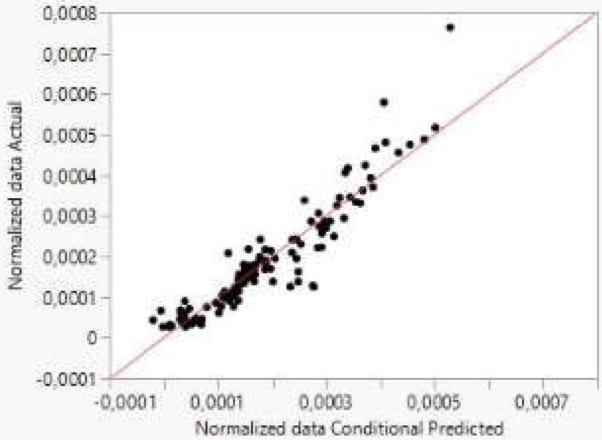
3.2 Mixed ANOVA

Fit Mixed

Actual by Predicted Plot



Actual by Conditional Predicted Plot



Fit Statistics

-2 Residual Log Likelihood	-1995,636
-2 Log Likelihood	-2168,062
AICc	-2146,244
BIC	-2119,234

Random Effects Covariance Parameter Estimates

Variance Component	Estimate	Std Error	95% Lower	95% Upper	Wald p-Value
Participants	4,0752e-9	1,22e-9	1,684e-9	6,4664e-9	0,0008*
Residual	2,8417e-9	4,167e-10	2,1738e-9	3,8744e-9	
Total	6,9169e-9	1,2551e-9	4,9915e-9	1,0225e-8	

Fixed Effects Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|	95% Lower	95% Upper
Intercept	0,000187	1,2048e-5	31,0	15,52	<,0001*	0,0001624	0,0002115
age group[Child]	6,8521e-5	1,2048e-5	31,0	5,69	<,0001*	4,3949e-5	0,0000931
Condition[mean BB1]	1,0519e-5	8,0401e-6	93,0	1,31	0,1940	-5,447e-6	2,6485e-5
Condition[mean BB2]	3,9344e-5	8,0401e-6	93,0	4,89	<,0001*	2,3378e-5	0,0000553
Condition[mean BB3]	6,7642e-5	8,0401e-6	93,0	8,41	<,0001*	5,1675e-5	0,0000836
Condition[mean BB1]*age group[Child]	-6,727e-6	8,0401e-6	93,0	-0,84	0,4049	-2,269e-5	9,2389e-6
Condition[mean BB2]*age group[Child]	1,2411e-5	8,0401e-6	93,0	1,54	0,1261	-3,555e-6	2,8377e-5
Condition[mean BB3]*age group[Child]	3,1128e-5	8,0401e-6	93,0	3,87	0,0002*	1,5162e-5	0,0000471

Fixed Effects Tests

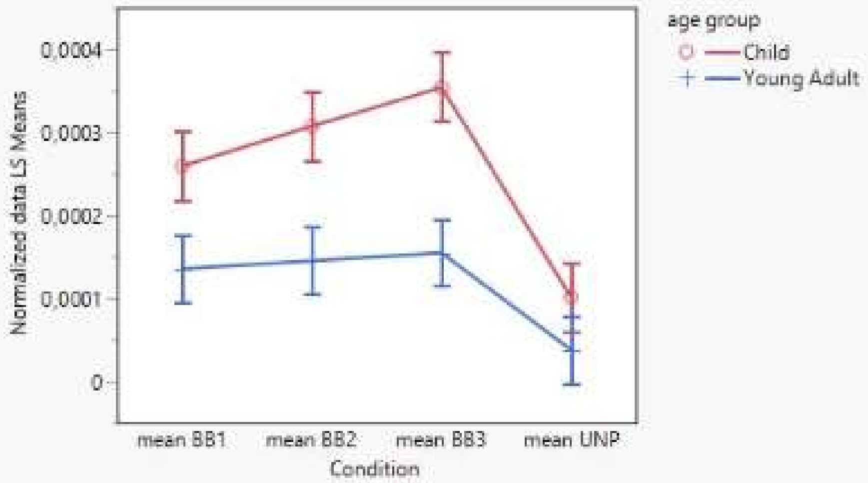
Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
age group	1	1	31,0	32,34639	<,0001*
Condition	3	3	93,0	77,50638	<,0001*
Condition*age group	3	3	93,0	9,7586995	<,0001*

