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Faculteit Revalidatiewetenschappen

master in de revalidatiewetenschappen en de kinesitherapie

Masterthesis

A review on beat perception ability and its influence on gait parameters with RAS on patients with neurological disorders

Anne Ceulemans
Febe Schuurmans

Eerste deel van het scriptie ingediend tot het behalen van de graad van master in de revalidatiewetenschappen en de kinesitherapie

PROMOTOR :
Prof. dr. Peter FEYS

COPROMOTOR :
dr. Lousin MOUMDJIAN

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A review on beat perception ability and its influence on gait parameters with RAS on patients with neurological disorders

"Does beat perception ability influence the walking performance in neurological patients and healthy adults after auditory- based gait training?"

Highlights:

- Most research on rhythmic, auditory-cued stimulation while walking is done on patients with Parkinson's disease.
- There is a direct effect of multiple experimental paradigms such as metronome cues, high or low groove music on gait parameters in good and poor beat perceivers.
- Both good and bad perceivers benefit from walking to auditory cues.
- More research is needed on beat perception ability when using RAS as an intervention on patients with neurological disorders specifically the patients with Multiple Sclerosis (MS).

Students: Ceulemans Anne (1746586) and Febe Schuurmans (1747358)

Promotor: Prof. Dr. Peter Feys

Copromotor: Dr. Lousin Moumdjian

Context of master thesis

The research scope of this master's thesis is situated in the domain of neurological rehabilitation, especially in the area of auditory-based interventions. Walking problems are a common problem in neurological populations. Many studies already focus on the benefits of auditory cued gait training, but almost none examine the ability to perceive beats of this population. Therefore, an investigation into the influence of beat perception during auditory cued gait training is appropriate.

This duo-master thesis by Anne Ceulemans and Febe Schuurmans is supervised by Prof. Dr. Peter Feys, as promoter, and Dr. Lousin Moumdjian, as co-promoter. A centralized format will be applied. The entire master thesis is spread over two years. This year, a literature review and a study protocol will be written at Hasselt University in Diepenbeek. Next year, the study protocol will be conducted as a pilot study at Noorderhart Rehabilitation & MS in Pelt.

This year's master thesis contains two parts. First, the literature review provides more scientific background to the influence of beat perception on the benefits of auditory cued gait training. Secondly, the study protocol describes the design of a method to investigate this influence of beat perception. This research is embedded in a recently approved FWO project (2021-2025).

The research question is formulated by two thesis students in consultation with a promoter and co-promoter. The study protocol is student-generated and will not be used in an actual study. The contribution to the completion of the literature review and study protocol is the same for both thesis students.

Part 1: Literature review

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1. Abstract

Background: Rhythmic auditory stimulation (RAS) with music or metronome has been experienced as a good gait improvement tool for healthy adults and for people with neurological disorders such as Parkinson Disease (PD), Multiple Sclerose (MS) and stroke. Many studies investigated the influence of RAS on gait, but almost never considered the beat perception ability of the participants.

Methods: This systematic review is based on literature found in two databases: PubMed and Web of Science. It included randomized controlled trials and cross-sectional studies. Beat perception ability and gait parameters (cadence, stride/step time, stride/step length, stride length variability and speed) were the assessed outcome measures.

Results: The five articles, included in this review, involved three different groups of participants: stroke (n = 22), Parkinson Disease (n = 14) and healthy controls (n = 322). The synthesis of these articles revealed an effect of beat perception, measured by the BAASTA or a perception subtest BAT, on response of auditory cued stimulation in all three groups. Both good and bad beat perceivers benefit from auditory stimuli.

Discussion and conclusion: Four studies are observational and one study is interventional. All studies have a moderate quality. The data extraction of these studies shows that beat perception has an influence on gait when auditory cued stimulation is used. Further research on this topic is still needed.

Goal: This protocol will examine whether beat perception has an impact on the benefits of RAS on walking performance, or more briefly, is there a difference between good and bad beat perceivers when walking with RAS on patients with a neurological disease/healthy controls in relation with an intervention?

Operationalization of the research question: Patients with MS will perform a six-week rhythmic, auditory intervention while walking on a treadmill at the Rehabilitation & MS centre in Pelt. Beat perception and gait parameters will be assessed in pre- and post-testings.

Keywords: Neurological disorders, healthy adults, beat perception, rhythmic auditory stimulation, gait.

