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Faculteit Revalidatiewetenschappen

master in de revalidatiewetenschappen en de kinesitherapie

Masterthesis

Maturation of sensory reweighting in children

Pieter Beyens
Sam Van Hout
Eerste deel van het scriptie ingediend tot het behalen van de graad van master in de revalidatiewetenschappen en de kinesitherapie

PROMOTOR :
Prof. dr. Pieter MEYNS

BEGELEIDER :
Mevrouw Maud VAN DEN BOGAART

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Maturation of Sensory Reweighting in Children

What are the ages of achievement of mature sensory reweighting during different somatosensory and visual conditions in standing position?

Highlights

- Sequential maturation of somatosensory, visual and vestibular integration
- Differences in postural control between absent and inappropriate visual information conditions due to vestibular function
- Mature sensory reweighting does not equal mature postural control

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Setting

This review is conducted within the scope of pediatric rehabilitation and biomechanical research.

The relevance of this review can be attributed to a better understanding of the developmental changes in postural control, more specifically in sensory reweighting. Up till now, no consensus concerning the maturation of sensory reweighting is present. This knowledge would be very useful in assessing the development of postural control of a child and whether or not this development is normal.

The review is conducted within the framework of the PhD study of Maud van den Boogaart, named "Biomechanical fundamentals on balance control across the lifespan". The clinical testings were almost completed and took place in REVAL, Hasselt University.

For our review, the central format, prescribed by the Faculty of Rehabilitation Sciences and Physiotherapy, Hasselt University, was used.

The research question was formulated by the two Master students in agreement with the co-promotor. The literature study afterwards was conducted independently by the two students.

A new research protocol was constructed by the two Master students in collaboration, based on already existing protocols, conducted in the same research field.

Part 1: literature study

1. Abstract

Background: Postural control relies on the integration of the sensory and motor system. An important task of the sensory system is to adequately organize somatosensory, visual, and vestibular inputs. During changing sensory conditions, the sensory system should reorganize these inputs, known as sensory reweighting. No consensus is present about the age when mature sensory reweighting is achieved.

Methods: A systematic literature search was conducted using the databases of Web of Science (WOS) and PubMed, to involve all current evidence concerning the maturation of sensory reweighting. Data concerning differences in sensory reweighting of children compared to adults were extracted.

Results: A total of 30 studies were included. The sensory reweighting was found to mature between 3 and 6 years of age during visual perturbations, between 8 and 15 years of age during somatosensory perturbations, and around 16 years of age during visual and somatosensory perturbation. Sensory reweighting during sway-referenced visual environment and visual flow matured at a later age compared to the eyes-closed condition.

Discussion and conclusion: The exact ages when mature values of the sensory reweighting during different sensory conditions are achieved were uncertain, but a clear sequential order was present.

Aim: to describe the ages of achievement of mature postural control during the different sensory conditions of the SOT and to use those results to situate the ages of achievement of mature sensory reweighting.

Search question: What are the ages of achievement of mature sensory reweighting and postural control during each sensory condition of the SOT?

Keywords: postural control, maturation, sensory organization, sensory reweighting, children, standing balance, sensory organization test

2. Introduction

Postural control is a prerequisite of all functional activities and involves the control of two behavioral goals: stability and orientation (Horak & Macpherson, 1996; Shumway-Cook & Woollacott, 2017). Postural orientation is defined as the ability to establish and maintain an appropriate position of body segments relative to one another and the environment (Earhart, 2013; Shumway-Cook & Woollacott, 2017). Postural stability is defined as the ability to control the center of mass (COM) within the base of support (BOS) (Shumway-Cook & Woollacott, 2017).

To maintain postural control, adequate integration of neural and musculoskeletal components is required (Horak & Macpherson, 1996; Shumway-Cook & Woollacott, 2017). The essential neural components consist of motor processes, including the coordination of synergistic muscle work, sensory processes, including individual sensory systems and the organization of the sensory inputs, and higher-level cognitive processes, including cognitive resources and postural strategies (Shumway-Cook & Woollacott, 2017).

The natural environment stimulates all our sensory systems (Lickliter, 2011). The sensory inputs for postural control are divided into three classes, namely somatosensory inputs, visual inputs, and vestibular inputs (Woollacott & Shumway-Cook, 1990). Adequate organization of all the sensory systems is a fundamental part of postural control.

The organization of sensory inputs in healthy adults is context-specific (Shumway-Cook & Woollacott, 1985). When some of the afferent inputs are temporally unreliable, a selection of specific sensory systems needs to be made (Nashner & McCollum, 1985), this process is called sensory reweighting (Carver, Kiemel, & Jeka, 2006). During unperturbed stance in healthy adults, the central nervous system (CNS) relies on all sensory inputs, with an emphasis on the somatosensory system. The CNS relies primarily on the visual system, when the support surface is narrow, compliant, or unsteady, thus when the somatosensory information is unreliable. The same process happens in unfamiliar somatosensory situations, as in a novel stance. The main function of the vestibular system is to resolve sensory conflicts, by providing an orientational reference. However, during both inappropriate or absent somatosensory and visual information, the CNS relies on the vestibular system (Lee & Lishman, 1975; O'Sullivan, Schmitz, & Fulk, 2013). These findings, and thereby the hierarchical organization of sensory information for healthy adults during standing position, have been well established.

In children, however, higher levels of instability during standing position are found, shown by multiple balance outcomes (Cuisinier, Olivier, Vaugoyeau, Nougier, & Assaiante, 2011; Gouleme, Ezane, Wiener-Vacher, & Bucci, 2014). An improvement in these outcomes occurs throughout childhood (Rival, Ceyte, & Olivier, 2005; Verbecque, Vereeck, & Hallemans, 2016; Wolff et al., 1998). This improvement in postural control during standing position can be attributed to changes in the body morphology and refinement of motor coordination, sensory organization, and sensorimotor integration (Shumway-Cook & Woollacott, 2017).

Sensory organization has been found to show maturational changes and is, therefore, a contributor to the changes in postural control throughout the course of life (Hirabayashi & Iwasaki, 1995). A possible explanation is that adequate sensory reweighting during altering sensory conditions needs to be learned (Shumway-Cook & Woollacott, 2017).

During inappropriate somatosensory and visual inputs, the postural responses of the young children were inadequate and lead to loss of balance, this was not found for older children or adults. (Forssberg & Nashner, 1982). Postural control in children during changing sensory conditions is not yet mature, this could be attributed to the function of sensory systems and their reweighting.

Different studies have investigated the maturation of the sensory systems, their integration, and the reweighting during changing sensory conditions, but no unequivocal conclusion could be established.

The aim of this review, therefore, is to assess the maturation of the postural control in standing position during changing somatosensory and visual conditions, and, therefore, the maturation of the sensory reweighting.

3. Methods

3.1. Research question

The goal of this review was to describe the maturation of sensory reweighting during changing sensory conditions throughout childhood. Based on the present evidence, the next research question was stated: What are the ages of achievement of mature sensory reweighting during different somatosensory and visual conditions in standing position?

3.2. Literature search

Papers were selected from PubMed and Web of Science (WOS) until the 5th of May 2020. The search query was built and optimized in deliberation, after running several trial versions and by using a PICO, which can be found in appendix 1. The used search query was a combination of search terms for postural control, standing position, somatosensory and/or visual disturbances, and the correct age categories. Terms within each group were linked by the Boolean operator "OR" and the groups were linked by the Boolean operator "AND". A more detailed description can be found in appendix 2. Checking the reference list of the included papers, to find additional literature, was done independently by both researchers. In the end, an expert was consulted and checked the list of included papers on possible missing material.

3.3. Selection criteria

Inclusion criteria were: a) a comparison of at least one group of healthy children with one group of healthy adults; b) assessment of sensory reweighting during a standing balance task with double limb support; and c) an available full-text in English or Dutch. Exclusion criteria were: a) the inclusion of participants with motor, sensory or cognitive disorders with an impact on postural control; b) the inclusion of participants who take medication with an effect on the postural control; or c) the inclusion of athletes. The selection criteria are described in table 1.

Eligibility was independently assessed by two reviewers, by the screening of titles and abstracts. Full-texts were evaluated afterwards on in- and exclusion criteria for a final selection of literature. Studies excluded based on the full-text were sorted in specific groups, depending on the reason for exclusion. Studies could be excluded because a) no comparison of at least one group of healthy children with one group of healthy adults was present; b) sensory reweighting during a standing balance task with double-limb support was not assessed; c) the full-text was not available; or d) the full-text was not written in Dutch or English.

The resulting lists of studies were compared between the two reviewers after the evaluations of eligibility by title, abstract, and finally full-text. Afterwards, differences were discussed until a consensus was found, if a consensus could not be found, a third, independent, person was consulted.

The same strategy was adopted to select articles from the reference lists.

Table 1. Selection criteria

Inclusion criteria	Exclusion criteria
Comparison of at least one group of healthy children (2-17 years old) and one group of healthy adults (18-44 years old)	Studies including participants with motor, sensory or cognitive disorders with an impact on postural control
Assessment of sensory reweighting during a standing balance task with double limb support	Studies including participants who take medication with an effect on postural control
Full-text available and written in Dutch or English	Studies including athletes

3.4. Quality assessment

The quality of the included studies was assessed independently by two reviewers. Afterwards, the results of these assessments were compared between the two reviewers, and differences were discussed until a consensus was found. If a consensus could not be found, a third, independent, person was consulted.

All included studies had a comparative cross-sectional study design. No existing valid and reliable quality checklist was found for this type of cross-sectional research, hence a new checklist was constructed. The final form was based on checklists recommended by Cochrane and checklists made by authors of reviews in the same research field (Baldan, Alouche, Araujo, & Freitas, 2014; Downes, Brennan, Williams, & Dean, 2016; Ku, Abu Osman, & Wan Abas, 2014; Mazaheri, Coenen, Parnianpour, Kiers, & van Dieën, 2013; NIH). The criteria of the checklist are presented in table 2. The full template of the checklist is presented in appendix 3.

Table 2. Quality Assessment

1. Is the objective of the study clearly described?
2. Is the study design clearly described and appropriate for the stated aims?
3. Is the sample adequately selected and described?
   - 3.1. Is the sample size justified?
   - 3.2. Are the methods used to recruit the participants well described, equal in both groups, and correct?
   - 3.3. Are the criteria for inclusion and exclusion described?
   - 3.4. Are the participants' characteristics described in detail and was there a correction for a confounding effect? Was the sample frame taken from an appropriate population base so that it closely represented the target population under investigation?
4. Do the methods allow reproducibility?
   - 4.1. Are the experimental procedures clearly described to ensure homogeneity?
   - 4.2. Is the data extraction clearly described?
   - 4.3. Are the statistical tests used appropriate and clearly described?
5. Do the methods meet all the objectives proposed?
6. Are the measuring instrument valid and reliable?
7. Are the main outcome clearly stated?
8. Are the results valid, reliable and according to the sample studied?
9. Are the results presented clearly and with statistical significance and confidence intervals?
10. Is the question of the study adequately answered in the discussion?
11. Are the implications for clinical practice following the results of the study?
12. Are the conclusions appropriate, given the study methods, interpreted logically, supported by the literature and results, and clearly stated?

Every criterion was rated with "complied" or "not complied". If too little information was available, the criterion was rated "not complied" and further explanation was given in the appropriate column. Every criterion that was rated "complied", was attributed one point. Every criterion that was rated "not complied", was attributed zero points. Emphasis was placed on the criteria about the experimental procedure (criterion 4.1) and the clarity of the presentation of the results (criterion 9) by deducting one point when rated "not complied", because of their importance to the quality of the study. The quality of the studies was rated adequate if there was a total score of nine or more out of seventeen. Studies that scored eight or less in total, were discussed by both reviewers and excluded from the review if the quality was found to be too low.

Afterwards, an analysis of the strengths and weaknesses of each study was conducted. This analysis was based on the quality assessment and the most prominent findings in the full-texts.

3.5. Data-extraction

The following data were extracted from the selected studies: the population, divided into age groups (age, number, and sex), the measurement instruments and the outcome variables, the sensory conditions (visual and somatosensory), the trial duration and number of repetitions, the posture, and the relevant results.

Only the groups of participants that conformed to the selection criteria were included, other groups were ignored.

The data extraction was done by two reviewers and disagreements about the extracted data were discussed until a consensus was found. If no consensus could be found, a third, independent, person was consulted.

4. Results

4.1. Results Study selection

After implementing the search query in PubMed and WOS, 742 studies were included after the removal of 212 duplicates. After an eligibility assessment, based on the titles, 581 studies were excluded and the remaining 161 studies were included for further assessment.

Thereafter, the abstracts of the remaining studies were assessed against the selection criteria and excluded if an inconsistency was found. Ninety-seven studies were excluded because no healthy children group and healthy adult group were present and 13 studies were excluded because there was no assessment of sensory reweighting during a standing balance task with double limb support.

Finally, the full-texts of the remaining 51 studies were assessed against the selection criteria and excluded if an inconsistency was found. Fourteen studies were excluded because no healthy children group and healthy adult group were compared and five studies were excluded because there was no assessment of sensory reweighting during a standing balance task with double limb support. Also, one study was excluded because athletes were included, three studies were excluded because the full-text was not available in Dutch or in English and two studies were excluded because there was no full-text available. An overview of the excluded studies and the reasons for exclusion at full-text level is presented in appendix 4.

After a selection based on the full-texts of the studies, 26 studies were included.

Afterwards, a screening of the reference lists of all of the included studies was conducted and an additional eight studies were included.

In total, 34 studies were included in the quality assessment. An overview of the study selection presented in a flowchart can be found in appendix 5.

4.2. Results quality assessments

The results of the quality assessment are summarized in appendix 6. The quality was rated inadequate of four studies, which scored 8 points or less. These studies were excluded after deliberation.

The most prominent reason for exclusion of the study by a) Foster, Sveistrup, and Woollacott (1996) was an inadequate description of the sample and experimental procedure; b) Godoi and Barela (2016) was an inadequate description of the experimental procedure and results; and c) Peterka and Black (1990) and Sakaguchi, Taguchi, Miyashita, and Katsuno (1994) was an inadequate description of the sample and results.

The results of the analysis of the strengths and weaknesses were taken into account during the interpretation of the results. The strengths-weaknesses analysis can be found in appendix 7.

4.3. Results data-extraction

Participant characteristics

The participants in the 30 included studies ranged from 3 to 90 years of age, however, the specific age groups differed between studies. Details on the participant characteristics can be found in appendix 8.

Sensory conditions

The implementation of somatosensory and visual perturbation differed between studies. Changing visual conditions were achieved by eyes closed (EC), a sway-referenced visual environment (VS), visual flow, or a moving room. Changing somatosensory conditions were achieved by a compliant surface (CS), a sway-referenced surface (SS), whole-body vibration, or Achilles tendon vibration. Combinations of multiple perturbations were possible. A description of the sensory conditions in each study can be found in appendix 8.

Characteristics of outcome variables

The results were interpreted in terms of differences in postural control between age groups during different sensory conditions. Based on these differences, maturation of the different sensory systems and sensory reweighting can be assessed.

During inappropriate or absent visual information, postural control should rely on the somatosensory system and to a lesser extent on the vestibular system. During inappropriate somatosensory information, postural control should rely on the visual system and to a lesser extent on the vestibular system. During inappropriate or absent visual and inappropriate somatosensory information, postural control should rely on the vestibular system (Saha, 2016; Shumway-Cook & Woollacott, 2017). Details on the outcomes are presented in appendix 9.

The outcome variables were divided into two groups: center of pressure (COP) and body sway. COP was measured by a force platform, while body sway was measured by a tracking device, mounted on the body, including all outcomes concerning COM.

An explanation of the unfamiliar outcome variables can be found in appendix 10.

Absent or inappropriate visual information

Eyes closed conditions

Center of pressure

Concerning the somatosensory ratios, Ferber-Viart, Ionescu, Morlet, Froehlich, and Dubreuil (2007) found a difference between 6-to-8-year-olds and adults. However, no difference with adults was found for 3-to-4-year-olds by Hirabayashi and Iwasaki (1995) and Steindl, Kunz, Schrott-Fischer, and Scholtz (2006), 7-to-9-year-olds by Cherng, Chen, and Su (2001), and 6-year-olds by Peterson, Christou, and Rosengren (2006). Ionescu, Morlet, Froehlich, and Ferber-Viart (2006) found the ratio to be greater for 11-to-12-year-olds, compared to adults.

Concerning the equilibrium scores, a difference was found between 7.5-year-olds and adults by Rine, Rubish, and Feeney (1998), between 8-to-10-year-olds and adults by Ferber-Viart et al. (2007), and between 7-to-8- and 9-to-10-year-olds, but not between other neighboring age groups, by Steindl et al. (2006). However, Hirabayashi and Iwasaki (1995) found no differences between neighboring age groups.

Concerning the stability percentage, Ionescu et al. (2006) found no differences between 11-to-12-year-olds and adults.

Concerning the ellipse area, a difference with adults was found for 5-year-olds by Hsu, Kuan, and Young (2009) and 11-year-olds by Hsu et al. (2009); Scharli, van de Langenberg, Murer, and Muller (2012). However, Cherng et al. (2001) found no difference in the ellipse area or proportional change between 7-to-9-year-olds and adults.

Concerning the COP velocity, a difference was found between 4-to-7- and 8-to-13-year-olds by C. L. Riach, Starkes, J.L. (1994) and between 10-year-olds and adults by Wu, McKay, and Angulo-Barroso (2009). However, no difference was found between 12-year-olds and adults by Ionescu et al. (2006) and Wachholz, Tiribello, Promsri, and Federolf (2019). No difference in the change from EO to EC between 5-to-16-year-olds and adults was found by Hytonen, Pyykko, Aalto, and Starck (1993)

Concerning the amplitude, Oba, Sasagawa, Yamamoto, and Nakazawa (2015) found a difference between 5-to-6-year-olds and adults when normalized to height, but not when using absolute values. No difference between 7-to-9-year-olds and adults was found by Cherng et al. (2001).

Body sway

Concerning the somatosensory index, no age effect was found by Faraldo-Garcia, Santos-Perez, Labella-Caballero, Crujeiras, and Soto-Varela (2013).

Concerning the amount of body sway, a difference was found between 11-year-olds and adults by Scharli et al. (2012). No differences with adults were found for 3-to-4-year-olds by Greffou, Bertone, Hanssens, and Faubert (2008) and Wann, Mon-Williams, and Rushton (1998).

Oba et al. (2015) found an age x visual condition interaction effect on the acceleration of the COM (COM_{acc}) and peak power of the COM_{acc}, but no age effect on the EC/EO ratio of the peak power of the COM_{acc}. Furthermore, the mean power frequency (MPF) and peak power frequency (PPF) of the COM_{acc} showed differences between 5-to-6-year-olds and adults, but no age x visual condition interaction effect.