Multiple Comparisons for Condition*age group

Least Squares Means Estimates

Condition	age group	Estimate	Std Error	DF	Lower 95%	Upper 95%
mean BB1	Child	0,00025929	0,00002079	60,744	0,0002177	0,00030087
mean BB1	Young Adult	0,00013570	0,00002017	60,744	0,0000954	0,00017604
mean BB2	Child	0,00030725	0,00002079	60,744	0,0002657	0,00034883
mean BB2	Young Adult	0,00014539	0,00002017	60,744	0,0001050	0,00018572
mean BB3	Child	0,00035426	0,00002079	60,744	0,0003127	0,00039584
mean BB3	Young Adult	0,00015497	0,00002017	60,744	0,0001146	0,00019530
mean UNP	Child	0,00010118	0,00002079	60,744	0,0000596	0,00014276
mean UNP	Young Adult	0,00003776	0,00002017	60,744	-0,0000026	0,00007810

Least Squares Means Plot



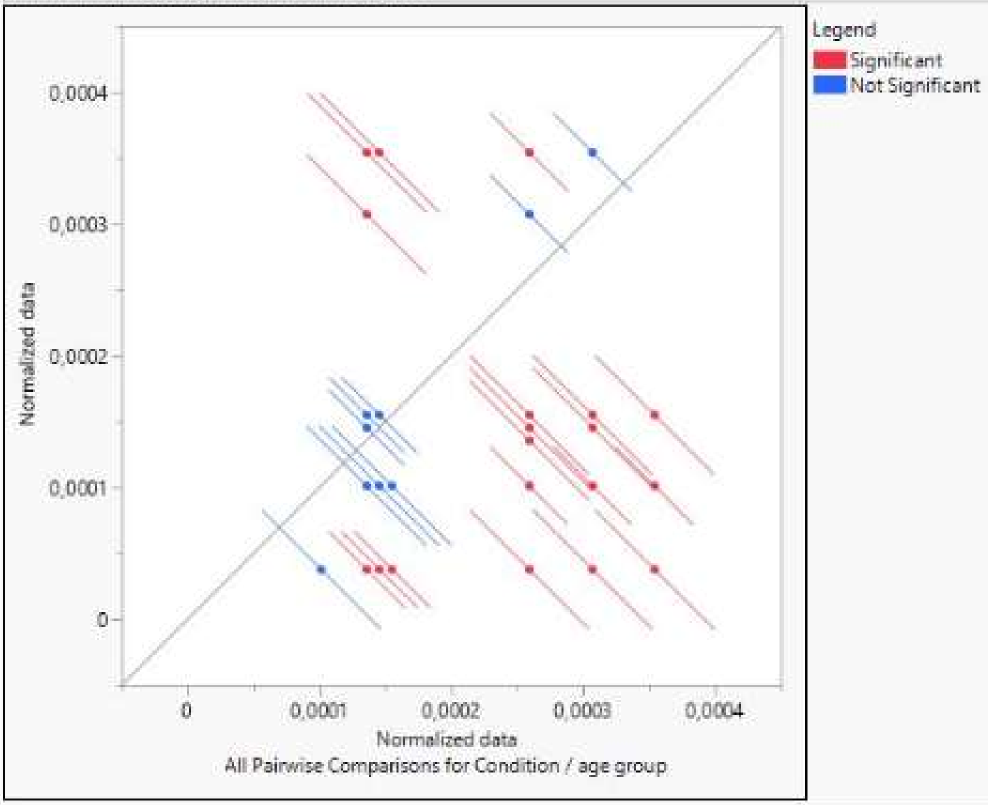
Tukey HSD All Pairwise Comparisons

Quantile = 3,10105, Adjusted DF = 93,0, Adjustment = Tukey-Kramer

All Pairwise Differences

Condition	age group	-Condition	-age group	Difference	Std Error	t Ratio	Prob>|t|	Lower 95%	Upper 95%
mean BB1	Child	mean BB1	Young Adult	0,000124	0,0000290	4,27	0,0012*	0,000034	0,000213
mean BB1	Child	mean BB2	Child	-0,000048	0,0000188	-2,54	0,1902	-0,000106	0,000010
mean BB1	Child	mean BB2	Young Adult	0,000114	0,0000290	3,93	0,0039*	0,000024	0,000204
mean BB1	Child	mean BB3	Child	-0,000095	0,0000188	-5,04	<,0001*	-0,000153	-0,000037
mean BB1	Child	mean BB3	Young Adult	0,000104	0,0000290	3,60	0,0115*	0,000014	0,000194
mean BB1	Child	mean UNP	Child	0,000158	0,0000188	8,39	<,0001*	0,000100	0,000217
mean BB1	Child	mean UNP	Young Adult	0,000222	0,0000290	7,65	<,0001*	0,000132	0,000311
mean BB1	Young Adult	mean BB2	Child	-0,000172	0,0000290	-5,92	<,0001*	-0,000261	-0,000082