2. Introduction

Gait disorders are a major problem in many neurological disorders and increase the risk of falls and physical disability (Moon, Sung et al. 2016). One of the ways to improve gait parameters such as speed, stride length and cadence, is the use of rhythmic auditory stimulation (RAS) (Cha, Kim et al. 2014). Rhythmic auditory stimulation (RAS) is a method of gait rehabilitation in which patients synchronize their footsteps to a metronome or musical beats (Leow, Rinchon et al. 2015). Previous studies have demonstrated that the use of auditory cues is effective for conditions such as stroke ((Ghai and Ghai 2019); (Cha, Kim et al. 2014); (Yoo and Kim 2016)), Parkinson Disease ((Erra, Mileti et al. 2019); (Wittwer, Webster et al. 2013)) and MS ((Shahraki, Sohrabi et al. 2017); (Ghai and Ghai 2019); (Moumdjian, Moens et al. 2019)). Even in healthy controls, the presence of a rhythmic beat, musically or non-musically, can have an effect on gait performance (N. de Bruin, 2015). Many articles deal with the effects of auditory stimulation on gait, but most of them never mention anything about the participant's beat perception ability. Beat perception is a cognitive skill that enables the recognition of a regular pulse (or beat) in music and the synchronous response to that pulse in dancing and musical ensemble playing. Functional imaging has shown that various cortical and subcortical areas are active during beat perception and synchronisation (Merchant, Grahn et al. 2015). In particular, the basal ganglia and SMA are involved during beat perception ((Grahn and Brett 2007); (Grahn 2009)). The most common perceptual tests for beat perception ability measurement come from the Battery for the Assessment of Auditory Sensorimotor and Timing Abilities (BAASTA). The BAASTA is a tool for the systematic assessment of perceptual and sensorimotor timing skills. The BAASTA tool applies four different tests: duration discrimination, anisochrony detection with tones, anisochrony detection with music and a version of the beat alignment test (BAT) (Bella, Farrugia et al. 2017). The BAT uses a voting system based on whether the beats are the same or not. The BAASTA also uses this voting system as well as the ability to synchronize with fingertapping. The main goal of these perceptual tests is to detect rhythm disorders, such as beat deafness. Beat deafness is characterized by poor performance in perceiving durations in auditory rhythmic patterns or poor synchronization of movements with auditory rhythms (e.g. with musical beats) (Dalla Bella and Sowiński 2015). Besides rhythm disorder cases, also good perceivers, who score good at the perceptual tests, are determined (Sowiński and Dalla Bella 2013). Evidence was found already that rhythm perception is impaired in stroke (Patterson, Wong et al. 2018) and discrimination of beat-based rhythms is impaired in Parkinson disease (Grahn and Brett 2009). (Patterson, Wong et al. 2018) described the assessment of perceptual and sensorimotor timing in neurologic patient populations as a potential to pave the way for rehabilitation strategies when timing skills appear to play a critical role.

This review focuses on this critical role of beat perception. Studies assessing beat perception prior to gait training using a form of RAS are examined and the differences in the positive effects on the gait parameters are withheld. With this information, it is investigated if the impact of beat perception could be of great importance to the domain of gait rehabilitation and walking performance. We hypothesize that the effects of RAS are better in good perceivers, especially on the main gait parameters, such as stride length, walking speed and cadence.

To our knowledge, this systematic review is the first to investigate the influence of beat perception ability on gait parameter using RAS.

3. Methods

3.1 Research question

Does beat perception ability influence the walking performance in neurological patients and healthy adults after using RAS during gait training?

Based on the research question undermentioned PICO followed:

Table 1: PICO

Population	Neurological population & healthy adults
Intervention	Rhythmic auditory stimulation
Control	/
Outcome	Beat perception and gait parameters (cadence, stride/step time, stride/step length, stride length variability and speed)

3.2. Search strategy

The included studies were collected from PubMed and Web of Science (WoS). The same search strategy was applied in both databases. The applied search terms are shown in Table 15. Additional filters were not used in this search strategy. The search was conducted in May 2021.

The screening on title/abstract was performed with the 'Rayyan' software that supports a quick inclusion and exclusion selection process.

3.3. Eligibility criteria

3.3.1 Inclusion criteria

Studies were included when they met the following inclusion criteria: (1) population: people with neurological disorders or healthy adults, (2) intervention: all studies providing any type of auditory cued training or stimuli, (3) outcome measures: all studies providing specific information on the influence of beat perception on gait parameters, and (4) study type: all study types except systematic reviews, meta-analysis, practice guidelines, conferences, papers.