Cherng, Lee, and Su (2003) found that the median frequency of shear forces, which represents the COM vibration, is greater during the EC compared to EO condition for adults in the anteroposterior (AP) direction, this was not found for children or in the mediolateral (ML) direction.

Liang, Beerse, Ke, and Wu (2017) found that the total power, which represents the COM density, of body sway was higher during the EO compared to the EC condition for adults, but not for children.

Sway-referenced visual conditions

COP measurements

Concerning the somatosensory ratio, no difference was found between 6-year-olds and adults by Rine et al. (1998).

Concerning the equilibrium scores, a difference was found between 6-to-7.5-year-olds and adults by Rine et al. (1998), between 8-to-10- and 10-to-12-year-olds by Ferber-Viart et al. (2007), and between 9-to-10- and 11-to-12-year-olds by Steindl et al. (2006).

Concerning the ellipse area, Cherng et al. (2001) found no difference in values or proportional change between 7-to-9-year-olds and adults.

Visual flow or moving room

COP measurements

Concerning the stability percentage and COP velocity, Ionescu et al. (2006) found a difference between 12-year-olds and adults.

Concerning the COP amplitude, Lim et al. (2018) found no difference between 10-year-olds and adults.

Body sway

Concerning the amount of body sway, a difference was found between 12-to-15-year-olds and adults by Greffou et al. (2008). No difference was found between 3-to-4-year-olds and adults by Wann et al. (1998). Polastri and Barela (2013) found that 4- and 8-year-olds increased their sway amplitude from a low to a high amplitude/velocity (ampl./vel.) oscillation, this was not found for 12-year-olds and adults. Only 33% of the 5-to-7-year-olds completed all the dynamic trials in the study by Polastri and Barela (2013).

Concerning the gain values, Godoi and Barela (2008) found decreasing values with increasing age. A difference with adults was found for 3-to-4-year-olds, not 10-to-12-year-olds, by Wann et al. (1998) and for 8-year-olds, not for 12-year-olds, by Rinaldi, Polastri, and Barela (2009).

During changing visual stimulus frequencies, Polastri and Barela (2013); Rinaldi et al. (2009); Wann et al. (1998) found greater body sway reactions and slower adaptation to changes in stimulus frequencies for 4- and 8-year-olds, Rinaldi et al. (2009) found greater body sway reactions for children compared to adults. However, no difference between age groups was found by Barela, Sanches, Lopes, Razuk, and Moraes (2011).

Concerning the coherence, an increase of coupling strength with increasing age was found by Godoi and Barela (2008) and Barela et al. (2011). Rinaldi et al. (2009) found the stimulus frequency sway amplitude of 4- and 8-year-olds to be more influenced by changing stimulus frequency, compared to 12-year-olds and adults. Wann et al. (1998) found that visual induced sway was present in 89% of the 3-to-4-year-olds, 72% of the 10-to-12-year-olds, and 36% of the adults.

Concerning the phase values, Polastri and Barela (2013) and Sparto et al. (2006) found that children tended more to lead, while adults rather lagged the visual stimulus. However, Wann et al. (1998) found all age categories to lag. Godoi and Barela (2008) and Barela et al. (2011) found no differences between age groups.

Greffou et al. (2008) found a greater root mean square of the velocity (vRMS) during higher oscillation frequencies for 8-to-15-year olds, not for adults.

Lim et al. (2019) found a significant postural response during peripheral visual contraction and full visual expansion in children, not in adults. During full visual contraction, the return to the baseline in children was delayed compared to adults.

Inappropriate somatosensory information

Compliant surface

COP measurements

Concerning the visual ratio, mature values were found for 7-to-9-year-olds by Cherng et al. (2001) and 11-to-12-year-olds by Ionescu et al. (2006).

Concerning the ellipse area, a difference with adults was found for 3-to-7-year-olds by Hsu et al. (2009).

Concerning the COP velocity, a difference with adults was found for 3-to-7-year-olds by Hsu et al. (2009). A difference in change of velocity from FS to CS was found between 5-to-16-year-olds and adults by Hytonen et al. (1993).

Concerning the COP amplitude, Cherng et al. (2001) found no difference between 7-to-9-year-olds and adults.

Body sway

Concerning the visual index, the lowest values were found for 40-to-49-year-olds Faraldo-Garcia et al. (2013).

Concerning the COM vibration, Cherng et al. (2003) found the surface effect to be greater for 7-to-9-year-olds compared to adults in the ML direction, however, not in the AP direction.

Concerning the velocity, Faraldo-Garcia et al. (2013) found greater values for 16-to-20-year-olds, compared to 20-to-29-year-olds.

Sway-referenced surface

COP measurements

Concerning the visual ratio, a difference with adults was found for 7.5-year-olds by Rine et al. (1998), 10-year-olds by Peterson et al. (2006), and 12-to-14-year-olds by Ferber-Viart et al. (2007). Furthermore, regarding neighboring age groups, a difference was found between 11-to-13- and 14-to-15-year-olds by Hirabayashi and Iwasaki (1995) and between 9-to-10- and 11-to-12-year-olds by Steindl et al. (2006). However, no difference with adults was found for 7-to-10-year-olds by Sparto et al. (2006) and 11-to-12-year-olds by Ionescu et al. (2006).

Concerning the equilibrium scores, a difference with adults was found for 7.5-year-olds by Rine et al. (1998) and 12-to-14-year-olds by Ferber-Viart et al. (2007); Rine et al. (1998). Furthermore, regarding neighboring age groups, a difference was found between 9-to-10- and 11-to-12-year-olds by Steindl et al. (2006), however, no differences were found by Hirabayashi and Iwasaki (1995)

Ionescu et al. (2006) found a difference between 11-to-12-year-olds and adults concerning the ellipse area and stability percentage, but not concerning COP velocity.

Achilles tendon and whole-body vibration

COP measurements

Concerning the COP velocity, Cuisinier et al. (2011) found a difference between 11-year-olds and adults. The velocity during vibration (vib.) was found to be larger compared to non-vib. for 7-to-11-year-olds by Cuisinier et al. (2011), 6-to-15-year-olds by Hytonen et al. (1993), and 10-year-olds by S. M. McKay, Wu, and Angulo-Barroso (2014), but not for adults.

Concerning the COP amplitude, S. M. McKay et al. (2014) found greater values for 6- and 10-year-olds compared to adults in the AP and ML direction. In the AP direction, the values decreased from vib. to post-vib. for 10-year-olds and adults, but remained constant for 6-year-olds. In the ML direction, a decrease from vib. to post-vib. was present in 6- and 10-year-olds, but not in adults.

Body sway

Liang et al. (2017) found a greater ML COM amplitude during immediate post-vib. compared to pre-vib., vib., and five minutes post-vib. for 6-to-9-year-olds, while adults remained constant. No difference between groups was found in the AP direction. They also found the sway area to decrease from pre-vib. to vib., increase at immediate post-vib., and decrease to pre-vib. values at five minutes post-vib for 6-to-9-year-olds, while adults maintained their values. Furthermore, they found that the increase in velocity from the static to the whole-body vib. condition was greater for 6-to-9-year-olds compared to adults in the AP and ML direction.

Haptic cue

Body sway

Barela, Jeka, and Clark (2003) found no age differences concerning gain values. Furthermore, they found phase values to be greater for 4-year-olds, compared to older children and adults, and variability in body sway to be greater in 4-to-8-year-olds, compared to adults.

Absent/inappropriate visual information and inappropriate somatosensory information

Eyes closed and compliant surface

COP measures

Concerning the vestibular ratio, a difference was found between 7-to-9-year-olds and adults by Cherng et al. (2001) .

Concerning the ellipse area, a difference was found between 6-year-olds and adults by Hsu et al. (2009), and a greater proportional change for 7-to-9-year-olds, compared to adults, was found by Cherng et al. (2001).

Concerning the COP velocity, a difference was found between 11-year-olds and adults by Hsu et al. (2009).

Concerning the COP amplitude, a difference was found between 7-to-9-year-olds and adults in the AP direction, not in the ML direction, by Cherng et al. (2001).

Body sway

Faraldo-Garcia et al. (2013) found the vestibular index to be the greatest for 40-to-49-year-olds

Eyes closed and sway-referenced surface

COP measures

Concerning the vestibular ratio, a difference with adults was found for 14-to-15-year-olds by Hirabayashi and Iwasaki (1995). Steindl et al. (2006) found the values of 15-to-16-year-olds to be greater compared to 13-to-14-year-olds and adults.

Concerning the equilibrium scores, a difference with adults was found for 7.5-year-olds by Rine et al. (1998), 12-to-14-year-olds by Ferber-Viart et al. (2007) and 14-to-15-year-olds by Hirabayashi and Iwasaki (1995). Steindl et al. (2006) found a difference between 13-to-14- and 15-to-16-year-olds.

Ionescu et al. (2006) found a difference between 11-to-12-year-olds and adults concerning the stability percentage, but not concerning the ellipse area and the COP velocity.

Sway-referenced visual environment and compliant surface

COP measures

Concerning the vestibular ratio, a difference between 12-to-14-year-olds and adults was found by Ferber-Viart et al. (2007). However, Peterson found mature values for 12-year-olds.

Concerning the ellipse area, a greater proportional change for 7-to-9-year-olds, compared to adults, was found by Cherng et al. (2001).
Concerning the COP amplitude, a difference was found between 7-to-9-year-olds and adults in the AP direction, not in the ML direction Cherng et al. (2001).

Sway-referenced visual environment and sway-referenced surface

COP measures

Concerning the vestibular ratio, a difference with adults was found for 7.5-year-olds by Rine et al. (1998). However, Ionescu et al. (2006) found no difference between 11-year-olds and adults.
Concerning the equilibrium scores, a difference with adults was found for 7.5-year-olds by Rine et al. (1998) and 12-to-14-year-olds by Ferber-Viart et al. (2007). Furthermore, regarding neighboring age groups, a difference was found between 9-to-10- and 11-to-13-year-olds by Hirabayashi and Iwasaki (1995) and between 9-to-10- and 11-to-12-year-olds by Steindl et al. (2006).

Optokinetic visual stimulation and sway-referenced surface

COP measures

Ionescu et al. (2006) found a difference between 12-year-olds and adults concerning the stability percentage and the ellipse area, but not concerning the COP velocity.

<u>Visual preference</u>

A difference was found between 11-to-12-year-olds and adults by Ferber-Viart et al. (2007); Ionescu et al. (2006) and between 6-to-8- and 10-to-12-year-olds, but not between other age groups, by Ferber-Viart et al. (2007). However, Peterson et al. (2006) found no differences between age groups.

5. Discussion

5.1. Reflection on the quality of studies

In general, the objective, design, aim, results, and conclusion of the studies were all very clearly described.

The reproducibility of almost all studies was sufficient, due to a clear description of methodology.

Experimental procedures were in general clearly described, but a recurrent lack of clear descriptions of rest intervals and to a lesser extent posture limits the reproducibility of some studies.

The description of rest intervals was commonly absent. A difference in rest interval length could influence the results because of a possible fatigue-effect. Especially the studies with short or undescribed rest intervals in combination with a non-randomized trial-order should be critically assessed. The description of posture often was incomplete. Variances in posture can affect the results in different ways. A difference in feet positioning influences the BOS and a difference in arm position influences the COM. Both variables can influence the complexity of postural control.

The selection criteria were formulated vaguely and implicitly in some studies. This could contribute to differences in the interpretation of healthy subjects by authors and therefore to conflicts in the results.

Normalization of results to patients' anthropometric characteristics is commonly absent. This possibly contributes to differences in the results, while these characteristics differ between children and adults. For example, feet length influences the BOS and, therefore, the limits of stability. Studies with no or no mentioning of normalization should, therefore, be critically assessed.

The description of the validity and reliability of the measurement instruments and the results was inadequate in all but two studies.

Justification of sample sizes was absent in all studies. This could have implications on the power of the studies, which can cause difficulties in finding significant differences. Considerations concerning the power of the studies are necessary, especially in studies with small sample sizes.

5.2. Reflection on conclusions related to research questions

None of the included studies integrated all sensory conditions when assessing the maturation of sensory reweighting. Therefore, no complete assessment concerning the ages of achievement of mature sensory reweighting during different sensory conditions has been conducted.

While postural control relies on the integration of the sensory and motor system, sensory reweighting can not be directly deduced. Therefore, a distinction was made between two groups of outcome variables. The sensory ratios indicate the integration of the sensory systems, while differences in postural control during the EO-FS condition are taken into consideration. The other outcomes, that do not consider baseline differences, also include the motor system and sensorimotor integration. Therefore, sensory reweighting was based on sensory ratios and general postural control on the other outcomes.

Absent or inappropriate visual information

During these conditions, the subject should rely primarily on the somatosensory system. Therefore, when mature values during these conditions are reached, mature integration of the somatosensory system is implied.

When all findings are taken together, a sequential development, starting with maturation during EC conditions, further followed by maturation during VS conditions, and finally maturation during visual disorientation conditions, is found. The precise maturational ages, however, remain dubious and should be further examined.

Eyes closed

The somatosensory ratios suggest achievement of mature somatosensory function during EC conditions by 3 to 4 years of age, based on the findings by Hirabayashi and Iwasaki (1995) and Steindl et al. (2006). However, Ferber-Viart et al. (2007) found this to be true for 8-to-10-year-olds. Two studies situated the achievement of mature values between both ages, however, these studies included no younger groups and thus implied the maturation to be more probable by 3 to 4 years of age (Cherng et al., 2001; Peterson et al., 2006).

The results suggest achievement of mature postural control during EC conditions between 8 and 12 years of age (Cherng et al., 2001; Cherng et al., 2003; Ferber-Viart et al., 2007; Oba et al., 2015; C. L. Riach & Starkes, 1994; Steindl et al., 2006; Wachholz et al., 2019). However, Hsu et al. (2009) found the ellipse area of 6-year-olds to be equal to the ellipse area of adults. This could be attributed to the fact that they did not normalize the ellipse area to anthropometric characteristics, while Cherng et al. (2001) did. Furthermore, Wann et al. (1998) found the body sway to be mature for 3-to-4-year-olds, however, due to the small sample sizes, this result was considered less valuable.

Remarkably, Cherng et al. (2003) and Liang et al. (2017) found adults to be sensitive to changes from EO to EC conditions, while this was not present in children. This does not stroke with the general assumption of children being more sensitive to changes in visual conditions. However, these findings concern changes compared to the EO conditions. A possible explanation is that children are already close to their limits of stability during normal conditions and adults have more of a buffer.

A noticeable finding is the difference between equilibrium scores and sensory ratios. Ferber-Viart et al. (2007) and Steindl et al. (2006) each found the maturational age to be higher according to the equilibrium scores, compared to the sensory ratios. This could be explained by the involvement of the values during the EO-FS conditions in the calculation of sensory ratios, which can differ between age groups. The equilibrium score is, on the other hand, relative to a fixed value. This implies that the equilibrium score is sensitive to absolute differences between sensory conditions or age groups, while this is not necessarily true for the sensory ratios.

Sway-referenced visual conditions

The somatosensory ratios suggest achievement of mature somatosensory function during VS conditions by 6 years of age (Rine et al., 1998).

The results suggest achievement of mature postural control during VS conditions between 8 and 12 years of age (Cherng et al., 2001; Steindl et al., 2006). A remarkable finding by Cherng et al. (2001) was the lack of a difference in the ellipse area between 7-to-9-year-olds and adults, while Ferber-Viart et al. (2007) and Steindl et al. (2006) found a difference in equilibrium scores between 8-to-10- and 11-to-12-year olds. This could be explained by the fact that equilibrium scores indicate the postural stability in the AP direction, which is the direction of the visual perturbation, while the ellipse area indicates postural stability in both the AP and ML direction.

Visual flow or moving room

The results suggest that postural control during visual flow matures at least until 12 years of age (Ionescu et al., 2006; Polastri & Barela, 2013; Rinaldi et al., 2009).

However, Lim et al. (2018) found no difference between 10-year-olds and adults. This deviant finding could be attributed to a difference in visual stimulation. A digital projection of dots was used, which could be considered as less natural and therefore possibly easier to ignore, compared to a moving room.

Gain values tended to decrease and coherence tended to increase with increasing age (Godoi & Barela, 2008; Polastri & Barela, 2013; Rinaldi et al., 2009; Wann et al., 1998). Greffou et al. (2008) and (Lim et al., 2019) found children to be more sensitive to changes in visual conditions, which was not present for adults. These results imply higher influence, but less efficient use of visual information by children compared to adults.

A remarkable finding, is the slower reaction of children to changes in visual conditions, compared to adults (Lim et al., 2019; Polastri & Barela, 2013; Rinaldi et al., 2009). This implies that children are capable of sensory reweighting, however, not as efficiently as adults.

<u>Inappropriate somatosensory information</u>

During these conditions, the subject should rely primarily on the visual system. Therefore, when mature values during these conditions are reached, mature integration of the visual system is implied.

When all findings are taken together, a sequential development becomes apparent, starting with maturation during CS conditions, followed by maturation during SS conditions. The precise maturational ages, however, remain dubious and should be further examined.

Compliant surface

The visual ratios suggest achievement of mature visual function during CS conditions by least at 8 years of age (Cherng et al., 2001), while no younger participants were included.

The results suggest achievement of mature postural control during CS conditions by 8 years of age (Hsu et al., 2009).

A remarkable finding by Cherng et al. (2003), was the greater sensitivity to surface conditions of the COM vibration for 7-to-9-year-olds compared to adults in ML, but not in AP direction. A possible explanation, suggested by Hong, James, and Newell (2008), involves the more rapid development of postural control in the AP direction compared to the ML direction, related to the gait development.

Sway-referenced surface

The visual ratios suggest achievement of mature visual function during SS conditions around 15 years of age (Ferber-Viart et al., 2007; Hirabayashi & Iwasaki, 1995; Steindl et al., 2006). However, Peterson et al. (2006) found mature visual ratios for 11-year-olds. No clear cause for this ambiguity was present. Sparto et al. (2006) found no difference for 7-to-10-year-olds, however, their findings were based on an adjusted RMS value that controls for baseline differences, which restricts comparison with the other results using equilibrium scores.

The results suggest achievement of mature postural control during SS conditions by 15 to 16 years of age (Ferber-Viart et al., 2007; Hirabayashi & Iwasaki, 1995; Steindl et al., 2006).