mean BB1	Young Adult	mean BB2	Young Adult	-9,687e-6	0,0000183	-0,53	0,9995	-0,000066	0,000047
mean BB1	Young Adult	mean BB3	Child	-0,000219	0,0000290	-7,54	<,0001*	-0,000308	-0,000129
mean BB1	Young Adult	mean BB3	Young Adult	-0,000019	0,0000183	-1,05	0,9645	-0,000076	0,000037
mean BB1	Young Adult	mean UNP	Child	0,000035	0,0000290	1,19	0,9324	-0,000055	0,000124
mean BB1	Young Adult	mean UNP	Young Adult	0,000098	0,0000183	5,36	<,0001*	0,000041	0,000155
mean BB2	Child	mean BB2	Young Adult	0,000162	0,0000290	5,59	<,0001*	0,000072	0,000252
mean BB2	Child	mean BB3	Child	-0,000047	0,0000188	-2,49	0,2108	-0,000105	0,000011
mean BB2	Child	mean BB3	Young Adult	0,000152	0,0000290	5,26	<,0001*	0,000062	0,000242
mean BB2	Child	mean UNP	Child	0,000206	0,0000188	10,93	<,0001*	0,000148	0,000265
mean BB2	Child	mean UNP	Young Adult	0,000269	0,0000290	9,30	<,0001*	0,000180	0,000359
mean BB2	Young Adult	mean BB3	Child	-0,000209	0,0000290	-7,21	<,0001*	-0,000299	-0,000119
mean BB2	Young Adult	mean BB3	Young Adult	-9,58e-6	0,0000183	-0,52	0,9995	-0,000066	0,000047
mean BB2	Young Adult	mean UNP	Child	0,000044	0,0000290	1,53	0,7915	-0,000046	0,000134
mean BB2	Young Adult	mean UNP	Young Adult	0,000108	0,0000183	5,89	<,0001*	0,000051	0,000164
mean BB3	Child	mean BB3	Young Adult	0,000199	0,0000290	6,88	<,0001*	0,000109	0,000289
mean BB3	Child	mean UNP	Child	0,000253	0,0000188	13,43	<,0001*	0,000195	0,000312
mean BB3	Child	mean UNP	Young Adult	0,000317	0,0000290	10,93	<,0001*	0,000227	0,000406
mean BB3	Young Adult	mean UNP	Child	0,000054	0,0000290	1,86	0,5836	-0,000036	0,000144
mean BB3	Young Adult	mean UNP	Young Adult	0,000117	0,0000183	6,41	<,0001*	0,000061	0,000174
mean UNP	Child	mean UNP	Young Adult	0,000063	0,0000290	2,19	0,3678	-0,000026	0,000153