3.3.2 Exclusion criteria

Studies with the following criteria were excluded: (1) population: studies that did not involve humans or included children under the age of 18, (2) intervention: all studies providing other cued training than auditory cued (3) language: full text was not available in Dutch or English and (4) study type: all studies without beat perception as an outcome measure.

3.4 Quality check

Two different checklists were used to screen the quality of the articles. The experimental design was checked with the PEDro scale (Moseley, Elkins et al. 2020). The observational studies were screened with the STROBE checklist (von Elm, Altman et al. 2014).

3.5 Data extraction

Data extraction included: participants, study design, intervention/experimental paradigm, assessment instruments and their conclusion. To obtain a complete description of the population, patient characteristics such as disorder, severity of disability , age and number of participants were extracted. In addition, all primary and secondary outcome measures and their results were extracted, more in particular, gait parameters and beat perception ability. Furthermore, the inclusion and exclusion criteria of the studies were extracted as well.

4. Results

4.1 Search strategy

A total of 258 hits were found, 124 on PubMed and 134 on WoS. After removing 64 duplicates and manually adding two articles, 196 articles were withheld as potentially useful. After the initial screening based on title and abstract, only 13 articles remained for the full text screening. To every article that was excluded for further analysis, an exclusion reason was assigned. In this analysis, the following exclusion reasons were used: (1) wrong population: children under the age of 18, (2) wrong intervention: every other intervention than RAS or any other form of cues than auditory cues, (3) wrong outcome: no assessment of the influence of beat perception on gait parameters, (4) wrong study design: systematic review, tables, conferences… as described above (3.3. Eligibility criteria), (5) language: no Dutch or English version available, (6) animal studies, (7) no abstract: only title of the study available and (8) duplicates.
The updates of the search strategy and the number of hits are summarized in Table 16.

During the full text screening, the same exclusion reasons as described above were used. The result of this screening led to a selection of five articles that could be included. The information flow of the screening process is shown in the PRISMA diagram (Figure 1).