Achilles tendon or whole-body vibration

The results suggest achievement of mature postural control during vibration not yet to be present by 9 to 11 years of age (Cuisinier et al., 2011; Liang et al., 2017; S. M. McKay et al., 2014). Remarkable findings are the higher post-vibration values in children (Liang et al., 2017; S. M. McKay et al., 2014), indicating slower sensory reweighting, and the faster maturation of postural control in the AP direction, compared to the ML direction (Liang et al., 2017). Both of these findings have been discussed earlier.

Absent or inappropriate visual information and inappropriate somatosensory information

During these conditions, the subject should rely primarily on the vestibular system. Therefore, when mature values during these conditions are reached, mature integration of the vestibular system is implied.

Too little unequivocal information was available for each sensory condition, therefore, all conditions were discussed together.

The vestibular ratios suggest no achievement of mature vestibular function before 16 years of age. Ionescu et al. (2006) and Peterson et al. (2006) found no difference between 12-year-olds and adults, however, respectively a non-significant trend and a very small sample size of the 12-year-old group were present.

The results suggest no achievement of mature postural control during visual and somatosensory perturbations before 16 years of age (Ferber-Viart et al., 2007; Hirabayashi & Iwasaki, 1995; Steindl et al., 2006). However, Hsu et al. (2009) disagreed and found mature postural control at younger ages, which could be explained by the fact that no normalization for anthropometric characteristics was conducted.

A remarkable finding by Steindl et al. (2006) was the greater vestibular ratio for 15-to-16-year-olds, which implies better function of the vestibular system, compared to adults. This difference is also present in the equilibrium scores during the EC-SS condition. However, during the VS-SS condition, adults show higher equilibrium scores, compared to 15-to-16-year-olds. Both conditions require reliance on the vestibular system, therefore, better vestibular function for 15-to-16-year-olds, compared to adults, can not be concluded.

A remarkable finding by Cherng et al. (2001) was the increase in COP amplitude from EO-FS to EC-CS and VS-CS in the AP direction, but not in the ML direction. Cherng et al. (2001) explained this difference by a faster maturation of the hip strategy, important for ML postural control, compared to the ankle strategy, important for AP postural control. This finding, however, disagrees with our earlier results. Another possible explanation is that the compliant surface has a more direct influence on ankle control, compared to hip control.

Visual preference

Based on the findings, a decrease of visual preference with increasing age is plausible (Ferber-Viart et al., 2007; Ionescu et al., 2006). However, Peterson et al. (2006) found no difference between age groups. The exact age of of achievement of mature visual preference, however, remains uncertain.

General findings

When all results are taken together, a clear maturational effect on postural control and the use of sensory information is visible. This is in line with the results of Gouleme et al. (2014), which presented an increase in cancelling time with increasing age during all sensory conditions, which indicates a better use of sensory information.

The development of the different sensory systems can be placed in sequential order, which has already been defined in previous literature (Brandt, Wenzel, & Dichgans, 1976; Forssberg & Nashner, 1982; Shumway-Cook & Woollacott, 1985, 2017) and is hereby confirmed. The somatosensory system matures first, between 3 and 6 years of age, followed by the visual system, between 8 and 15 years, and ultimately by the vestibular system, around 16 years of age.

Remarkably, another sequential order is present. The postural control in the AP direction matures before the postural control in the ML direction. This could be attributed to gait development (Hong et al., 2008), which leads to more experience concerning postural control in this direction.

An interesting finding is the sequential development of postural control between perturbations of the same sensory systems.

Concerning the sensory reweighting during visual perturbations, somatosensory integration during visual deprivation (EC) matures well before somatosensory integration visual disturbance (VS and moving room/visual flow). These differences can be attributed to the development of the vestibular system, of which the main function is to act as a reference to guide sensory reweighting. During, for example, the EC condition, no visual info is available, which makes this situation more convenient

to reweight the sensory information, compared to a situation in which erroneous visual information is present, such as during the VS, moving room, or visual flow conditions. Simply put, when no information of a specific sensory system is available, this sensory system can not be used. However, when erroneous information of a sensory system is available, the emphasis on that system has to be downgraded. This is where the vestibular system comes in action and provides a reliable reference frame, which can be used to select the appropriate sensory system. Therefore, if the vestibular system has not yet reached full functionality, this process operates less efficiently. Similar theories have already been developed concerning the influence of the referential function of the vestibular system on postural development (Ferber-Viart et al., 2007; Hirabayashi & Iwasaki, 1995; Ionescu et al., 2006).
Similar findings are present concerning sensory reweighting during somatosensory perturbations. The visual integration and postural control during CS conditions mature well before the visual integration and postural control during SS conditions or Achilles tendon/whole-body vibration. This could be attributed to the fact that a CS downsizes the magnitude of the somatosensory feedback since the ankles are free to move through a certain range before the resistance of the foam increases. This is in contrast with the incorrect somatosensory information, provided by the SS and Achilles tendon/whole-body vibration. Therefore, the CS condition is less challenging, compared to the SS condition.

Another interesting finding is the difference in maturation between the sensory ratios and postural control. The sensory ratios indicate the sensory function and consider the values during the EO-FS condition, while the other outcomes indicate postural control and do not consider the values during the EO-FS condition. In the younger age groups, the sensory ratios achieve mature values well before the postural control. This difference decreases with increasing age, which can be explained by changes in the body morphology and refinement of motor coordination and sensorimotor integration (Shumway-Cook & Woollacott, 2017).

5.3 Reflection of strengths and weaknesses of study design

Theremay be some possible limitations in this review. The first limitation concerns the use of a self-constructed quality assessment tool, therefore, reliability and validity were not assessed. The second limitation concerns the use of language criteria in the selection process, which could contribute to a selection bias. The third limitation concerns the limited access to research articles. Two articles had to be excluded, because of an unavailable full-text. The fourth limitation concerns the use of varying outcome variables and measurement instruments, which made the comparison of literature more complex. The fifth limitation concerns the use of young adults as a reference group, while Faraldo-Garcia et al. (2013) suggested changes in sensory organization well into adulthood.

5.4 Recommendations for future studies

This review has exposed some possible gaps in the current literature, further research should be conducted to gain more insight.

First, more research should be conducted concerning the reliability and validity of the measurement instruments and outcome variables used in this research field. A great variety of measurement instruments and outcome variables were used in the current literature, while little or no information was present about their validity and reliability. This variety limits the comparability.

Second, more research should be conducted concerning the sensory reweighting throughout the entire course of life. When assessing the maturation of sensory reweighting, young adults are commonly considered the reference group. However, Faraldo-Garcia et al. (2013) presented changes in sensory reweighting until well into adulthood. This should be considered when selecting a reference group.

Third, future research should narrow down the age ranges of groups, to be able to formulate more exact findings.

6 Conclusion

A clear sequential order in sensory reweighting during different sensory conditions is present, however, the exact ages of achievement of mature sensory reweighting, and therefore the integration of the different sensory systems, remain dubious. First, the sensory reweighting during absent or inappropriate visual information, and therefore the integration of the somatosensory system, matures between 3 and 6 years of age. Second, the sensory reweighting during inappropriate somatosensory information, and therefore the integration of the visual system, matures between 8 and 15 years of age. Third, the sensory reweighting during absent or inappropriate visual information and inappropriate somatosensory information, and therefore the integration of the vestibular system, matures around 16 years of age.

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Part 2: protocol

1. Introduction

Postural control is the ability to control the center of mass (COM) within the base of support and to establish and maintain an appropriate position of body segments relative to one another and the environment (Earhart, 2013; Shumway-Cook & Woollacott, 2017).

Postural control requires adequate interaction between the neural and musculoskeletal systems (Horak & Macpherson, 1996; Shumway-Cook & Woollacott, 2017). The essential neural components consist of motor processes, including the coordination of synergistic muscle work, sensory processes, including individual sensory systems and the organization of the sensory inputs, and higher-level cognitive processes, including cognitive resources and postural strategies (Shumway-Cook & Woollacott, 2017).

The integration of visual, vestibular, and somatosensory information attributes to the postural control (Woollacott & Shumway-Cook, 1990). Context-specific integration of the sensory systems, however, is required for optimal postural control (Shumway-Cook & Woollacott, 1985). This is called sensory reweighting.

Postural control is known to be less efficient in children compared to adults, based on various postural control outcomes, which implies a maturational effect (Cuisinier et al., 2011; Gouleme et al., 2014).

Adequate sensory reweighting during altering sensory conditions needs to be learned (Shumway-Cook & Woollacott, 2017) and, therefore, attributes to the improvement of postural control throughout childhood (Rival et al., 2005; Verbecque et al., 2016; Wolff et al., 1998). Based on our previous literature study, no certainty is present concerning the ages of achievement of mature postural control and sensory reweighting during changing sensory conditions.

To assess this maturational effect, differences in postural control between age groups should be measured. This can be accurately done by recording the body movements in standing position during different sensory conditions, known as posturography (Kapteyn et al., 1983), of which computerized dynamic posturography (CPD) is considered to be the gold standard (Saha, 2016). Neurocom International developed a CPD system, named the Equitest System. No description of the validity or reliability of the Neurocom Equitest System for healthy children is present in the current literature, however, the Neurocom Equitest System has proven to be reliable in adults (Tesio, Rota, Longo, & Grzeda, 2013).

The Neurocom Equitest System consists of two parts, the sensory organization test (SOT) and the motor control test.

The most useful form to establish the integration of each sensory system, and therefore sensory reweighting, is the SOT (Chaudhry, Bukiet, Ji, & Findley, 2011; Saha, 2016). The SOT evaluates the participant's response to a variety of sensory altered conditions, which limit or emphasize the use of specific sensory inputs.

An important consideration is that the vestibular system can not be perturbed by the SOT. This implies the input of the vestibular system always to be correctly available. However, the primary function of the vestibular system is to provide a referential frame, not to act as a direct sensory feedback system for the maintenance of postural control. This means that the main contribution of vestibular input lies within the process of sensory reweighting and that it contributes only for a small part to balance when reliable somatosensory or visual inputs are available (Shumway-Cook & Woollacott, 2017).

The Neurocom Equitest System computes the equilibrium score (ES) as an indicator for the postural control in the anteroposterior (AP) direction. However, Chaudhry et al. (2005) found the postural stability index (PSI) to be more valid and reliable compared to the ES when assessing postural control in the AP direction. The computation of the PSI includes anthropometric characteristics, such as the body weight and height, these are not included in the ES calculation. Also, the PSI can be calculated when the subject falls, while an ES of zero would be attributed (Chaudry 2005).

Based on these outcomes, the sensory ratios can be computed, which indicate the function of the somatosensory, visual, and vestibular system, and therefore the sensory reweighting. Commonly, only three of the five possible ratios are calculated, one for each sensory system. However, based on our previous literature search, the other two conditions can also provide relevant information.

2. Aim of the study

This study will be conducted as part of a Master's thesis at the Faculty of Rehabilitation Sciences, Hasselt University. The testing will be conducted in the research center of rehabilitation sciences REVAL in Diepenbeek.

In light of the ambiguity about the maturational process of the different sensory systems, the purpose of this study is to describe the ages of achievement of mature postural control during the different sensory conditions of the SOT and to use those results to situate the ages of achievement of mature sensory reweighting.

A novel approach will be implemented by computing the PSI values, to ensure reliable and valid results, and by computing the sensory ratio for every possible ratio, for a more complete insight.

2.1. Research question

What are the ages of achievement of mature sensory reweighting and postural control during each sensory condition of the SOT?

2.2. Hypotheses

Based on the research question, the following hypotheses were formulated:

- Sensory reweighting during the eyes closed, fixed surface condition is hypothesized to be mature at 3 to 4 years of age.
- Sensory reweighting during the sway-referenced visual environment, fixed surface condition is hypothesized to be mature at 5 to 6 years of age.
- Sensory reweighting during the eyes open, sway-referenced surface condition is hypothesized to be mature at 13 to 14 years of age.
- Sensory reweighting during the eyes-closed, sway-referenced surface condition is hypothesized to be mature at 15 to 16 years of age.
- Sensory reweighting during the sway-referenced visual environment, sway-referenced surface condition is hypothesized to be mature at 17 to 18 years of age.
- Sensory reweighting will be mature under all sensory conditions for the 19-to-25-year-olds.
- In 3-to-8-year-olds, mature values of the sensory ratios will be achieved well before mature values of the PSI, this difference will not be present in older children and adults.

3. Methods

3.1. Design of the study

A cross-sectional study will be conducted. Participants will be categorized into different age groups and will undergo a SOT on one single moment, using the Neurocom Equitest System.

3.2. Participants

Participants will be allocated to different groups according to their age. Children between 3 and 18 years of age will be allocated per two years of age and adults will be allocated to groups of 19-to-25-year olds, 26-to-35-year-olds, and 36-to-45-year-olds. The aim is to include an equal number of male and female participants in each group.

Multiple adult groups were included to ensure correct reference values when assessing the maturation of postural control and sensory reweighting.

3.2.1. Inclusion criteria

- Healthy individuals between 3 and 45 years of age
- The ability to stand independently
- Understanding of English and/or Dutch

3.2.2. Exclusion criteria

- The intake of medication with a possible influence on balance performance
- Participation in sports at top level
- Height < 203 cm
- Any motor, sensory, or cognitive disorders with a possible influence on balance performance
- Recurrent symptoms of dizziness or motion sickness

3.2.3. Recruitment

The required sample size to ensure a power of 0.8 needs to be computed. Participants will mainly be recruited from the community through social media, e-mail, and flyers.

3.3. Medical ethics

Approval will be requested at the medical ethics committee of Hasselt University. Signed informed consent of all participants, or their guardians if minors, will be required.

3.4. Procedure

Brief standardized history will be taken by letting the participants fill out a questionnaire, to ensure they fulfill the following criteria: 1) no neurological or musculoskeletal impairment with an effect on balance; 2) no symptoms of dizziness or lightheadedness; 3) normal or corrected to normal vision; 4) no history of concussion; 5) no complaints of motion sickness; 6) no use of medication with an effect on the CNS or balance; 7) no participation in sports at top level.

Participants will be asked to take place on the force plate barefooted and maintain an upright position with their feet at shoulder-width on a mediolateral line parallel with the axis of the force platform, their arms hanging passively by the sides of their trunk, and their gaze fixed at a picture (9 x 10 cm) attached to the front wall at eye level. Further technical details of the Neurocom Equitest System can be found in appendix 11 (Natus, 2015). Participants were requested to wear comfortable loose clothing. For safety reasons, a safety harness that does not limit sway will be put on by children under 6 years of age, older participants will be informed and able to choose for themselves. Furthermore, a researcher stood within reach, but out of sight, during every trial.
Parents were asked not to encourage their children during the testing.

Each condition will last for 20 seconds and 3 trials were performed for each condition. The conditions will be as followed:

- *Condition 1*: fixed surface with eyes open in a static visual environment. All sensory inputs are available and reliable.
- *Condition 2*: fixed surface with eyes closed. Reliable somatosensory and vestibular inputs are available.
- *Condition 3*: fixed surface with eyes open in a sway-referenced visual environment. Reliable somatosensory, reliable vestibular, and inappropriate visual inputs are available.
- *Condition 4*: sway-referenced surface with eyes open in a static visual environment. Reliable visual, reliable vestibular, and inappropriate somatosensory inputs are available.
- *Condition 5*: sway-referenced surface with eyes closed. Reliable vestibular and inappropriate somatosensory inputs are available.
- *Condition 6*: sway-referenced surface with eyes open in a sway-referenced visual environment. Reliable vestibular, inappropriate somatosensory and inappropriate visual inputs are available.

“Fixed surface” refers to the conditions where the force platform is static. “Sway-referenced surface” refers to the conditions where the force platform moves according to the body sway of the participant and thereby reduces somatosensory feedback by eliminating alterations in proprioceptive feedback of the ankles. “Sway-referenced visual environment” refers to the conditions where the visual environment moves according to the body sway of the participant and thereby disturbs the visual feedback. Both the environment and the surface are controlled by the COP movements in the AP direction (Chaudhry et al., 2011; Saha, 2016).

The order of the conditions will be randomized while precluding the succession of two the same conditions. Before starting the next trial, at least ten seconds and full balance recovery are required. After every sixth condition, a rest period of two minutes will be implemented, during this rest, the participant is requested to sit down.

To ensure visual deprivation during the eyes-closed conditions, an opaque goggle will be worn.
If a participant does not maintain a fixed gaze, the trial will be excluded and repeated at the end.

3.5. Outcomes

Outcomes will be measured in the AP direction, while postural control in this direction is related to gait development, thus more clinically relevant (Hong et al., 2008), and all sensory perturbations occur in this direction.

3.5.1. Primary outcomes

Postural stability index

The PSI is an indicator of postural sway in the AP direction and is defined as the percentual ratio of the destabilizing torque due to gravity and the total stabilizing torque. A score of 100 indicates perfect balance, the deviation from this score indicates the magnitude of instability (Chaudhry et al., 2005). The equation to calculate the PSI can be found in appendix 12.

Sensory ratio

The sensory ratio provides a percentual contribution of each sensory system to postural control. Visual preference represents the degree to which an individual relies on visual information, even when incorrect. The calculation is based on the PSI, obtained during each sensory condition.

- Somatosensory ratio (eyes closed): $\frac{\text{condition 2}}{\text{condition 1}} \times 100$
- Visual ratio: $\frac{\text{condition 4}}{\text{condition 1}} \times 100$
- Vestibular ratio (eyes closed): $\frac{\text{condition 5}}{\text{condition 1}} \times 100$
- Visual preference: $\frac{\text{condition 3 + condition 6}}{\text{condition 2 + condition 5}} \times 100$

Besides the conventional ratios, the ratios involving the other two conditions were also computed.

- Somatosensory ratio (visual disturbance): $\frac{\text{condition 3}}{\text{condition 1}} \times 100$
- Vestibular ratio (visual disturbance): $\frac{\text{condition 6}}{\text{condition 1}} \times 100$

3.5.2. Secondary outcomes

The percentual losses of balance per group will be registered. A loss of balance is defined as taking a step, suspending in the harness, swinging with arms, or falling over. It is calculated by dividing the losses of balance by the total number of trials conducted for that group and afterwards multiplying by 100.

3.6. Data analysis

Statistical analysis will be conducted using SAS JMP Pro 14. The comparison of the outcome variables between age groups and sensory conditions will be conducted using a two-way ANOVA. If a significant age effect would be present, Tukey post hoc tests will be employed to test possible differences between age groups during the same sensory condition. The level of statistical significance will be set at 0.05.

4. Timing

Approval by the medical ethics committee of Hasselt University is required for the commencement of this study, the request will be applied in July 2020 and will presumably be processed and approved by the end of August 2020. Afterwards, from September 2020 onwards, the recruitment of participants can be commenced, which will last until adequate sample size is reached. When a participant will be recruited, a date for the testing will be set. The clinical testing will commence in October and be completed by the end of February 2021. Afterwards, the data-analysis will be conducted, which will be completed by the end of March 2021. Afterwards, the results can be described and conclusions can be drawn, this should be accomplished by the end of May 2021.
The deadline for submission is situated at the beginning of June 2021.
The stated timing is provisional and might be adjusted, depending on several external factors.