All Pairwise Comparisons Scatterplot



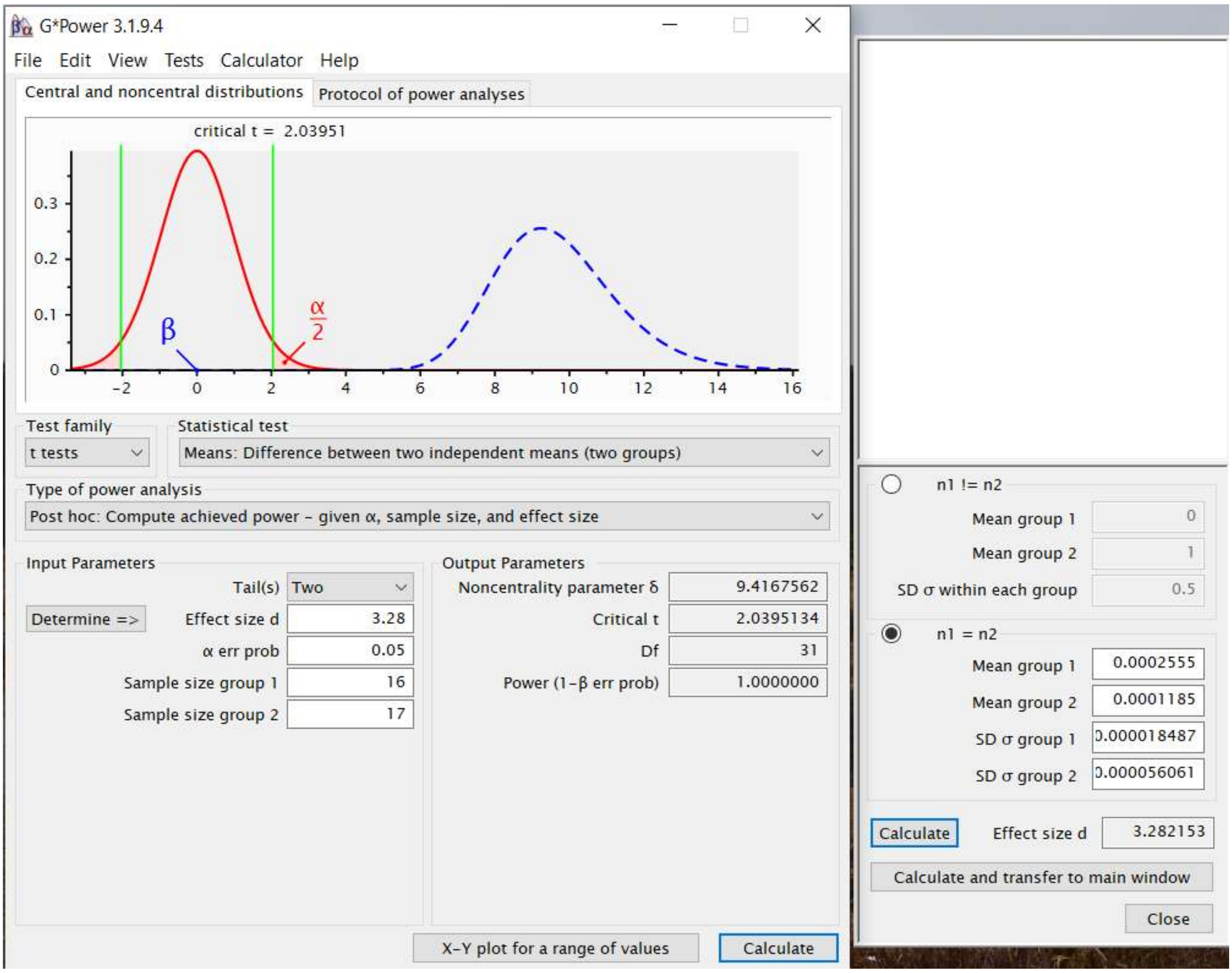
Appendix 4. Crossed-effects

TukeyHSD crossed effects

Age group	Condition	-Age group	-Condition	Difference	Std Error	t Ratio	Prob>|t|	Lower 95%	Upper 95%
Child	mean UNP	Young Adult	mean BB1	-0.000035	0.000029	-1.19	0.9324	-0.00012	0.000055
Child	mean UNP	Young Adult	mean BB2	-0.000044	0.000029	-1.53	0.7915	-0.00013	0.000046
Child	mean UNP	Young Adult	mean BB3	-0.000054	0.000029	-1.86	0.5836	-0.00014	0.000036
Child	mean BB1	Young Adult	mean UNP	0.000222	0.000029	7.65	<.0001*	0.000132	0.000311
Child	mean BB1	Young Adult	mean BB2	0.000114	0.000029	3.93	0.0039*	0.000024	0.000204
Child	mean BB1	Young Adult	mean BB3	0.000104	0.000029	3.6	0.0115*	0.000014	0.000194
Child	mean BB2	Young Adult	mean UNP	0.000269	0.000029	9.3	<.0001*	0.00018	0.000359
Child	mean BB2	Young Adult	mean BB1	0.000172	0.000029	5.92	<.0001*	0.000082	0.000261
Child	mean BB2	Young Adult	mean BB3	0.000152	0.000029	5.26	<.0001*	0.000062	0.000242
Child	mean BB3	Young Adult	mean UNP	0.000317	0.000029	10.93	<.0001*	0.000227	0.000406
Child	mean BB3	Young Adult	mean BB1	0.000219	0.000029	7.54	<.0001*	0.000129	0.000308
Child	mean BB3	Young Adult	mean BB2	0.000209	0.000029	7.21	<.0001*	0.000119	0.000299

Pairwise comparisons of COP mean velocity values between different age groups and different conditions. Significant differences are indicated by an asterisk (*p < 0.05). UNP, condition without a balance board; BB1, condition with the lowest balance board; BB2, condition with the middle balance board; BB3, condition with the highest balance board.