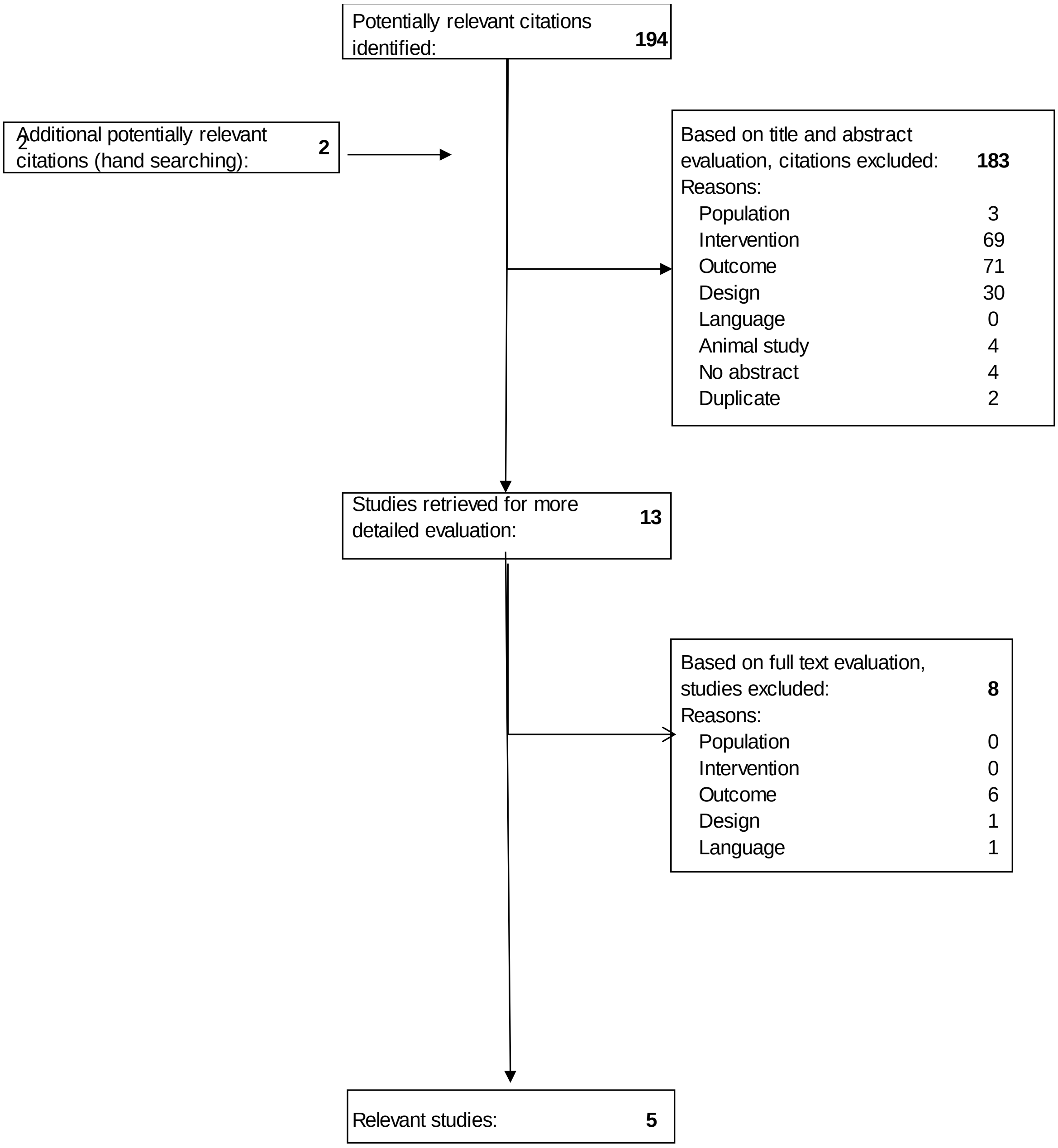

Figure 1: PRISMA flowchart

4.2 Quality assessment

Table 2 shows the scores of the STROBE for the four cross-sectional studies.

All articles had a clear description of the title, the abstract, the scientific background, the hypotheses and the investigation objectives. The description of the applied methods was fair, but none of the articles mentioned the study design or how the sample size was calculated. The results reporting was rather poor: none of the studies reported missing data or described fully the main results. The discussion section was good in all articles.

The experimental study of Bella, Benoit et al. 2017 scored six out of eleven on the PEDro scale, which corresponds to a good methodological quality (Cashin and McAuley 2020). Details of this score are visible in Table 3.

Table 2: Quality assessment cross-sectional studies

Criteria STROBE*	(Leow, Parrott et al. 2014)	(Roberts 2017)	(Ready, McGarry et al. 2019)	(Crosby, Wong et al. 2020)
Title and Abstract				
1. Title and abstract (a/b)	X / ✓	X / ✓	X / ✓	X / ✓
Introduction				
2. Background/rationale	✓	✓	✓	✓
3. Objectives	✓	✓	✓	✓
Methods				
4. Study design	X	X	X	X
5. Setting	✓	✓	✓	✓
6. Participants	✓	✓	✓	✓
7. Variables	✓	✓	✓	✓
8. Data sources/measurement	✓	✓	✓	✓
9. Bias	✓	✓	X	X
10. Study size	X	X	X	X
11. Quantitative variables	✓	✓	✓	✓
12. Statistical methods (a/b/c/d/e)	✓/ ✓/ X / X / X	✓/ ✓/ X / X / X	✓/ ✓/ X / X / X	✓/ ✓/ X / X / X
Results				
13. Participants (a/b/c)	X / ✓ / X	X / ✓ / X	X / ✓ / X	✓ / X / X
14. Descriptive data (a/b)	✓ / ✓	X / X	✓ / X	✓ / ?
15. Outcome date	✓	✓	✓	✓
16. Main results (a/b/c)	X / X / ?	X / X / ?	X / X / ?	✓ / X / ?
17. Other analyses	X	✓	✓	✓
Discussion				
18. Key results	✓	✓	✓	✓
19. Limitations	✓	✓	X	✓
20. Interpretation	✓	✓	✓	✓
21. Generalisability	✓	X	✓	✓
Other information				
22. Funding	✓	X	X	✓
Total score	15/22	13/22	12/22	14/22

✓: criteria is fulfilled X : criteria is not fulfilled/ not applicable ? : unknown
*Criteria specification (for further specification, see (von Elm, Altman et al. 2014))

Table 3: Quality assessment experimental design

Criteria PEDro scale*	(Bella, Benoit et al. 2017)
1. Eligibility criteria	✓
2. Randomized allocation	X
3. Concealed allocation	X
4. Similarity between groups at baseline	✓
5. Blinding of subjects	X
6. Blinding of therapists	X
7. Blinding of assessors	X
8. Outcome measures obtained from at least 85% of initially allocated subjects	✓
9. All received treatment or key outcome was analysed by "intention-to-treat"	✓
10. Between-group statistical comparisons	✓
11. Both point and variability measures provided	✓
Total score	6/11

✓: criteria is fulfilled   X : criteria is not fulfilled/ not applicable

* Criteria specification (for further specification, see (Moseley, Elkins et al. 2020))

4.3 Data extraction

4.3.1 Participant's characteristics

Participant's characteristics of each study are shown in Table 4.