A clear representation of the schedule is presented in table 3.

Table 3. schedule

	July 2020	August 20200	September 2020	October 2020	November 2020	December 2020	Januar 2021	February 2021	March 2021	April 2021	May 2021	June 2021
Processing by the ethics committee	X	X	X									
Recruitment			X	X	X	X	X					
Testing				X	X	X	X	X				
Data-analysis									X			
Results + conclusion										X	X	
Submission												X

5. References protocol

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Appendices

1. PICO search query

Patient	**Healthy children aged 3 – 18 years old**
Intervention	Somatosensory and/or visual perturbation during a standing position
Comparison	Healthy adults
Outcome	Center of pressure and body sway movements

2. Search strategy

Search Strategy Web of Science

	Term	Resultaten 6/4	Resultaten 5/5
1	"postural balance"	2.320	2.342
2	“posture”	44.657	44.972
3	"postur*”	83.878	84.445
4	“equilibrium”	562.596	565.510
5	“balance”	505.202	509.119
6	“stability”	1.583.602	1.597.869
7	“Biomechanical Phenomena/physiology”	1	1
8	1 OR 2 OR … OR 7	2.610.077	2.630.755
9	"standing position"	3.116	3.130
10	"stance"	29.409	29.622
11	"standing"	144.656	145.567
12	“upright”	18.759	18.851
13	9 OR 10 OR 11 OR 12	187.119	188.310
14	"posturography"	2.394	2.410
15	“CTSIB”	42	43
16	"sensory reweighting"	136	136
17	“multisensory reweighting”	8	8
18	"sensory organization"	48	49
19	“sensory organization”	660	661
20	“sensory reorganization”	3	3
21	“sensory reorganization”	21	21
22	“SOT”	4.903	4.930
23	“Equitest”	156	156
24	“sensory reintegration”	8	8
25	“sensory processing”	5.334	5.376
26	“sensory integration”	2.032	2.040
27	“foam”	73.209	73.987
28	“Tendon*” AND “vibration*”	1.387	1.395
29	“visual disorientation”	25	26
30	“visual flow”	240	240
31	“optic flow”	3.292	3.297
32	“moving room”	71	72
33	“swinging room”	3	3
34	“sway-referenced”	116	116
35	“sensory conflict”	262	263
36	“sensory manipulation”	59	59
37	"visual perturbation"	79	80
38	"visual disturbance"	1.500	1.508
39	"sensory perturbation"	31	31
40	"sensory disturbance"	913	920
41	"somatosensory perturbation"	3	3
42	"somatosensory disturbance"	13	13
43	“proprioceptive disturbance”	9	9
44	“proprioceptive perturbation”	14	14
45	“eyes closed"	4.213	4.247
46	"blindfolded"	1.307	1.318
47	“unstable surface”	512	514

48	“compliant surface”	310	312
49	14 OR 15 OR … OR 48	100.659	101.603
50	“oscillation”	151.563	152.321
51	“oscillated”	3.876	3.897
52	“dynamic”	1.381.043	1.391.885
53	“unreliable”	30.602	30.831
54	“noisy”	70.943	71.526
55	“altered”	414.370	416.683
56	“disturbed”	65.784	66.166
57	“disturbance”	189.664	191.127
58	“perturb*”	397.880	399.741
59	50 OR 51 OR … OR 58	2.595.249	2.612.842
60	“sensory info”	1	1
61	“sensory information”	7.619	7.661
62	“sensory input”	5.141	5.160
63	“somatosensory information”	738	741
64	“somatosensory input”	526	525
65	“visual information”	16.297	16.396
66	“visual input”	3.351	3.365
67	“proprioceptive input”	354	355
68	“proprioceptive information”	854	857
69	“vestibular input”	397	397
70	“vestibular information”	464	467
71	60 OR 61 OR …OR 71	33.809	33.984
72	59 AND 71	5.034	5.062
73	“Growth and Development”	39.214	39.543
74	“Adolescent”	172.689	173.688
75	“Child”	428.447	431.066
76	“Human development”	14.532	14.653
77	“boys”	100.217	100.788
78	“girls”	114.531	115.216
79	“adolescent*”	412.405	414.732
80	“teen*”	42.383	42.630
81	“youth*”	159.557	160.977
82	“child*”	1.839.362	1.848.622
83	“human development”	14.532	14.653
84	“maturation”	191.857	192.817
85	75 OR 76 OR … OR 85	2.384.090	2.396.678
86	8 AND 13 AND 72 AND 85	332	334

Search Strategy PubMed

	Term	**Resultaten 6/4**	**Resultaten 5/5**
1	"postural balance" [MeSH Terms]	22.731	22.850
2	“posture” [MeSH Terms]	73.003	73.158
3	"postur*” [Title/Abstract]	61.852	62.105
4	“equilibrium” [Title/Abstract]	132.940	133.434
5	“balance” [Title/Abstract]	217.107	218.391
6	“stability” [Title/Abstract]	416.650	420.090
7	“Biomechanical Phenomena/physiology” [MeSH Terms]	10.699	10.764
8	1 OR 2 OR … OR 7	854.710	860.116
9	"standing position" [MeSH Terms]	333	359
10	"stance" [Title/Abstract]	14.698	14.780

11	"standing" [Title/Abstract]	74.307	74.705
12	“upright” [Title/Abstract]	14.832	14.884
13	9 OR 8 OR … OR 12	99.631	100.151
14	"posturography" [Title/Abstract]	1.852	1.862
15	“CTSIB” [Title/Abstract]	46	46
16	"sensory reweighting"[Title/Abstract]	133	108
17	“multisensory reweighting” [Title/Abstract]	9	8
18	"sensory organisation" [Title/Abstract]	46	46
19	“sensory organization” [Title/Abstract]	565	570
20	“sensory reorganisation” [Title/Abstract]	2	2
21	“sensory reorganization” [Title/Abstract]	16	16
22	“SOT” [Title/Abstract]	1.785	1.801
23	“Equitest” [Title/Abstract]	158	158
24	“sensory reintegration” [title/abstract]	7	6
25	“sensory processing” [title/abstract]	4.757	4.789
26	“sensory integration” [title/abstract]	1.422	1.426
27	“foam” [title/abstract]	19.934	20.095
28	(“Tendon*” [Title/Abstract] AND “vibration*”[Title/Abstract])	851	853
29	“visual disorientation” [title/abstract]	32	32
30	“visual flow” [title/abstract]	121	121
31	“optic flow” [title/abstract]	1.367	1.368
32	“moving room” [title/abstract]	53	53
33	“sway-referenced” [title/abstract]	116	116
34	“sensory conflict” [Title/Abstract]	206	206
35	“sensory manipulation” [Title/Abstract]	45	45
36	"visual perturbation"[Title/Abstract]	72	72
37	"visual disturbance"[Title/Abstract]	2.076	2.082
38	"sensory perturbation"[Title/Abstract]	25	25
39	"sensory disturbance"[Title/Abstract]	1.530	1.533
40	"somatosensory disturbance"[Title/Abstract]	16	16
41	"proprioceptive perturbation"[Title/Abstract]	14	14
42	"proprioceptive disturbance"[Title/Abstract]	7	7
43	eyes closed"[Title/Abstract]	4.287	4.310
44	"blindfolded" [Title/Abstract]	1.106	1.111
45	“unstable surface” [title/abstract]	254	255
46	“compliant surface” [title/abstract]	124	125
47	14 OR 15 OR … OR 46	40.746	40.996
48	“oscillation” [title/abstract]	23.077	23.174
49	“oscillated” [title/abstract]	1.793	1.797
50	“dynamic” [title/abstract]	342.112	344.456
51	“unreliable” [title/abstract]	14.214	14.277
52	“noisy” [title/abstract]	13.040	13.111
53	“altered” [title/abstract]	381.960	383.616
54	“disturbed” [title/abstract]	41.751	41.910
55	“disturbance” [title/abstract]	78.204	78.517
56	“perturb*” [title/abstract]	106.869	107.353
57	48 OR 49 OR … OR 56	965.318	970.328
58	“sensory information” [title/abstract]	6.259	6.283
59	“sensory input” [title/abstract]	4.804	4.818
60	“somatosensory information” [title/abstract]	748	746
61	“somatosensory input” [title/abstract]	523	518
62	“visual information” [title/abstract]	8.550	8.586
63	“visual input” [title/abstract]	2.809	2.821
64	“proprioceptive input” [Title/Abstract]	380	382
65	“proprioceptive information”[Title/Abstract]	774	776
66	“vestibular input” [Title/Abstract]	434	434
67	vestibular information” [Title/Abstract]	478	478

68	62 OR 63 OR … OR 76	23.986	24.072
69	57 AND 68	3.571	3.589
70	47 OR 69	43.703	43.972
71	“Growth and Development” [MeSH Terms]	1.392.848	1.397.941
72	“Adolescent” [MeSH Terms]	2.001.429	2.007.903
73	“Child” [MeSH Terms]	1.887.055	1.892.734
74	“Human development” [MeSH Terms]	65.529	65.791
75	“boys”[Title/Abstract]	85.458	85.795
76	“girls” [Title/Abstract]	91.757	92.129
77	“adolescent*”[title/abstract]	251.732	253.132
78	“teen*”[title/abstract]	30.200	30.338
79	“youth*”[title/abstract]	78.315	78.854
80	“child*”[title/abstract]	1.403.784	1.409.331
81	“human development”[title/abstract]	6.703	6.746
82	maturation [title/abstract]	143.181	143.738
83	71 OR 72 OR …OR 82	4.774092	4.790.365
84	8 AND 13 AND 70 AND 83	616	619

3. Quality assessment tool

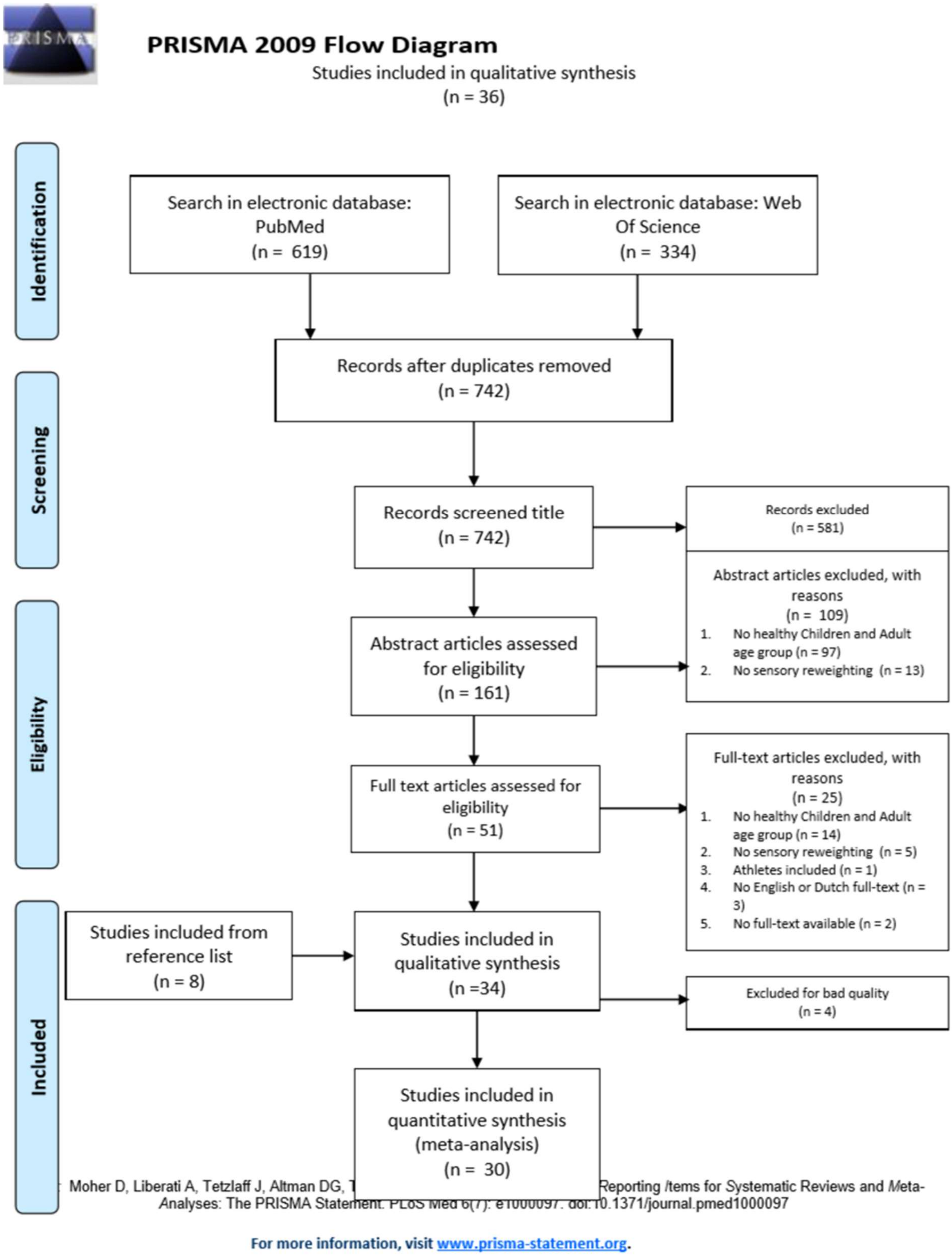
	Complied	Not complied	Further explanation if needed
1. Is the objective of the study clearly described?			
2. Is the study design clearly described and appropriate for the stated aims?			
3. Is the sample adequately selected and described?			
3.1. Is the sample size justified?			
3.2. Are the methods used to recruit the participants well described and correct (informed consent)?			
3.3. Are the criteria for inclusion and exclusion described?			
3.4. Are the participants' characteristics described in detail and was there a correction for a confounding effect (confounders were taken into account or matching of groups)? Is the sample frame taken from an appropriate population base so that it closely represents the target population under investigation?			
4. Do the methods allow reproducibility?			
4.1. Are the experimental procedures clearly described to ensure homogeneity (foot placement, marker placement, camera setup, perturbation, movement tasks, trial duration, rest interval)?			
4.2. Is the data extraction clearly described?			
4.3. Are the statistical tests used appropriate and clearly described?			
5. Do the methods meet all the objectives proposed?			
6. Are the measuring instruments valid and reliable?			

7. Are the main outcomes clearly stated?			
8. Are the results valid, reliable and according to the sample studied?			
9. Are the results presented clearly and with statistical significance and confidence intervals?			
10. Is the question of the study adequately answered in the discussion?			
11. Are the limitations acknowledged and described?			
12. Are the conclusions appropriate, given the study methods, interpreted logically, supported by the literature and results, and clearly stated?			

4. Exclusion full-text

Reason for exclusion	Number	References
No Comparison healthy of children (2-17 years old) and adults (18-44 years old).	14	(Accornero, Capozza, Rinalduzzi, & Manfredi, 1997; Aust, 1996; Bermudez Rey, Clark, & Merfeld, 2017; Fujimoto, Egami, Demura, Yamasoba, & Iwasaki, 2015; Gomez et al., 2009; Gouleme et al., 2014; Hatzitaki, Zisi, Kollias, & Kioumourtzoglou, 2002; Kim, Nussbaum, & Madigan, 2008; Liaw, Chen, Pei, Leong, & Lau, 2009; M. J. McKay et al., 2017; Nardone, Siliotto, Grasso, & Schieppati, 1995; Schmuckler, 1997; Sibley, Beauchamp, Van Ooteghem, Paterson, & Wittmeier, 2017; Stoffregen, Hove, Schmit, & Bardy, 2006; Stoffregen, Schmuckler, & Gibson, 1987)
No sensory reweighting standing balance task during double limb support	4	(Balogun, Akindele, Nihinlola, & Marzouk, 1994; Blanchet, Prince, & Messier, 2019; M. J. McKay et al., 2017; C. L. Riach & Starkes, 1993; Viel, Vaugoyeau, & Assaiante, 2009)
Athletes included	1	(Busquets, Aranda-Garcia, Ferrer-Uris, Marina, & Angulo-Barroso, 2018)
No English or Dutch full-text	3	(Gawron, Pospiech, Orendorz-Fraczkowska, & Noczynska, 2002; Perotti, Barela, Polastri, & Tani, 2012; Steindl, Ulmer, & Scholtz, 2004)
No full-text available	2	(Diener, Dichgans, Guschlbauer, & Bacher, 1986; Tjernstrom, Oredsson, & Magnusson, 2006)

5. Flowchart



Flowchart study selection - *Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009) Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. https://doi.org/10.1371/journal.pmed.1000097*

6. Summary of quality assessment

	1. Object clearly described?	2. Study design? Appropriate for aims?	3. Sample selected adequately?	3.1. sample size justified?	3.2. Methods to recruit? Informed consent?	3.3. Inclusion and exclusion criteria?	3.4. Participans' characteristics? Correction for confounding effect?	4. Do the methods allow for reproducibility?	4.1 Experimental procedures?	4.2 Data extraction?	4.3 Statistical tests?	5. Methods meet objectives?	6. Measuring instruments valid and reliable?	7. Main outcomes clearly stated?	8. Results valid, reliable and according to sample?	9. Results presented? With statistical significance and confidence intervals?	10. Study questions answered?	11. Limitations described?	12. Conclusions?	score
Barela et al. (2003)	X	X			X	X			X	X	X	X		X		X	X	X	X	13
Barela et al. (2011)	X	X			X	X			X	X	X	X		X		X	X		X	12
Cherng and Chen (2001)	X	X				X			X	X	X	X		X		X	X		X	11
Cherng et al. (2003)	X	X				X			X	X	X	X		X		X	X		X	11
Cuisinier et al. (2011)	X	X			X	X			X	X	X	X		X		X	X		X	12
Faraldo-Garcia et al. (2013)	X	X				X			X	X	X	X		X		X	X		X	11
Ferber-Viart et al. (2007)	X	X				X			X	X	X	X		X		X	X		X	11
Ferronato and Barela (2011)	X	X			X	X			X	X	X	X		X		X	X		X	12
Foster et al. (1996)	X	X								X		X		X		X	X	X	X	8
Godoi and Barela (2008)	X	X			X					X	X	X		X		X	X		X	9
Godoi and Barela (2016)	X				X	X				X	X	X		X			X		X	7
Greffou et al. (2008)	X	X				X			X	X	X	X		X		X	X	X	X	12