Appendix 5. Post-hoc computation of achieved power (G*Power®)



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UHASSELT
KNOWLEDGE IN ACTION

INVENTARISATIEFORMULIER WETENSCHAPPELIJKE STAGE DEEL 2

DATUM	INHOUD OVERLEG	HANDTEKENINGEN
25 sep 2020	Bespreking verloop/planning	Promotor: Copromotor/Begeleider: Student(e): Student(e): Pieter Beyens
26 nov 2020	Uitleg software voor data-analyse (SIMI)	Promotor: Copromotor/Begeleider: Student(e): Student(e): Pieter Beyens
26 jan 2021	Extra vragen m.b.t. software → op probleem gebotst	Promotor: Copromotor/Begeleider: Student(e): Student(e): Pieter Beyens
4 ma 2021	Specificatie onderzoeksvraag + uitkomstmaten	Promotor: Copromotor/Begeleider: Student(e): Student(e): Pieter Beyens
19 ma 2021	Bespreking verdere data-analyse + statistische analyse	Promotor: Copromotor/Begeleider: Student(e): Student(e): Pieter Beyens
22 apr 2020	Probleem statistiek → bespreken oplossing	Promotor: Copromotor/Begeleider: Student(e): Student(e): Pieter Beyens
		Promotor: Copromotor/Begeleider: Student(e): Student(e):
		Promotor: Copromotor/Begeleider: Student(e): Student(e):
		Promotor: Copromotor/Begeleider: Student(e): Student(e):
		Promotor: Copromotor/Begeleider: Student(e): Student(e):

In te vullen door de promotor(en) en eventuele copromotor aan het einde van MP2:

Naam Student(e): ………………………………………………………………… Datum:……………………….........

Titel Masterproef: ………

1) Geef aan in hoeverre de student(e) onderstaande competenties zelfstandig uitvoerde:
   - NVT: De student(e) leverde hierin geen bijdrage, aangezien hij/zij in een reeds lopende studie meewerkte.
   - 1: De student(e) was niet zelfstandig en sterk afhankelijk van medestudent(e) of promotor en teamleden bij de uitwerking en uitvoering.
   - 2: De student(e) had veel hulp en ondersteuning nodig bij de uitwerking en uitvoering.
   - 3: De student(e) was redelijk zelfstandig bij de uitwerking en uitvoering
   - 4: De student(e) had weinig tot geringe hulp nodig bij de uitwerking en uitvoering.
   - 5: De student(e) werkte zeer zelfstandig en had slechts zeer sporadisch hulp en bijsturing nodig van de promotor of zijn team bij de uitwerking en uitvoering.

Competenties	**NVT**	**1**	**2**	**3**	**4**	**5**
Opstelling onderzoeksvraag	O	O	O	O	O	O
Methodologische uitwerking	O	O	O	O	O	O
Data acquisitie	O	O	O	O	O	O
Data management	O	O	O	O	O	O
Dataverwerking/Statistiek	O	O	O	O	O	O
Rapportage	O	O	O	O	O	O

2) <u>Niet-bindend advies:</u> Student(e) krijgt toelating/geen toelating (schrappen wat niet past) om bovenvermelde Wetenschappelijke stage/masterproef deel 2 te verdedigen in bovenvermelde periode. Deze eventuele toelating houdt geen garantie in dat de student geslaagd is voor dit opleidingsonderdeel.

3) Deze wetenschappelijke stage/masterproef deel 2 mag wel/niet (schrappen wat niet past) openbaar verdedigd worden.

4) Deze wetenschappelijke stage/masterproef deel 2 mag wel/niet (schrappen wat niet past) opgenomen worden in de bibliotheek en docserver van de UHasselt.

Datum en handtekening Student(e)	Datum en handtekening promotor(en)	Datum en handtekening Co-promotor(en)