Participants with idiopathic Parkinson's disease had their onset average 8 years ago (SD = 2.8) and had moderate symptoms with an average Hoehn and Yahr stage of 2 (SD = 0.7, range = 0.5-3) and a score of 36.8 (SD = 19.1, range = 3-52) on the United Parkinson's Disease Rating Scale. Freezing of gait was considered as an exclusion criterion. For medication, the levodopa equivalent daily dose (LED) was calculated for both dopamine replacement (146.2 mg (SD = 160.8)) and dopamine agonists (241.5 (SD = 204.7). The total of LED was 360.0 (SD = 270.1) (Bella, Benoit et al. 2017).

The participants with chronic stroke had an average score of 5.2 (SD = 1.0) on the Chedoke McMaster Stroke Assessment (CMSA) of the legs and an average score of 3.7 (SD = 1.5) on the CMSA of the feet. The time post-stroke was average 6.4 (SD = 6.8) years (Crosby, Wong et al. 2020)**.** The cognitive abilities of the participants were assessed with the Montreal Cognitive Assessment and this resulted in an average score of 25.7 (SD = 2.6). In six of the participants, the affected side was right and in nine of the participants the affected side was left.

The healthy controls were undergraduate participants or older adults (>50 years) ((Ready, McGarry et al. 2019), (Roberts 2017), (Leow, Parrott et al. 2014), (Bella, Benoit et al. 2017)).

Table 4: Participant's characteristics

Study	Population	Number of participants (% female)	Mean age (year + SD)
(Crosby, Wong et al. 2020)	Stroke	22 (31%)	61.5 (±10.4)
(Ready, McGarry et al. 2019)	Healthy young adults	84 (54%)	18.7 (±0.90)
(Roberts 2017)	Healthy young & older adults	Young adults: 81 Older adults: 94	HY: 22 (±2.88) HO: 66 (±9.14)
(Bella, Benoit et al. 2017)	Parkinson's disease + healthy adults	PD: 14 (28%) HC: 20 (50%)	PD: 66.5 (±7.2) HC: 66.4 (±3.0)
(Leow, Parrott et al. 2014)	Healthy adults	43 (58%)	18-20

4.3.2 Study characteristics and outcome measures

Study design and main outcome measures of the studies are summarized in Table 5.

Table 5: Study design and main outcomes

Study	Study design	Main outcome: Gait parameters	Mean outcome: Beat perception ability
(Crosby, Wong et al. 2020)	Cross-sectional study	Gait asymmetry (TGA) Velocity	BAT-score
(Ready, McGarry et al. 2019)	Cross-sectional study	Cadence Stride time Stride length Stride velocity	BAT- score
(Roberts 2017)	Cross-sectional study	Cadence Stride length Stride length variability Stride velocity	BAT-score
(Bella, Benoit et al. 2017)	Quasi experimental design	Cadence Stride time Stride length Stride velocity	Inter-step interval Sync. Accuracy Sync. Variability
(Leow, Parrott et al. 2014)	Cross-sectional study	Step length Step time Stride length variability	BAT-score

4.3.3 Types of intervention

The main intervention was walking to auditory stimuli. The auditory stimuli were musically or rhythmically, provided by a music player or metronome. Leow, Parrott et al. 2014, Crosby, Wong et al. 2020, Ready, McGarry et al. 2019 and Roberts 2017 conducted an experimental paradigm. Bella, Benoit et al. 2017 excuted an four week training intervention.

4.3.3.1 Observational studies

Leow, Parrott et al. 2014, Crosby, Wong et al. 2020, Ready, McGarry et al. 2019 and Roberts 2017 executed an experimental paradigm in one day in which participants completed multiple cued trials.

All four paradigms started with a non-cued walk to measure baseline gait parameters, specifically preferred cadence.