Hirabayashi & Iwasaki (1995)	X	X				X				X	X	X		X		X	X		X	9
Hsu et al. (2009)	X	X				X	X		X	X	X	X		X		X	X		X	12
Hytönen et al. (1993)	X	X				X			X	X	X	X		X		X	X		X	11
Ionescu et al. (2006)	X	X			X	X	X		X	X		X		X		X	X		X	12
Liang et al. (2017)	X	X					X		X	X	X	X		X		X	X	X	X	12
Lim et al. (2018)	X	X			X	X	X		X	X	X	X	X	X		X	X	X	X	15
Lim et al. (2019)	X	X			X	X	X		X	X	X	X		X		X	X	X	X	14
Mckay et al. (2014)	X	X				X	X		X	X	X	X		X		X	X		X	12
Oba et al. (2015)	X	X				X	X		X	X	X	X		X		X	X	X	X	13
Peterka and Black (1990)		X				X			X	X	X	X		X				X	X	8
Peterson et al. (2005	X	X			X		X				X	X	X	X		X	X	X	X	11
Polastri and Barela (2013)	X	X							X		X	X		X		X	X		X	9
Riach and Starkes (1994)	X	X					X		X	X	X	X		X		X	X		X	11
Rinaldi et al. (2009)	X								X	X	X	X		X		X	X		X	9
Rine et al. (1998)	X	X			X	X			X	X	X	X		X	X	X	X	X	X	14
Sakaguchi et al. (1994)	X	X				X			X	X	X			X			X		X	8
Schärli et al. (2012)	X						X		X	X	X	X		X		X	X	X	X	11
Sparto et al. (2006)	X	X					X		X	X	X	X		X		X	X	X	X	12
Steindl et al. (2006)	X	X			X	X	X				X	X		X		X	X		X	10
Wachholz et al. (2019)	X	X			X	X	X		X	X	X	X		X		X	X	X	X	14
Wann et al. (1998)		X				X	X			X	X	X		X		X		X	X	9
Wu et al. (2009)	X	X				X	X		X	X	X	X		X		X	X	X	X	13

7. Strengths-weaknesses analysis

	Strengths	Weaknesses
Barela et al. (2003)	Clear description of the experimental procedures, recruitment methods and results	No information about participant characteristics Trail duration was too short Limitations not clearly described
Barela et al. (2011)	Clear description of the recruitment methods, eligibility criteria, experimental procedure, and the results	No information about participant characteristics Limitations not described
Cherng and Chen (2001)	Clear description of the experimental procedure and the results	No informed consent No information about the participant characteristics Limitations not described
Cherng et al. (2003	Clear description of the experimental procedure, eligibility criteria, and the results	No informed consent No clear description of the participants' characteristics Limitations not described
Cuisinier et al. (2011)	Clear description of the recruitment methods, experimental procedure, and the results	No clear description of the participants' characteristics Limitations not described
Faraldo-Garcia et al. (2013)	Clear description of the eligibility criteria, the experimental procedure, and the results	No information about participants characteristics No informed consent No post-hoc tests Limitations not described
Ferber-Viart et al. (2007)	Clear description of the eligibility criteria, the experimental procedure, and the results	No information about the recruitment procedure Limitations not described
Ferronato and Barela (2011)	Clear description of the recruitment methods, the inclusion criteria, the experimental procedure, and the results	No description of the participants' characteristics Limitations not described
Foster et al. (1996)	Clear description of the results Limitations described	No description of the recruitment methods No clear description of the participants' characteristics, the eligibility criteria, and the experimental methods The parents supported the child if he or she felled, but the researchers are not sure that parents supported the child during the visual disturbance
Godoi and Barela (2008)	Clear description of the recruitment methods and the results	No clear description of the participants' characteristics, the eligibility criteria and the posture during the experimental procedure Limitations not described
Godoi and Barela (2016)	Clear description of the recruitment strategy	No clear description of the eligibility criteria, the participants' characteristics and the results No description of the posture during the experimental procedure Limitations not described

Greffou et al. (2008)	Clear description of the eligibility criteria, the experimental procedure and the results Clear description of possible underlying causal mechanism of balance maturation	No clear description of the participants' characteristics No description of the recruitment methods
Hirabayashi and Iwasaki (1995)	Clear description of results, eligibility criteria, and statistical tests	No clear description of informed consent for adults and experimental procedure No description of the recruitment strategy and the posture during the experimental procedure No post-hoc tests for every condition Only neighboring age groups compared Limitations not described
Hsu et al. (2009)	Clear description of the eligibility criteria, the participants' characteristics, the experimental procedure, and the results	No description of informed consent and the recruitment strategy Limitations not described
Hytonen et al. (1993)	Clear description of the experimental procedure and the results	No description of the recruitment strategy and informed consent No clear description of the participants' characteristics Limitations not described Limited mentioning of p values
Ionescu et al. (2006)	Clear description of the recruitment strategy, the eligibility criteria, the participants' characteristics, the experimental procedure, and the results	Limitations not described
Liang et al (2017)	Description of the participants' characteristics Experimental procedure clearly described	Eligibility criteria not clearly described. No recruitment strategy described.
Lim et al. (2018)	Characteristics of the participants clearly described and results were controlled for height. Clear description of the test procedure, the eligibility criteria, and the results Limitations described	Large variance in results Only one speed of optical flow
Lim et al. (2019)	Clear description of the eligibility criteria, the participants' characteristics, the test procedure, and the results	The use of age groups instead of covariant analysis Children age range 8-12 years
S. M. McKay et al. (2014)	Clear description of the participants' characteristics, the experimental procedure, and the results Use of two children groups Limitations described	No description of the limitations Foot placement not described Limitations not described
Oba et al. (2015)	Clear description of the participants' characteristics, the test procedure, and the results Limitations described	No clear description of the recruitment procedure Only compared between 5 to 6 year old children and adults Short length of tests and small number of tests
Peterka and Black (1990)	Clear description of the experimental procedure Description of the limitations	No information about the recruitment procedure

		No clear description of the participants' characteristics, the eligibility criteria and the results
Peterson et al. (2006)	Equitest system has been shown reliable Description of participant characteristics, recruitment methods and results Limitations described	No clear description of the inclusion and exclusion criteria No clear description of the procedure Small sample size
Polastri and Barela (2013)	Three different age groups of children Clear description of the results	No description of the recruitment strategy, the eligibility criteria, and the participants' characteristics Posture during test procedure not clearly described Limitations not described
Riach and Starkes (1994)	Clear description of the participants' characteristics and correction for weight and height Clear description of the test procedure and the results	Limitations not described No clear description of the adult group and the eligibility criteria
Rinaldi et al. (2009)	Clear description of the experimental procedure and the results	No clear description of the recruitment methods, the eligibility criteria, and the participants' characteristics Limitations not described
Rine et al. (1998	Clear description of the experimental procedure and the results. Limitations described	Small sample size Non-random selection of subjects No clear description of the participants' characteristics
Sakaguchi et al. (1994)	Clear description of the experimental procedure and the eligibility criteria	No information about the participants' characteristics and the recruitment of the sample No clear description of the results Limitations not described
Scharli et al. (2012)	Clear description of participant characteristics, experimental procedure, and results Limitations described	Fatigue and learning effect not described Recruitment strategy not described No clear description of the eligibility criteria
Sparto et al. (2006)	Clear description of the participant characteristics, experimental procedure, and results Limitations described	No information about recruitment strategy Optical flow is slightly different from moving room Adults and children have different protocols Wide age range in children group (7-12 years)
Steindl et al (2006)	Clear description of participants characteristics, the eligibility criteria, and the results Small age groups across the whole childhood	No clear description of the experimental procedure Limitations not described Only neighboring age groups compared
Wachholz et al. (2019)	Clear description of the recruitment strategy, the participants characteristics, the exclusion criteria the experimental procedure and the results Limitations described	Small sample size Only the first 10 PMs were analyzed No randomized order of trails
Wann et al. (1998)	Clear description of the participants' characteristics and the results	No information about an informed consent

	Limitations described	No description of the posture during the experimental procedure No clear research question Small sample size No description of age of the nursery children (conflicting indications) Free swinging room (slight decrease of amplitude) Recording posture from the head
Wu et al. (2009)	Clear description of the participant characteristics, the eligibility criteria, the experimental procedure, and the results Limitations described	Assumption of the symmetrical body No description of the recruitment strategy

8. Data-extraction: part one

Reference (publication year)	Group (age range or mean ± SD): no. of subjects (n) (male/female)	Measurements instrument; outcome variables	Sensory perturbation		Trial		Posture
			Vis.	Propr.	Duration (s)/ condition	Reps./ cond.	
Barela et al. (2003)	N = 10 for each group; all males Age 4 (4.0 ± 0.3); age 6 (6.1 ± 0.3); age 8 (8.0 ± 0.3); A (22.8 ± 2.3)	Tracking system; 3D body sway & COM Force platform; COP	EO/EC	Touch plate movement (0.2, 0.5 & 0.8 Hz)	60	1	Barefoot Feet slightly separated Right index finger touches center of touch plate, with elbow flexed 165° Left arm hung passively
Barela et al. (2011)	N = 8 for each group 8-year-olds (8.46 ± 0.34); 12-year-olds (12.44 ± 0.40) A (21.75 ± 2.49)	Tracking system; body sway (AP)	Static room/visual flow	FS	60	Static: 1 Flow: 2	Barefoot Feet placed comfortably apart Arms relaxed alongside the body
Cherng et al. (2003)	C (7.8 ± 0.9; 6.8 – 9.4): n = 17 (8M/9F) A (21.1 ± 1.3; 18.8 – 23.2): n = 17 (8M/9F)	Force platform; GRF, torsional moment, & COP	EO/EC /VS (dome)	FS/CS	30	3	Barefoot Feet together Arms hanging by the sides
Cherng and Chen (2001)	C (7.8 ± 0.9; 6.8 – 9.4): n = 17 (8M/9F) A (21.1 ± 1.3; 18.8 – 23.2): n = 17 (8M/9F)	Force platform; GRF, torsional moment, & COP	EO/EC/VS (dome)	FS/CS	30	3	Barefoot Feet together Arms hanging by the sides
Cuisinier et al. (2011)	Age 7 (7.3 ± 0.19): n = 8 (4M/4F); age 8 (8.2 ± 0.2): n = 8 (5M/3F); age 9 (9.2 ± 0.38): n = 7 (4M/3F); age 10 (10.1 ± 0.14): n = 6 (2M/4F); age 11 (11.4 ± 0.26): n = 8 (4M/4F) A (25.7 ± 2.25): n = 9 (7M/2F)	Force platform; GRF; frontal & sagittal torques (M_y & M_x)	EO	FS/tendon vibration	30	4	Barefoot Feet 4 cm apart in ML direction Semi-tandem position with left tiptoe in line with right heel Arms hanging loosely by their sides

Faraldo-Garcia et al. (2013)	Total (44.9; 16-81): n = 70 (35M/ 35F) 7 age groups: n = 10 (5M/5F) in each group (< 20, 20-29, 30-39, 40-49, 50-59, 60-69, ≥70)	Tracking system; body sway	EO/EC	FS/CS	20	1	Feet at shoulder width apart
Ferber-Viart et al. (2007)	Age 6-8 (6.7 ± 0.09): n = 34 (12M/22F); age 8-10 (8.6 ± 0.08): n = 35 (19M/15F); age 10-12 (10.4 ± 0.07): n = 71 (36M/35F); age 12-14 (12.3 ± 0.09): n = 35 (19M/16F) A (20.1 ± 0.2): n = 64 (28M/36F)	Force platform; COP	EO/EC/VS	FS/SS	30	2	/
Ferronato and Barela (2011)	N = 25/group Age 4 (4.23 ± 0.33); age 8 (8.23 ± 0.35); age 12 (12.02 ± 0.30) A (24.02 ± 2.12)	Force platform; COP	EO/EC (opaque goggle)	FS	30	5	Feet parallel and slightly apart in ML direction
Godoi and Barela (2008)	N = 70; 35M/35F; equally distributed Age 4 (4.09 ± 0.36); age 6 (6.10 ± 0.38); age 8 (8.07 ± 0.31); age 10 (9.88 ± 0.21); age 12 (12.26 ± 0.23); age 14 (14.21 ± 0.36) A (22.52 ± 2.44)	Tracking system; body sway	Visual flow; varying distance	FS	60	1	/
Greffou et al. (2008)	Total: n = 32 (16M/16F) Age 5-7: n = 6; age 8-10: n = 7; age 11-14: n = 6; age 15-19: n = 6; age 20-25: n = 7	Tracker system; body sway	EO/EC/moving room	FS	68	3 for EO, moving room; 2 for EC & EO, static control	Barefoot Feet together Arms crossed
Hirabayashi and Iwasaki (1995)	Total C: n = 112 (56M/56F) Age 3-4: n = 12 (5M/7F); age 5-6: n = 21 (11M/10F); age 7-8: n = 18 (9M/9F); age 9-10: n = 22 (11M/11F); age 11-13: n = 20	Force plate (Equitest); COG	EO/EC/VS	Fixes surface/SS	20	3	

	(10M/10F); age 14-15: n = 19 (10M/9F) A (20-60) n = 26 (15M/11F)						
Hsu et al. (2009)	Total C: n = 251 (136M/115F) Age 3: n = 12; age 4: n = 43; age 5: n = 45; age 6: n = 28; age 7: n = 21; age 8: n = 21; age 9: n = 20; age 10: n = 19; age 11: n = 23; age 12: n = 19 A (32 ± 1): n = 23 (9M/14F)	Force platform; COG	EO/EC	FS/CS	60	1	"Stand up straight and keep body as stable as possible."
Hytonen et al. (1993)	Total: n = 212 Age 6-15: n = 18; age 16-30: n = 45; age 31-45: n = 18; age 46-60: n = 100; age 61-75: n = 16; age 76-90: n = 15	Force platform: COP	EO/EC	FS/CS/ vibration on calf muscles after baseline measure	180	1	Heels together and feet in a 30° angle Arms crossed over chest
Ionescu et al. (2006)	Age 11-12 (11.9 ± 0.1): n = 29 (M17/F12) A (20.1 ± 0.2): n = 68 (28M/40F)	Dynamic posturography: force platform	EO/EC/ visual disorientation	FS/unstable surface	30	/	Feet shoulder-width
Liang et al. (2018)	C (8.1 ±1.8): n = 14 (6M/8F) A (24.5 ± 3.9): n = 14 (6M/8F)	Tracking system; COM (AP & ML)	EO/EC	Whole-body vibration	40	2 for the A 1 for the C	Barefoot Feet hip width apart Hands on the hips
Lim et al. (2018)	C (10 ± 1.3): n = 14 (12M/6F) A (27 ± 6.8): n = 18 (17M/1F)	Force platform; COP	Static surrounding/ visual flow	FS	60	2	Barefoot Feet together Arms along the side of the body
Lim et al. (2019)	C (10; 8 – 12): n = 18 (12M /6F) A (27; 18 – 37): n = 18 (17M/1F)	Force platform: COP	Visual flow	FS	60	2	Barefoot Feet together
S. M. McKay et al. (2014)	Younger C (6.33 ± 0.59): n = 10 (5M/5F); older C (10.33 ± 0.92): n = 10 (4M/6F) A (20.5 ± 1.39): n = 10 (2M/8F)	Force platform: COP in AP and ML direction	EO/EC	Tendon vibration	40	3	Barefoot Hands on the iliac crests
Oba et al. (2015)	C (5.4 ± 0.5; 5-6): n = 10 (4M/6F) A (25.7 ± 2.2): n = 15 (9M/6F)	Force platform: GRF vertical and AP direction	EO/EC	FS	30	3	Barefoot Feet at shoulder-width

							Arms along the side of the body
Peterson et al. (2006)	Total children: n = 154 (80M/74F; 6-12) Age 6: n = 9; (5M/4F); age 7: n = 26 (12M/14F); age 8: n = 35 (21M/14F); age 9: n = 36 (16M/20F); age 10: n = 20 (11M/9F); age 11: n = 18 (11M/7F); age 12: n = 20 (9M/11F) A (20-22): n = 20 (9M/11F)	Force platform: COP	EO/EC/VS	FS/SS	20	2	/
Polastri and Barela (2013)	Age 4 (3.7 ± 0.22): n = 10 (5M/5F) Age 8 (8.1 ± 0.28): n = 10 (5M/5F) Age 12 (12.1 ± 0.48): n = 10 (5M/5F) A (22 ± 2.4; 20-27): n = 10 (4M/6F)	Tracking system: body sway	Static surround/ moving room (low/high ampl. – vel. oscillation)	FS	60	1x static; 6x low ampl-vel; 1x high ampl-vel	
Riach and Starkes (1994)	Age 4: n = 6; Age 5: n = 8; Age 6: n = 6; Age 7: n = 9 Age 8: n = 8; age 9: n = 10; age 10: n = 5; age 11: n = 13; age 12: n = 6; age 13: n = 10 A: n = 26	Force platform: GRF & force moments around AP & ML axis	EO/EC	FS	20	1	Barefoot Feet together
Rinaldi et al. (2009)	Age 4 (4.6 ± 0.2): n = 7; age 8 (8.3 ± 0.2): n = 8; age 12 (12.2 ± 0.4): n = 10 A (21 ± 2.7): n = 10	Tracking system: body sway	Fixed surround/Low /high ampl.-vel.	FS	2 min low ampl./vel. 1 min high ampl./vel. 2 min low ampl./vel.		/
Rine et al. (1998)	Age 3 (3.5 ± 0.29): n = 6; age 4-5 (4.58 ± 4.3): n = 5; age 6-7.5 (7.25 ± 0.3): n = 12 A (24.7 years ± 2.3 years): n = 11	Force platform: location of COM, degree of AP displacement (sway angle)	EO/EC/VS	FS/SS	2	20s	Arms along the side of the body

Schärli et al. (2012)	Age 5 (5.7 ± 0.58): n = 16; age 8 (8.3 ± 0.49): n = 15; age 11 (11.6 ± 0.58): n = 14 A (28.6 ± 3.43; 18 – 35): n = 15	Force plate: GRF (Fx, Fy & Fz) and moments (Mx, My & Mz)	EC/EO	FS	30	1	Barefoot Feet together Arms freely hanging
Sparto et al. (2006)	C (9.8 ± 1.5; 7-12): n = 19 (M9/F10) A (23.8 ±2.9; 21-30): n = 20 (M9/F11)	Force platform: COP Tracking device: head sway, pelvic sway & COM	C: 30s stationary room, 30s visual flow A: 30s baseline/90s visual flow	FS/sway-referenced platform	Dif. for each freq.	1	Barefoot Feet at shoulder width Arm crossed over the chest
Steindl et al. (2006)	C: (10 ± 0.4; 3.5 – 16.2): n = 140 (70M/70F) Age 3-4 (3.8 ± 0.3); age 5-6 (5.6 ± 0.4); age 7-8 (7.7 ± 0.6); age 9-10 (9.5 ± 0.4); age 11-12 (11.3 ± 0.4); age 13-14 (13.5 ± 0.5); age 15-16 (15.5 ± 0.5) A (30.5 ± 8 years 4 month;; 17 – 49): n = 20 (10M/10F)	Force plate: force measurement	EO/EC/VS	FS/SS	20	2	
Wachholz et al. (2019)	Adolescents (12.4 ± 1.3): n = 20 (M15/F8) A (26.9 ± 2.3): n = 15 (15M/0F)	AMTI force plate: COP	EO/EC	FS	EO: 30 EC: 60		Feet hip width Hands on the hips
Wann et al. (1998)	C (10-12): n = 6 C (nursery aged: 3-4): n = 6 A: n = 6	Tracking system: head movement & room movement	EO/EC/ swinging room (amplitude (low, medium & high)	FS	16	1	
Wu et al. (2009)	Young C (6.3 ± 0.6): n = 9 (5M/4F) Older C (10.4 ± 0.9): n = 8 (4M/4F) A (20.5 ± 1.4): n = 10 (2M/8F)	Force platform (Bertec); Tracking system (Vicon): kinematic date	EO/EC	FS	40	3	Barefoot Hands-on the iliac crest

A = adults; ampl. = amplitude; AP = anteroposterior; C = children; COM = centre of mass; COP = centre of pressure; CS = compliant surface; EC = eyes closed; EO = eyes open; FS = fixed surface; GRF = ground reaction force; ML = mediolateral; s = seconds; SS = surface referenced surround; vel. = velocity; VS = visual referenced surround

9. Data-extraction: part 2

Reference	Outcome variables COP	Body sway	Results
Barela et al. (2003)		Gain	No sign. age effect
		Phase	Sign. age effect (p < .005): age 4 > age 6, 8 & A
		Variability	Sign. age effect (p < .005) age 4, 6 & 8 > A; no sign. dif. between C
Barela et al. (2011)		Coherence	Increase with increasing age: age 8 < A (p = .0061)
		Gain	No sign. age effect
		Phase	No sign. age effect
Cherng et al. (2003)	Median frequency of shear forces		<u>AP direction</u> No sign. age x surface interaction; C > A Sign. age x vis. interaction effect (p = .0377): EC > EO in A, not in C No sign. age by vis. by surface interaction <u>ML direction</u> Sign. age x surface interaction (p = .0052): effect surface in C > A No sign. age x vis. interaction
Cherng and Chen (2001)	Sway area		Sign. age x vis. interaction (p < .001) Sign. age x surface interaction (p < .001) Sign. age x vis. x surface interaction (p < .003) CS: sign. age x vis. interaction; FS: no age x vis. Interaction FS : C > A CS : C > A
	Proportional change of sway area		EC-CS: C > A (p < .05) VS-CS: C > A (p < .05) No other dif.
	Sensory ratio		Vestibular: C < A (p < .006) Somatosensory & visual: no dif. between C & A
	Proportional change of COP		AP direction: sign. age x sens. cond. interaction (p < .0001): - EC-CS: C > A (p < .0002) - VS-CS: C > A (p < .05) ML direction: no sign. age x sens. cond. interaction
Cuisinier et al. (2011)	Sway area		No sign. age x sens. cond. interaction Sign. decrease with increasing age
	Mean amplitude		No sign. age x sens. cond. interaction No main age effect
	Mean velocity		Sign. age x sens. cond interaction (p < .0001):

			- Vib.: age 7 > age 10 & 11 > A (p < .05) - Non-vib.: no sign. age effect - Vib. > non-vib. in age 7, 8, 9, 10 & 11 (p < .001), not sign. in A
Faraldo-Garcia et al.(2013)		Angular velocity	EO-CS: age 16-20 > age 20-29 (no overlap of confidence intervals)
		Sens. index	Sign. age effect on visual index (p = .001): lowest in age 40-49 Sign. age effect on vestibular index (p = .004): highest in age 40-49 No sign. age effect on somatosensory index
Ferber-Viart et al. (2007)	Equilibrium score		EO, FS: age 8-10 < age 12-14 (p = .0006) & A (p = .001); no sign. dif. between age 10-12 & A EC, FS: age 8-10 < age 12-14 (p = .0002) & A (p < .0001); no sign. dif. between age 10-12 & A VS, FS: age 6-8 < age 8-10 (p = .02), 10-12 (p < .0001), 12-14 (p < 0.0001) & 20-22 (p < .0001); age 8-10 < age 10-12 (p = .01) & age 12-14 (p = .008) EO- SS: age 12-14 < A (p = .01) EC-SS: age 12-14 < A (p = .004) VS-SS: age 12-14 < A (p < .0001)
	Sensory ratio		Somatosensory ratio: age 6-8 < A (p = .004); no sign. dif. between age 8-10 & A Visual ratio: age 12-14 < A (p = .007) Vestibular ratio: age 12-14 < A (p = .004)
	Visual preference		Age 6-8 < age 10-12 (p = .04); no other sign. dif. between age groups
Ferronato and Barela (2011)	COP trajectories		AP & ML direction: no sign. age x vis. interactions for mean sway ampl. or predominant frequency
	Rambling		AP & ML direction: no sign. age x vis. interactions for mean sway ampl. (predominant frequency not described)
	Trembling		AP & ML direction: no sign. age x vis. interactions for mean sway ampl. or predominant frequency
Godoi and Barela (2008)		Variability	Room oscillation: age 4 > all other groups; age 6, 8, 10 and 14 > A
		Coherence	Sign. age effect (p < .001): coupling strength increases with increasing age Sign. age x distance interaction (p < .001): increase of coherence values with increasing distance until age 10, constant coherence values after age 12
		Gain	Sign. age effect (p < .001): decreasing trend with increasing age Sign. age x distance interaction (p < .001): decrease in gain values as distance increases in ages 4, 6 & 10, constant gain values in ages 8, 12, 14 & A
		Phase	No sign. age effect or sign. age x distance interaction
		Amplitude	Sign. age effect (p < .001): decreasing trend with increasing age Sign. age x distance interaction (p < .001): increase of deviation values with increasing distance until age 10, constant deviation values after age 12

Greffou et al. (2008)		Angular deviation	No sign. dif. between EO & EC; sign. age x oscillation frequency interaction (p = .0001): sign. dif. between 0.5 Hz & other two cond. for A, sign. dif. between 0.5 & 0.25 Hz only for age 16-19; other age groups showed no sign. Dif.
		RMS of velocity	No sign. dif. between EO & EC; sign. age x oscillation frequency interaction (p = .0001): ages 8-11 & 12-15: 0.5 Hz > 0.25 Hz > 0.125 Hz, no age or oscillation effect from age 16-19 onwards
Hirabayashi and Iwasaki (1995)	Equilibrium score		No mentioning of interaction effects with age EC-SS: sign. dif. between age 7-8 & age 9-10 and between age 14-15 and A (p < .05); VS-SS: sign. dif. between age 9-10 & 11-13 (p < .05); no sign. dif. between other neighbouring age groups
	Sensory ratio		Somatosensory function: almost no dif. between age 3-4 & A Visual function: age 11-13 < age 14-15 (p < .05), no sign. dif. between age 14-15 & A Vestibular function: age 14-15 < A (p < .05)
Hsu et al. (2009)	Velocity		EO-FS: age 3-6 > A (p < .05), no sign. dif. between age 12 & A EC-FS: mature values at age 7 EO-CS: age 3-7 > A (p < .01), no sign. dif. between age 8-12 & A EC-CS: age 3-11 > A (p < .05), no sign. dif. between age 12 & A
	Surface area		EO, FS: age 3-4 > A (p < .05), no sign. dif. between age 5-12 & A EC, FS: age 3-5 > A (p < .05) EO-CS: age 3-7 > A (p < .001), no sign. dif. between age 8-12 & A EC-CS: age 3-6 > A (p < .05), no sign. dif. between age 7-12 & A
Hytonen et al. (1993)	Velocity		No sign. dif. for EO - EC between C & A Dif. vib. - non-vib.: C > other groups (p < .05) Dif. FS – CS: C > age 31-45 (sign.)
Ionescu et al. (2006)	Stability percentages		EO & EC: no sign. different Age 11-12 < A in vis. disorientation (p = .02), EO-unstable surface (p < .0001), EC-unstable surface (p = .02), vis. disorientation-unstable surface (p < .0001)
	Velocity		Age 11-12 > A (p = .01) in vis. disorientation Age 11-12 > A (p = .09 (trend)) in vis. disorientation-unstable surface No sign. age effects in other cond.
	Surface area		Age 11-12 > A in vis. disorientation (p = .003), EO-unstable surface (p = .0005) and vis. disorientation-unstable platform (p = .0007) No other sign. dif.
	Sensory ratio		Somatosensory and visual system: age 11-12 > A (trend) Vestibular system: age 11-12 < A (trend) Visual dependence age 11-12 > A (p = .009)
Liang et al. (2017)		Average velocity	AP & ML direction: increase from static to vib. cond. in C > A (resp. p = .02 & p = .04)

		Range	AP direction: no age x phase interaction ML direction: sign. age x phase interaction (p = .001): A constant, C during Post_ 0 > other phases
		Ellipse area	Group by phase interaction (p = .003): constant in A; decrease from static to vib. cond., increased at post_0, and decreased at post_5 in C
		Fractal dimension	Group by phase interaction (p = .002): C > A during vib. in AP direction
		Total power	AP: C = A during all conditions ML: constant in A, C: post_0 > all other phases
		Median frequency	Sign. age x phase interaction (p = .002): C > A during vib. in AP direction
		Scaling exponent	AP direction: age x vis. interaction (p = .032: EO > EC in A, not in C ML direction: no interaction effect mentioned
Lim et al. (2018	Mean position (AP)		No sign. age effect across visual cond.
Lim et al. (2019)	AP postural response		<u>Within-trial changes</u> Full vis. contraction: post. response of A & C, A return to baseline between 21-40s (p < .0001) and C return to baseline between 41-60s (p < .0001) Peripheral visual contraction: post. response and return to baseline between 41-60s in C (p < .0001), no sign. post. in A Full visual expansion: post. response and return to baseline between 41-60s in C (p = .002), no sign. post. response in A No sign. main or interaction effects in other cond. <u>Between trial changes</u> Central visual contraction: sign. reduction in C (p < .007), not in A No sign. main or interaction effects in other groups
S. M. McKay et al. (2014)	mean velocity		AP: sign group x phase interaction (p = .026): increase rate from pre-vib. to vib. & post-vib. cond.: YC and OC > A ML: sign. age x phase interaction (p = .0237): pre-vib. < post-vib < vib. in YC & OC; no phase effect in A
	Max COP shift		AP: sign. age x phase interaction (p = .0143): YC > OC > A during vib., YC > OC and A during post-vib.; vib. similar to post-vib. cond. in YC, decrease in other OC & A; ML: sign. age x phase interaction (p = .0292): vib. > post-vib. in YC & OC, no sign. dif. in A; YC & OC > A during vib. and post-vib.
Oba et al. (2015)	Amplitude		No sign. age x phase interaction EC: normalized for height: C > A
	SD amplitude		No interaction effects mentioned
		Acceleration	Sign. age x vis. interaction (p = .003)

		Normalized peak power of COM acceleration	Sign. age x vis. interaction (p = .002) No sign. dif. of EC/EO ratio between C & A EO & EC: C > A
		Mean power frequency of COM acceleration	No sign. age x vis. Interaction EO & EC: C > A
		Peak power frequency of COM acceleration	No sign. age x vis. Interaction EO & EC: C > A
Peterson et al. (2006)	Sensory ratio		Somatosensory: adult-like at age 6-12 Visual: adult-like at age 11 Vestibular: adult-like at age 12 No age effect on visual preference
Polastri and Barela (2013)		Mean amplitude	High ampl./vel. trial: age 4 & 8 increased values compared to low ampl./vel. trials (p < .04), no sign. dif. in age 12 and A (p > .05)
		Gain	No sign. age effect Down-weighting to stimulus: age 4-8 < age 12 and A (p < .008) Age 12 & A: high ampl./vel. trial < low ampl./vel. trial (p < .05), no sign. dif. in age 4 and 8 (p >.05) Age 4: up-weighting of body responses to visual stimulus in the trials after the high ampl./vel. trial, with gain values similar to those during the high ampl./vel. trial; age 8: similar up-weighting as in age 4, but gain values similar to those in the trials before the high ampl./vel. trial only after the 6th trial
		Phase	Age 4 > age 8 and 12 (p < .03) and C > A (p < .04) Age 4 and 8 (‘+’) > age 12 (‘0’) > A (‘-’) No sign. age x sens. condition interaction
		Variability	No sign. age x sens. condition interaction
		Velocity variability	No sign. age x sens. condition interaction
Riach and Starkes (1994)	Velocity		No sign. age x sens. condition interaction Age 4, 5, 6 & 7 > age 8, 9, 10, 11, 12 & 13
	Influence of physical factors		Sign. age x vis. interaction: sign. age effect in EO (p < .05), not in EC Age 4, 5, 6 & 7 > age 8, 9, 10, 11, 12 & 13
Rinaldi et al. (2009)		Transient gain	Sign. age x sens. cond. interaction (p < .02): no age effect in low ampl./vel. condition; age 4 > age 8, 12 and A during low-to-high ampl./vel.; age 4 > age 8 > age 12, constant in A during high-to-low ampl./vel.
		Gain	Age 4 & 8 > age 12 & A
		Phase	sign. group x condition interaction High ampl./vel.: C (“+” values) > A (“0”) Low ampl./vel.: C & A (“0”)

		Stimulus frequency sway amplitude	Sign. age x phase interaction (p < .001): ages 4 & 8: high ampl./vel. > both low ampl./vel.; age 12: high ampl./vel. > 2nd low ampl./vel.; A: 1st low ampl./vel > 2nd low ampl./vel
Rine et al. (1998)	Equilibrium score		EO and VS: age 3 < age 6-7.5 (p ≤ .05) < A EC: age 3-5 < age 6-7.5 (p ≤ .004) < A All conditions: C < A
	Variability in equilibrium score		EO, SS and EC-SS: age 3 < age 4-5 (p < .05) EC: age 3 > age 7-7.5 (p < .05) VS: age 3 > age 4-7.5 (p < .004)
	Maturational changes		Somatosensory function: age 6 Visual function: age 7.5 Vestibular function: age 7.5
Schärli et al. (2012)		Head movement	EC: age 5 > age 8 (p < .001) age 11 > A (p < .001)
	95% ellipse area		No sign. age effect on ΔEA between EC & EO EC: age 5 > age 8 (p < .001) > age 11 (p = .003) > A (p = .011)
	Sample entropy		EC: age 5 > age 8 (p = .018) and age 11 > A (p = .044); EO: age 11 > A (p = .003); no other sign. dif. No sign. age effect on ΔSE between EO and EC
Sparto et al. (2006)	Magnitude		FS: value of C = 1.8 times value of A SS: value of C = 2.0 times value of A in SS Ratio SS/FS similar between C and A
	Response magnitude for optical flow		Sign. age x surface interaction (p = .006): A: FS 90% smaller than SS; C: FS 50% smaller than SS; no other sign. interactions
		Phase	No effect of surface; C > A at 0.1Hz (p < .001), no sign. dif. at 0.25 Hz
Steindl et al. (2006)	Equilibrium score		EO-FS: age 5-6 < age 7-8 (p ≤ .01) EC-FS: age 7-8 < age 9-10 (p ≤ .01) VS-FS age 9-10 < age 11-12 (p ≤ .01) EO-SS: age 5-6 < age 7-8 and age 9-10 < age 11-12 (p ≤ .05) EC-SS: age 3-4 < age 5-6 (p ≤ .01) and age 13 -14 < age 15-16 (p ≤ .05) VS-SS: age 3-4 < 5-6 and age 9-10 < age 11-12 (p ≤ .01) No other dif. between neighbouring age groups.
	Sensory ratio		Proprioceptive: 98% in age 3-4 Visual: age 9-10 < age 11-12 (p < .01), no further development after age 15-16 Vestibular: age 3-4 < age 5-6 (p <.01); age 13-14 < age 15-16 (p < .01); age 15-16 > A (p < .05)
Wachholz et al. (2019)	Mean velocity		Adolescents > A (p = .01) in EO, no age effects in other cond.
	SD velocity		Adolescents > A (p = .014) in EO, no age effects in other cond.

Wann et al. (1998)		Amplitude	No sign. dif.
		Visual induced sway	89% in nursery aged C; 72% in age 10-12; 36% in A
		Mean gain	Nursery aged C > age 10-12 and A (p < .001)
		Phase	All negative (body sway leads room sway) No sign. effect of age, ampl. or any interaction
Wu et al. (2009)	Mean velocity		No age x vis. interaction EC > EO in all age groups

A = adults A = adults; Ampl. = amplitude; AP = anteroposterior; C = children; Cond. = conditions; CS = compliant surface; Dif. = difference(s); EC = eyes closed; EO = eyes open; FS = fixed surface; ML = medio Lateral; OC = older children; OPTO = optokinetic stimulation; Sens. = sensory; Sign. = significant; SS = surface sway-referenced; Vel. = velocity; Vib. = vibration; Vis. = vision; VS = visual sway-referenced; YC = young children; ΔEA = ellipse area; ΔHM = difference in head movemen

10. Outcome variables

Body sway variability	"Position and velocity variability values indicate body sway amplitude and velocity (sway variability), respectively, at frequencies other than the 0.2 Hz frequency with higher values indicating higher variability. (Polastri & Barela, 2013, p3)
Cancelling time	"Canceling time is the time required to use sensorial inputs for controlling posture." (Gouleme et al., 2014, p171)
Coherence	"Coherence measures the strength of body sway in relationship to the room's movement: that is, how strongly body sway is coupled to the visual stimulus." (Godoi & Barela, 2006, p80)
Equilibrium score	"The SOT evaluates the equilibrium score for postural stability comparing anterior–posterior sway to a theoretical sway stability limit of 12.5˚ in six test conditions (C1–C6)." (Steindl et al., 2006, p478)
Fractal dimension	"In addition, fractal dimension was calculated as the degree to which the COM trajectory fit the metric space that it encompassed." (Liang et al., 2016, p149)
Gain	"is a measure of the dependence of induced body sway upon stimulus motion and was calculated as the ratio between the body sway amplitude spectrum and moving room amplitude spectrum at the driving frequencies." (Godoi & Barela, 2006, p80)
Mean position	"Mean COP position in the sagittal plane (COP-y), deriving from the COP data, was defined as the average deviation of the COP from the baseline position in the sagittal plane over the duration of the visual stimulus display." (Lim et al., 2018, p142)
Mean power frequency of COM acceleration	Represents acceleration of COM and therefore COM vibration (Cherng et al., 2003)
Shear forces	"Because the shear forces represents the acceleration of center of mass and the acceleration represents the vibrations of the center of mass in standing, we decided to measure and analyze the frequency spectra of the ground reaction shear forces in the anterior–posterior (A/P) and the medial/lateral (M/L) directions."
Peak power frequency of COM acceleration	"The maximum value of the power was determined as the peak power of the COM_{acc}."(Oba et al., 2015, p3)
Peak power of COM acceleration	"The frequency at which the peak power of the COM_{acc} was observed was defined as the peak power frequency (PPF)." (Oba et al., 2015, p3)
Phase	"Phase was computed as the argument of the transfer function, converted into degrees, and indicated the temporal relationship between visual stimulus and body sway." (Polastri & Barela, 2013, p3)
Postural response	"Postural responses were measured as the average deviation of the center-of-pressure from the baseline position in the anteroposterior plane (COPy)." (Lim et al., 2019, p177)
Proportional change of COP and sway area	"To examine the data in a slightly different way, we defined the condition of eyes-open, fixed-foot-support as the baseline condition and computed the proportional change of the mean sway area in each of the other five sensory conditions relative to the baseline condition." (Cherng & Chen,2001, p1174)
Rambling	COP vibration due to the movement of the reference point (Ferronato & Barela, 2011)
Root mean square velocity	"vRMS was used in order to quantify possible postural perturbations induced by the visual stimuli." (Greffou et al., 2008, p5)

Sample entropy	“sample entropy (SE) as an indicator for the regularity of COP movements,” (Scharli et al., 2012, p79)
Scaling exponent	The scaling exponent estimates the influence of previous movements on the center of pressure or the center-of-mass. (Liang et al., 2017)
Sensory index	Calculates a percentage of contribution of each system to postural control, based on body sway parameters. (Faraldo-Garcia et al., 2013)
Sensory ratio	The sensory ratios calculates the influence of every sensory system to postural control by dividing to the baseline measure. (Hirabayashi & Iwasaki, 1994)
Shear forces	“Because the shear forces represents the acceleration of center of mass and the acceleration represents the vibrations of the center of mass in standing, we decided to measure and analyze the frequency spectra of the ground reaction shear forces in the anterior–posterior (A/P) and the medial/lateral (M/L) directions.”(Cherng et al., 2003, P510-511)
Stability percentages	The stability percentage is a calculation of postural control based on the angular deviation compared to the stability limit. 0 indicates a fall and 100 indicates perfect postural control. (Ionescu et al., 2006)
Stimulus frequency sway amplitude	“SFSA corresponds to the amplitude value of the body sway at the driving frequency stimulus (i.e., 0.2Hz).” (Rinaldi et al., 2009, p226)
Total power	“Total power was the integrated area of the power spectrum.” (Liang et al., 2017, p150)
Transient gain	“This measure, therefore, indicates the change in gain magnitude due to the abrupt manipulation of the stimulus signal.” (Rinaldi et al., 2009, p226)
Trembling	“The trembling trajectory was determined by subtracting the estimated rambling trajectory from the corresponding COP trajectory which corresponded to the sway around the rambling trajectory (the equilibrium point).” (Ferronato et al., 2011, p484)
Visual preference	“The visual preference represents the degree to which a patient relies on visual information to maintain balance, even when the information is incorrect.” (Ferber-Viart et al., 2007, p1043)

11. Technical specifications NeuroCom Equitest System

- ± 10° of force plate rotation, maximum velocity of 50°/sec
- ± 10° of visual surround rotation, maximum velocity of 15°/sec
- Dual force plate 46 x 46 cm
- Maximum subject height: 203cm
- Maximum subject weight: 200kg

12. Formulas PSI and ES

ES = (12.5 – (ϑ_{max}*(A)* - ϑ_{max}*(P)*))/12.5 × 100, with ϑ_{max}*(A)* equal to the maximum anterior sway angel, ϑ_{max}*(P)* equal to the maximum posterior sway angle, and 12.5 as the assumed limit of stability in degrees in the AP direction.

PSI = (Σ|$mgh\vartheta$|/ Σ|τ|) × 100, with *m* equal to the participant's mass, *g* equal to 9.81 m/s², *h* equal to 0.55 × body length (average distance of COM to platform), ϑ equal to the body sway in radians, and τ equal to the stabilizing torque in the ankle

UHASSELT
KNOWLEDGE IN ACTION

Inschrijvingsformulier verdediging masterproef academiejaar 2019-2020, semester 2
Registration form jury Master's thesis academic year 2019-2020, semester 2

GEGEVENS STUDENT - *INFORMATION STUDENT*

Faculteit/School: **Faculteit Revalidatiewetenschappen**
Faculty/School: ***Rehabilitation Sciences***

Stamnummer + naam: **1643799 Beyens Pieter**
Student number + name

Opleiding/*Programme*: **1 ma revalid. wet. & kine**

INSTRUCTIES - *INSTRUCTIONS*

Neem onderstaande informatie grondig door.

Print dit document en vul het aan met DRUKLETTERS.

In tijden van van online onderwijs door COVID-19 verstuur je het document (scan of leesbare foto) ingevuld via mail naar je promotor. Je promotor bezorgt het aan de juiste dienst voor verdere afhandeling.

Vul luik A aan. Bezorg het formulier aan je promotoren voor de aanvullingen in luik B. Zorg dat het formulier ondertekend en gedateerd wordt door jezelf en je promotoren in luik D en dien het in bij de juiste dienst volgens de afspraken in jouw opleiding.
Zonder dit inschrijvingsformulier krijg je geen toegang tot upload/verdediging van je masterproef.

Please read the information below carefully.

Print this document and complete it by hand writing, using CAPITAL LETTERS.

In times of COVID-19 and during the online courses you send the document (scan or readable photo) by email to your supervisor. Your supervisor delivers the document to the appropriate department.

Fill out part A. Send the form to your supervisors for the additions in part B. Make sure that the form is signed and dated by yourself and your supervisors in part D and submit it to the appropriate department in accordance with the agreements in your study programme.
Without this registration form, you will not have access to the upload/defense of your master's thesis.

LUIK A - VERPLICHT - IN TE VULLEN DOOR DE STUDENT
PART A - MANDATORY - TO BE FILLED OUT BY THE STUDENT

Titel van Masterproef/*Title of Master's thesis:* VERSCHIL IN EVENWICHTSSTRATEGIEEN BIJ KINDEREN, ADOLESCENTEN EN JONGVOLWASSENEN

O behouden - *keep*

● wijzigen - *change to:* MATURATION OF SENSORY REWEIGHTING IN CHILDREN

/:

O behouden - *keep*

O wijzigen - *change to*:

In geval van samenwerking tussen studenten, naam van de medestudent(en)/*In case of group work, name of fellow student(s)*: SAM VAN HOUT

● behouden - *keep*

O wijzigen - *change to:*

LUIK B - VERPLICHT - IN TE VULLEN DOOR DE PROMOTOR(EN)
PART B - MANDATORY - TO BE FILLED OUT BY THE SUPERVISOR(S)

Wijziging gegevens masterproef in luik A/*Change information Master's thesis in part A:*

O goedgekeurd - *approved*

O goedgekeurd mits wijziging van - *approved if modification of:*

Scriptie/*Thesis:*

O openbaar (beschikbaar in de document server van de universiteit)- *public (available in document server of university)*

O vertrouwelijk (niet beschikbaar in de document server van de universiteit) - *confidential (not available in document server of university)*

Juryverdediging/*Jury Defense:*

De promotor(en) geeft (geven) de student(en) het niet-bindend advies om de bovenvermelde masterproef in de bovenvermelde periode/*The supervisor(s) give(s) the student(s) the non-binding advice:*

O te verdedigen/*to defend the aforementioned Master's thesis within the aforementioned period of time*

O de verdediging is openbaar/*in public*

O de verdediging is niet openbaar/*not in public*

O niet te verdedigen/*not to defend the aforementioned Master's thesis within the aforementioned period of time*

LUIK C - OPTIONEEL - IN TE VULLEN DOOR STUDENT, alleen als hij luik B wil overrulen
PART C - OPTIONAL - TO BE FILLED OUT BY THE STUDENT, only if he wants to overrule part B

In tegenstelling tot het niet-bindend advies van de promotor(en) wenst de student de bovenvermelde masterproef in de bovenvermelde periode/*In contrast to the non-binding advice put forward by the supervisor(s), the student wishes:*

O niet te verdedigen/*not to defend the aforementioned Master's thesis within the aforementioned period of time*

O te verdedigen/*to defend the aforementioned Master's thesis within the aforementioned period of time*

LUIK D - VERPLICHT - IN TE VULLEN DOOR DE STUDENT EN DE PROMOTOR(EN)
PART D - MANDATORY - TO BE FILLED OUT BY THE STUDENT AND THE SUPERVISOR(S)

Datum en handtekening student(en)
Date and signature student(s)

Pieter Beyens
02/06/20

Datum en handtekening promotor(en)
Date and signature supervisor(s)

UHASSELT

Pieter Beyens <pieter.beyens@student.uhasselt.be>

Formulieren masterproef

Pieter MEYNS <pieter.meyns@uhasselt.be> 30 mei 2020 om 01:59
Aan: Pieter Beyens <pieter.beyens@student.uhasselt.be>
Cc: Sam Van Hout <sam.vanhout@student.uhasselt.be>

Beste Pieter en Sam,

jullie krijgen een gunstig advies ter indiening.

Met vriendelijke groeten,

--

Pieter Meyns
Assistant Professor - Biomechanics
REVAL - Rehabilitation Research

T +32(0)11 26 93 95

www.uhasselt.be
Hasselt University - Campus Diepenbeek
Agoralaan Building A - B-3590 Diepenbeek
Office A0.02

Postal address:
Hasselt University
Martelarenlaan 42
B-3500 Hasselt

REVAL
REHABILITATION RESEARCH
UHASSELT

Op vr 29 mei 2020 om 23:22 schreef Pieter Beyens <pieter.beyens@student.uhasselt.be>:
[Tekst uit oorspronkelijke bericht is verborgen]

www.uhasselt.be
Campus Hasselt | Martelarenlaan 42 | BE-3500 Hasselt
Campus Diepenbeek | Agoralaan gebouw D | BE-3590 Diepenbeek
T + 32(0)11 26 81 11 | E-mail: info@uhasselt.be

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KNOWLEDGE IN ACTION

VOORTGANGSFORMULIER WETENSCHAPPELIJKE STAGE DEEL 1

DATUM	INHOUD OVERLEG	HANDTEKENINGEN
2/12	Onderzoeksvraag + zoekstrategie	Promotor: Copromotor/begeleider: MvdBogaert Student(e): Pieter Beyens Student(e):
7/02	verfijnen zoekstrategie +	Promotor: Copromotor/begeleider: MvdBogaert Student(e): Pieter Beyens Student(e):
18/2	Onderzoek balans controle vastleggen zoekstrategie	Promotor: Copromotor/begeleider: Student(e): ~~Pieter Beyens~~ Pieter Beyens Student(e):
24/3	skype meeting zoekstrategie, kwaliteitsbeoordeling	Promotor: Copromotor/begeleider: Student(e): Pieter Beyens Student(e):
9/4	Skype meeting artikels bespreken	Promotor: Copromotor/begeleider: Student(e): Pieter Beyens Student(e):
24/4	Skype meeting bespreking data - extractie	Promotor: Copromotor/begeleider: Student(e): Pieter Beyens Student(e):
14/5	Skype meeting bespreking inleiding + data extractie	Promotor: Copromotor/begeleider: Student(e): Pieter Beyens Student(e):
18/5	Skype meeting bespreking resultaten en conclusie	Promotor: Copromotor/begeleider: Student(e): Pieter Beyens Student(e):
		Promotor: Copromotor/begeleider: Student(e): ~~Pieter Beyens~~ Student(e):
	Niet-bindend advies: De promotor verleent hierbij het advies om de masterproef WEL/NIET te verdedigen.	Promotor: Copromotor/begeleider: Student(e): Student(e):

Verklaring op Eer

Ondergetekende, student aan de Universiteit Hasselt (UHasselt), faculteit revalidatiewetenschappen en kinesitherapie aanvaardt de volgende voorwaarden en bepalingen van deze verklaring:

1. Ik ben ingeschreven als student aan de UHasselt in de opleiding revalidatiewetenschappen en kinesitherapie, waarbij ik de kans krijg om in het kader van de opleiding mee te werken aan onderzoek van de faculteit revalidatiewetenschappen en kinesitherapie aan de UHasselt. Dit onderzoek wordt beleid door Prof. Dr. Pieter Meyns en kadert binnen het opleidingsonderdeel Wetenschappelijke stage deel 1. Ik zal in het kader van dit onderzoek creaties, schetsen, ontwerpen, prototypes en/of onderzoeksresultaten tot stand brengen in het domein van Biomechanica (hierna: "De Onderzoeksresultaten").

2. Bij de creatie van De Onderzoeksresultaten doe ik beroep op de achtergrondkennis, vertrouwelijke informatie[1], universitaire middelen en faciliteiten van UHasselt (hierna: de "Expertise").

3. Ik zal de Expertise, met inbegrip van vertrouwelijke informatie, uitsluitend aanwenden voor het uitvoeren van hogergenoemd onderzoek binnen UHasselt. Ik zal hierbij steeds de toepasselijke regelgeving, in het bijzonder de Algemene Verordening Gegevensbescherming (EU 2016-679), in acht nemen.

4. Ik zal de Expertise (i) voor geen enkele andere doelstelling gebruiken, en (ii) niet zonder voorafgaande schriftelijke toestemming van UHasselt op directe of indirecte wijze publiek maken.

5. Aangezien ik in het kader van mijn onderzoek beroep doe op de Expertise van de UHasselt, draag ik hierbij alle bestaande en toekomstige intellectuele eigendomsrechten op De Onderzoeksresultaten over aan de UHasselt. Deze overdracht omvat alle vormen van intellectuele eigendomsrechten, zoals onder meer - zonder daartoe beperkt te zijn - het auteursrecht, octrooirecht, merkenrecht, modellenrecht en knowhow. De overdracht geschiedt in de meest volledige omvang, voor de gehele wereld en voor de gehele beschermingsduur van de betrokken rechten.

6. In zoverre De Onderzoeksresultaten auteursrechtelijk beschermd zijn, omvat bovenstaande overdracht onder meer de volgende exploitatiewijzen, en dit steeds voor de hele beschermingsduur, voor de gehele wereld en zonder vergoeding:
   - het recht om De Onderzoeksresultaten vast te (laten) leggen door alle technieken en op alle dragers;
   - het recht om De Onderzoeksresultaten geheel of gedeeltelijk te (laten) reproduceren, openbaar te (laten) maken, uit te (laten) geven, te (laten) exploiteren en te (laten) verspreiden in eender welke vorm, in een onbeperkt aantal exemplaren;

[1] Vertrouwelijke informatie betekent alle informatie en data door de UHasselt meegedeeld aan de student voor de uitvoering van deze overeenkomst, inclusief alle persoonsgegevens in de zin van de Algemene Verordening Gegevensbescherming (EU 2016/679), met uitzondering van de informatie die (a) reeds algemeen bekend is; (b) reeds in het bezit was van de student voor de mededeling ervan door de UHasselt; (c) de student verkregen heeft van een derde zonder enige geheimhoudingsplicht; (d) de student onafhankelijk heeft ontwikkeld zonder gebruik te maken van de vertrouwelijke informatie van de UHasselt; (e) wettelijk of als gevolg van een rechterlijke beslissing moet worden bekendgemaakt, op voorwaarde dat de student de UHasselt hiervan schriftelijk en zo snel mogelijk op de hoogte brengt.

- het recht om De Onderzoeksresultaten te (laten) verspreiden en mee te (laten) delen aan het publiek door alle technieken met inbegrip van de kabel, de satelliet, het internet en alle vormen van computernetwerken;
- het recht De Onderzoeksresultaten geheel of gedeeltelijk te (laten) bewerken of te (laten) vertalen en het (laten) reproduceren van die bewerkingen of vertalingen;
- het recht De Onderzoeksresultaten te (laten) bewerken of (laten) wijzigen, onder meer door het reproduceren van bepaalde elementen door alle technieken en/of door het wijzigen van bepaalde parameters (zoals de kleuren en de afmetingen).

De overdracht van rechten voor deze exploitatiewijzen heeft ook betrekking op toekomstige onderzoeksresultaten tot stand gekomen tijdens het onderzoek aan UHasselt, eveneens voor de hele beschermingsduur, voor de gehele wereld en zonder vergoeding.

Ik behoud daarbij steeds het recht op naamvermelding als (mede)auteur van de betreffende Onderzoeksresultaten.

7. Ik zal alle onderzoeksdata, ideeën en uitvoeringen neerschrijven in een "laboratory notebook" en deze gegevens niet vrijgeven, tenzij met uitdrukkelijke toestemming van mijn UHasseltbegeleider Prof. Dr. Pieter Meyns.

8. Na de eindevaluatie van mijn onderzoek aan de UHasselt zal ik alle verkregen vertrouwelijke informatie, materialen, en kopieën daarvan, die nog in mijn bezit zouden zijn, aan UHasselt terugbezorgen.

Gelezen voor akkoord en goedgekeurd,

Naam: Pieter Beyens

Adres: Bruul 20A 2440 Geel

Geboortedatum en –plaats : 21/06/1998 Geel

Datum: 17/11/2019

Handtekening: Pieter Beyens

UHASSELT

AFSPRAKENNOTA

1. Organisatie

Naam	Universiteit Hasselt/transnationale Universiteit Limburg (Hierna: UHasselt/tUL)
Adres	Martelarenlaan 42 3500 Hasselt
Sociale doelstelling	De UHasselt/tUL is een dynamisch kenniscentrum van onderwijs, onderzoek en dienstverlening.
Werking van de organisatie	**Faculteiten** De UHasselt telt zes faculteiten die het onderwijs en onderzoek aansturen: o faculteit Architectuur en kunst o faculteit Bedrijfseconomische wetenschappen o faculteit Geneeskunde en levenswetenschappen o faculteit Industriële ingenieurswetenschappen o faculteit Rechten o faculteit Wetenschappen Elke faculteit stelt per opleiding een onderwijsmanagementteam (OMT) en een examencommissie samen. **Vakgroepen** Binnen de faculteiten opereren diverse vakgroepen. Zij groeperen alle personeelsleden die onderzoek en onderwijs verrichten binnen eenzelfde discipline. Elke vakgroep bestaat vervolgens uit een of meerdere onderzoeksgroepen. Zij staan in voor de organisatie van het gespecialiseerd onderzoek. Deze klassieke boomstructuur van faculteiten, onderzoeksgroepen en vakgroepen wordt doorkruist door de onderzoeksinstituten. De instituten groeperen onderzoekers uit verschillende onderzoeksgroepen die in bepaalde speerpuntdomeinen onderzoek uitvoeren. Daarbij wordt het volledige onderzoekspectrum afgedekt, van fundamenteel over toegepast onderzoek tot concrete valorisatietoepassingen.
Juridisch statuut	Autonome openbare instelling

Verantwoordelijke van de organisatie, die moet verwittigd worden bij ongevallen.

Naam	...
Functie	...
Tel. - GSM	...

2. De vrijwilliger: student-onderzoeker

Naam	Pieter Beyens
Correspondentieadres	Bruul 20A 2440 Geel
Tel. - GSM	0474669210

3. Verzekeringen

Waarborgen	De burgerlijke aansprakelijkheid van de organisatie.
Maatschappij	Ethias
Polisnummer	45009018

Waarborgen	Lichamelijke schade die geleden is door vrijwilligers bij ongevallen tijdens de uitvoering van het vrijwilligerswerk of op weg naar- en van de activiteiten.
Maatschappij	Ethias
Polisnummer	45055074

4. Vergoedingen

De organisatie betaalt geen vergoeding aan de vrijwilliger.

5. Aansprakelijkheid

De organisatie is burgerrechtelijk aansprakelijk voor de schade die de vrijwilliger aan derden veroorzaakt bij het verrichten van vrijwilligerswerk.

Ingeval de vrijwilliger bij het verrichten van het vrijwilligerswerk de organisatie of derden schade berokkent, is hij enkel aansprakelijk voor zijn bedrog en zijn zware schuld.

Voor lichte schuld is hij enkel aansprakelijk als die bij hem eerder gewoonlijk dan toevallig voorkomt.

Opgelet: voor het materiaal dat de vrijwilliger zelf meebrengt, is hij/zij zelf verantwoordelijk.

6. Geheimhoudingsplicht – verwerking persoonsgegevens

De vrijwilliger verleent de UHasselt toestemming om de gegevens die in het kader van zijn/haar inschrijving aan UHasselt werden verzameld, ook te gebruiken voor de uitvoering van deze afsprakennota (de evaluatie van de vrijwilliger alsook het aanmaken van een certificaat). UHasselt zal deze informatie vertrouwelijk behandelen en zal deze vertrouwelijkheid ook bewaken na de beëindiging van het statuut student-onderzoeker. De UHasselt neemt hiertoe alle passende maatregelen en waarborgen om de persoonsgegevens van de vrijwilliger conform de Algemene Verordening Gegevensbescherming (EU 2016/679) te verwerken.

De vrijwilliger verbindt zich ertoe om alle gegevens, documenten, kennis en materiaal, zowel schriftelijk als mondeling ontvangen in de hoedanigheid van student-onderzoeker aan de UHasselt als strikt vertrouwelijk te behandelen, ook indien deze niet als strikt vertrouwelijk werd geïdentificeerd. Indien de vertrouwelijke gegevens van de UHasselt ook persoonsgegevens bevatten dient de stagiair hiertoe steeds de Algemene Verordening Gegevensbescherming (EU 2016/679) na te leven en bij elke verwerking het advies van het intern privacycollege van de UHasselt in te winnen. Hij/zij verbindt zich ertoe om in geen geval deze vertrouwelijke informatie mee te delen aan derden of anderszins openbaar te maken, ook niet na de beëindiging van het statuut student-onderzoeker.

7. Concrete afspraken

Functie van de vrijwilliger

De vrijwilliger zal volgende taak vervullen: ...
Deze taak omvat volgende activiteiten: ...
De vrijwilliger voert zijn taak uit onder verantwoordelijkheid van de faculteit Revalidatiewetenschappen en kinesitherapie
De vrijwilliger wordt binnen de faculteit begeleid door...
Zijn vaste werkplek voor het uitvoeren van de taak is ...

De vrijwilliger zal deze taak op volgende tijdstippen uitvoeren:

- op de volgende dag(en):
  - maandag
  - dinsdag
  - woensdag
  - donderdag
  - vrijdag
  - zaterdag
  - zondag
- het engagement wordt aangegaan voor de periode van ... tot ... (deze periode kan maximaal 1 kalenderjaar zijn en moet liggen tussen 1 januari en 31 december).

Begeleiding

De organisatie engageert zich ertoe de vrijwilliger tijdens deze proefperiode degelijk te begeleiden en te ondersteunen en hem/haar van alle informatie te voorzien opdat de activiteit naar best vermogen kan worden uitgevoerd.
De vrijwilliger voert de taken en activiteiten uit volgens de voorschriften vastgelegd door de faculteit. Hij/zij neemt voldoende voorzorgsmaatregelen in acht, en kan voor bijkomende informatie over de uit te voeren activiteit steeds terecht bij volgende contactpersoon: ...

De vrijwilliger krijgt waar nodig vooraf een vorming. Het volgen van de vorming indien aangeboden door de organisatie, is verplicht voor de vrijwilliger.

De vrijwilliger heeft kennis genomen van het 'reglement statuut student-onderzoeker' dat als bijlage aan deze afsprakennota wordt toegevoegd en integraal van toepassing is op de vrijwilliger.

Certificaat

Indien de vrijwilliger zijn opdracht succesvol afrondt, ontvangt hij/zij een certificaat van de UHasselt ondertekend door de decaan van de faculteit waaraan de vrijwilliger zijn opdracht voltooide.

8. Einde van het vrijwilligerswerk.

Zowel de organisatie als de vrijwilliger kunnen afzien van een verdere samenwerking. Dat kan gebeuren:

- bij onderlinge overeenstemming;
- op vraag van de vrijwilliger zelf;
- op verzoek van de organisatie.

Indien de samenwerking op initiatief van de vrijwilliger of de organisatie wordt beëindigd, gebeurt dit bij voorkeur minstens 2 weken op voorhand. Bij ernstige tekortkomingen kan de samenwerking, door de organisatie, onmiddellijk worden beëindigd.

Datum: ...

Naam en Handtekening decaan

Naam en Handtekening vrijwilliger

Opgemaakt in 2 exemplaren waarvan 1 voor de faculteit en 1 voor de vrijwilliger.

Bijlage 1

Reglement betreffende het statuut van student-onderzoeker[1]

Artikel 1. Definities

Voor de toepassing van dit reglement wordt verstaan onder:
student-onderzoeker: een regelmatig ingeschreven bachelor- of masterstudent van de UHasselt/tUL die als vrijwilliger wordt ingeschakeld in onderzoeksprojecten. De opdrachten uitgevoerd als student-onderzoeker kunnen op geen enkele wijze deel uitmaken van het studietraject van de student. De opdrachten kunnen geen ECTS-credits opleveren en zij kunnen geen deel uitmaken van een evaluatie van de student in ket kader van een opleidingsonderdeel. De onderzoeksopdrachten kunnen wel in het verlengde liggen van een opleidingsonderdeel, de bachelor- of masterproef.

Artikel 2. Toepassingsgebied

Enkel bachelor- en masterstudenten van de UHasselt/tUL die voor minstens 90 studiepunten credits hebben behaald in een academische bacheloropleiding komen in aanmerking voor het statuut van student-onderzoeker.

Artikel 3. Selectie en administratieve opvolging

§1 De faculteiten staan in voor de selectie van de student-onderzoekers en schrijven hiervoor een transparante selectieprocedure uit die vooraf aan de studenten kenbaar wordt gemaakt.
§2 De administratieve opvolging van de dossiers gebeurt door de faculteiten.

Artikel 4. Preventieve maatregelen en verzekeringen

§1 De faculteiten voorzien waar nodig in de noodzakelijke voorafgaande vorming van student-onderzoekers. De student is verplicht deze vorming te volgen vooraleer hij/zij kan starten als student-onderzoeker.
§2 Er moet voor de betrokken opdrachten een risicopostenanalyse opgemaakt worden door de faculteiten, analoog aan de risicopostenanalyse voor een stagiair van de UHasselt/tUL. De faculteiten zien er op toe dat de nodige veiligheidsmaatregelen getroffen worden voor aanvang van de opdracht.
§3 De student-onderzoekers worden door de UHasselt verzekerd tegen:

- Burgerlijke aansprakelijkheid
- Lichamelijke ongevallen

en dit ongeacht de plaats waar zij hun opdrachten in het kader van het statuut uitoefenen.

Artikel 5. Vergoeding van geleverde prestaties

§1 De student-onderzoeker kan maximaal 40 kalenderdagen, gerekend binnen één kalenderjaar, worden ingeschakeld binnen dit statuut. De dagen waarop de student-onderzoeker een vorming moet volgen, worden niet meegerekend als gepresteerde dagen.

§2 De student-onderzoeker ontvangt geen vrijwilligersvergoeding voor zijn prestaties. De student kan wel een vergoeding krijgen van de faculteit voor bewezen onkosten. De faculteit en de student maken hier aangaande schriftelijke afspraken.

Artikel 6. Dienstverplaatsingen

De student-onderzoeker mag dienstverplaatsingen maken. De faculteit en de student maken schriftelijke afspraken over deal dan niet vergoeding voor dienstverplaatsingen. De student wordt tijdens de dienstverplaatsingen en op weg van en naar de stageplaats uitsluitend verzekerd door de UHasselt voor lichamelijke ongevallen.

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[1] Zoals goedgekeurd door de Raad van Bestuur van de Universiteit Hasselt op 15 juni 2017.

Artikel 7. Afsprakennota

§1 Er wordt een afsprakennota opgesteld die vooraf wordt ondertekend door de decaan en de student-onderzoeker. Hierin worden de taken van de student-onderzoeker alsook de momenten waarop hij/zij de taken moet uitvoeren zo nauwkeurig mogelijk omschreven.
§2 Aan de afsprakennota wordt een kopie van dit reglement toegevoegd als bijlage.

Artikel 8. Certificaat

Na succesvolle beëindiging van de opdracht van de student-onderzoeker, te beoordelen door de decaan, ontvangt hij een certificaat van de studentenadministratie. De faculteit bezorgt de nodige gegevens aan de studentenadministratie. Het certificaat wordt ondertekend door de decaan van de faculteit waaraan de student-onderzoeker zijn opdracht voltooide.

Artikel 9. Geheimhoudingsplicht

De student-onderzoeker verbindt zich ertoe om alle gegevens, documenten, kennis en materiaal, zowel schriftelijk (inbegrepen elektronisch) als mondeling ontvangen in de hoedanigheid van student-onderzoeker aan de UHasselt, als strikt vertrouwelijk te behandelen, ook indien deze niet als strikt vertrouwelijk werd geïdentificeerd. Hij/zij verbindt zich ertoe om in geen geval deze vertrouwelijke informatie mee te delen aan derden of anderszins openbaar te maken, ook niet na de beëindiging van zijn/haar opdracht binnen dit statuut.

Artikel 10. Intellectuele eigendomsrechten

Indien de student-onderzoeker tijdens de uitvoering van zijn/haar opdrachten creaties tot stand brengt die (kunnen) worden beschermd door intellectuele rechten, deelt hij/zij dit onmiddellijk mee aan de faculteit. Deze intellectuele rechten, met uitzondering van auteursrechten, komen steeds toe aan de UHasselt.

Artikel 11. Geschillenregeling

Indien zich een geschil voordoet tussen de faculteit en de student-onderzoeker met betrekking tot de interpretatie van dit reglement of de uitoefening van de taken, dan kan de ombudspersoon van de opleiding waarbinnen de student-onderzoeker zijn taken uitoefent, bemiddelen. Indien noodzakelijk, beslecht de vicerector Onderwijs het geschil.

Artikel 12. Inwerkingtreding

Dit reglement treedt in werking met ingang van het academiejaar 2017-2018.

BEOORDELING VAN DE WETENSCHAPPELIJKE STAGE-DEEL 1

Wetenschappelijke stage deel 1 (Masterproef deel 1- MP1) van de Master of Science in de revalidatiewetenschappen en de kinesitherapie bestaat uit **twee delen**:

1) De literatuurstudie volgens een welomschreven methodiek.
2) Het opstellen van het onderzoeksprotocol ter voorbereiding van masterproef deel 2.

Omschrijving van de **evaluatie**:

1) 80% van het eindcijfer wordt door de promotor in samenspraak met de copromotor gegeven op grond het product en van het proces dat de student doorliep om de MP1 te realiseren, met name het zelfstandig uitvoeren van de literatuurstudie en het zelfstandig opstellen van het onderzoeksprotocol, alsook de kwaliteit van academisch schrijven.
2) 20% van het eindcijfer wordt door de interne jury gegeven op grond van het ingeleverde product en de mondelinge presentatie waarin de student zijn/haar proces toelicht.

In de beoordeling dient onderscheid gemaakt te worden tussen studenten die, in samenspraak met de promotor, een nieuw onderzoek uitwerkten en studenten die instapten in een lopend onderzoek of zich baseren op voorgaande masterproeven of onderzoeksprojecten. Van deze laatste worden bijkomende inspanningen verwacht zoals bv. het bijsturen van de eerder geformuleerde onderzoeksvraag, de kritische reflectie over het onderzoeksdesign, het uitvoeren van een pilotexperiment.

Beoordelingskader:

Beoordelingskader: criteria op 20	
18-20	Excellente modelmasterproef
16-17	Zeer goede masterproef
14-15	Goede masterproef
12-13	Voldoende masterproef
10-11	Zwakke masterproef
≤ 9	Onvoldoende masterproef die niet aan de minimumnormen voldoet

ZELFEVALUATIERAPPORT

Onderstaand zelfevaluatierapport is een hulpmiddel om je wetenschappelijke stage -deel 1 zelfstandig te organiseren. Bepaal zelf je deadlines, evalueer en reflecteer over je werkwijze en over de diepgang van je werk. Check de deadlines regelmatig. Toets ze eventueel af bij je (co)promotor. Succes!

ZELFEVALUATIERAPPORT WETENSCHAPPELIJKE STAGE - DEEL 1 RWK

LITERATUURSTUDIE	Gestelde deadline	Behaald op	Reflectie
De belangrijkste concepten en conceptuele kaders van het onderzoekdomein uitdiepen en verwerken	01/11/19	21/11/19	
De belangrijkste informatie opzoeken als inleiding op de onderzoeksvraag van de literatuurstudie	01/12/19	29/11/19	
De opzoekbare onderzoeksvraag identificeren en helder formuleren in functie van de literatuurstudie	02/12/19	02/12/19	
De zoekstrategie op systematische wijze uitvoeren in relevante databanken	20/03/20	18/03/20	Na overleg met onze promotor hebben we op 24/3 onze onderzoeksvraag aangepast en hebben we de vorige stappen opnieuw uitgevoerd. De reeds gestelde deadlines zijn toen ook bijgesteld. De tijdsdruk is sinds toen duidelijk gestegen
De kwaliteitsbeoordeling van de artikels diepgaand uitvoeren	27/03/20-→ 20/04/20	22/04/20	Het bepalen van de checklist verliep wat moeizamer, aangezien er nog geen gevalideerd exemplaar was in dit domein. Nadien verliep dit heel vlot. We hebben meteen de artikels grondig gelezen, wat toen wel wat tijd kostte, maar achteraf een pluspunt was.
De data-extractie grondig uitvoeren	10/04/20 → 7/05/20	15/05/20	We hadden wat extra tijd nodig om alles bondig in een overzichtelijke tabel te zetten, de 1e maal hadden we namelijk te veel geselecteerd.
De bevindingen integreren tot een synthese	24/05/20	24/05/20	Door de grote variatie aan uitkomstmaten en groepen, was het best moeilijk om het overzicht te bewaren. Al bij al denken we dat we hier in geslaagd zijn.

ONDERZOEKSPROTOCOL	Gestelde deadline	Behaald op	Reflectie
De onderzoeksvraag in functie van het onderzoeksprotocol identificeren	25/05/20	25/05/20	Verliep vlot, omdat we al heel wat kennis hadden opgedaan tijdens deel 1.
Het onderzoeksdesign bepalen en/of kritisch reflecteren over bestaande onderzoeksdesign	29/05/20	27/05/20	Idem
De methodesectie (participanten, interventie, uitkomstmaten, data-analyse) uitwerken	29/05/20	28/05/20	Idem

ACADEMISCHE SCHRIJVEN	Gestelde deadline	Behaald op	Reflectie
Het abstract to the point schrijven	24/05/20	24/05/20	Moeilijk door de grote variatie aan uitkomstmaten en groepen
De inleiding van de literatuurstudie logisch opbouwen	14/05/20	14/05/20	Verliep vlot, breed beginnen en dan vernauwen bleek de juiste strategie te zijn
De methodesectie van de literatuurstudie transparant weergegeven	14/05/20	12/05/20	Na het uitvoeren van eens bepaald onderdeel, hebben we steeds meteen de bijhorende methodiek beschreven, wat een vlot verloop in de hand heeft geholpen.
De resultatensectie afstemmen op de onderzoeksvragen	17/05/20	19/05/20	Verliep moeizamer dan gedacht door de grote variatie aan uitkomstmaten en groepen
In de discussiesectie de bekomen resultaten in een wetenschappelijke tekst integreren en synthetiseren	24/05/20	24/05/20	Zeer intensief aan gewerkt om toch de deadline te halen. We hebben wel niet het idee dat we zaken moesten forceren en hadden toch nog voldoende tijd om te reflecteren.
Het onderzoeksprotocol deskundig technisch uitschrijven	29/05/20	28/05/20	Verliep vlot, omdat we al heel wat kennis hadden opgedaan tijdens deel 1. Terminologie en uitkomsten waren soms moeilijk.
Referenties correct en volledig weergeven	24/05/20	24/05/20	

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ZELFSTUREND EN WETENSCHAPPELIJK DENKEN EN HANDELEN	Aanvangsfase	Tussentijdse fase	Eindfase
Een realistische planning opmaken, deadlines stellen en opvolgen	Goed	Voldoende	Goed
Initiatief en verantwoordelijkheid opnemen ten aanzien van de realisatie van de wetenschappelijke stage	Voldoende	Goed	Zeer goed
Kritisch wetenschappelijk denken	Goed	Goed	Zeer goed
De contacten met de promotor voorbereiden en efficiënt benutten	Goed	Voldoende	Goed
De richtlijnen van de wetenschappelijke stage autonoom opvolgen en toepassen	Voldoende	Voldoende	Goed
De communicatie met de medestudent helder en transparant voeren	Zeer goed	Goed	Zeer goed
De communicatie met de promotor/copromotor helder en transparant voeren	Zeer goed	Zeer goed	Goed
Andere verdiensten:			