In Crosby, Wong et al. 2020, participants completed a total of 12 walking trials, nine synchronously with auditory stimuli and three during a dual task. The nine synchronised trails consisted of six trails with music and three with metronome. The dual task consisted of spelling words backwards. Each trail ended when at least 18 footsteps were measured. All 12 trails came in a random order. The nine synchronized trials were set to the participant's comfortable base cadence and began when the participant found the beat. Any strategy to find and maintain the beat was acceptable.

In Ready, McGarry et al. 2019, the experimental paradigm consisted of five different cued trials: songs with high groove/high familiarity, songs with high groove/low familiarity, songs with low groove/high familiarity, songs with low groove/low familiarity and metronome. Familiarity and groove were determined per participant on a 100-pt Likert scale. Each cued trial was presented twice, so the participant completed a total of 10 trials. Trials were performed in a random order at a comfortable pace.

The experimental paradigm of Roberts 2017 consisted of two different instructions arms: instructed to walk free to music and instructed to synchronize to the beat. Both arms received the same paradigm: 16 randomly cued trails with music or metronome and two control trails. Each trail consisted of at least 8 walk lengths. The control trails were in silence to measure changes in gait.

Leow, Parrott et al. 2014 presented 18 walking trails to the participants. The trails were divided into three cueing conditions (high groove, low groove and metronome) and into two different tempi (preferred cadence and 22.5% faster than preferred cadence). High and low groove were determined using a 10-point Likert scale. Each cued trial was randomly presented three times for the two different tempi. The trails were performed in a random order.

The details, used auditory stimuli and equipment of the different paradigms can be found
In Table 6.

4.3.3.2 Experimental study

The intervention of (Bella, Benoit et al. 2017) lasted one month and involved three training sessions per week. Only the patient group received training. Each training session consisted of three phases and lasted 10 minutes each. Phases one and three were identical. The patient's gait was cued for eight minutes, at +10% or -10% of the preferred cadence, depending on when the patient had the longest stride length at baseline. After these eight minutes the stimulation was stopped and the participant was required to continue walking at the same rate for two minutes. The second phase consisted of stop-and-go trails. During the first eight minutes the music was presented for 30 seconds and then stopped for five seconds. When the music stopped, the participant also had to take a pause. During the last two minutes, the same procedure was repeated, but then the 30 seconds were in silence. The only difference was that the participant had to decide when to start again. More details on frequency and volume are shown in Table 6

The details used auditory stimuli and equipment of the intervention in (Bella, Benoit et al. 2017) can be found in Table 6.

Table 6: Experimental paradigms and experimental conditions

Study	Details of training trials	Auditory stimuli	Equipment	Gait measure	Training frequency and volume	Duration of intervention
Experimental paradigms						
(Crosby, Wong et al. 2020)	1x silence (baseline) ↓ 12x random alternately: - music (6x) - metronome (3x) - dual task (3x)	Metronome; Western contemporary songs	/	Zeno™ walkway	1x; 1 baseline + 12 cued trials	1 day
(Ready, McGarry et al. 2019)	1x silence (baseline) ↓ 10x random alternately: - high groove/high familiarity (2x) - high groove/low familiarity (2x) - low groove/high familiarity (2x) - low groove/low familiarity (2x) - metronome (2x)	High groove/high familiarity, high groove/low familiarity, low groove/high familiarity, and low groove/low familiarity; Metronome	Music mixer (TwistedWave© 2015); noise-cancelling headphones (Bose® Quiet Comfort 3); Wireless headphones (Sennheiser® HDR 160)	Zeno™ walkway	1x; 1 baseline + 10 cued trials	1 day
(Roberts 2017)	1x silence (baseline) ↓ 8x 8 lengths random alternately music/ metronome ↓ 1x silence ↓ 8x 8 lengths random alternately music/ metronome ↓ 1x silence	Different genres (rock, latin, african, electronic music, Hip Hop, German Folk, Country…); metronome	Wireless headphones	Zeno™ walkway	1x; 1 baseline + 18 cued trials + 2 control trials	1 day
(Leow, Parrott, Grahn 2014)	1 silence (baseline) ↓ 18 walking trials in two tempi (preferred cadence and +22.5% faster) random alternately: - low groove music (3x) - high-groove music (3x) - metronome (3x)	Low-groove music, high-groove music, and metronome	Audacity (Free Software Inc., Boston, USA);	Zeno™ walkway	1x; 1h	1 day
Experimental conditions						
(Bella, Benoit et al. 2017)	**Fase 1 :** 8 min. music training (cues +10 or -10% preferred cadence) 2 min. silent training ↓ **Fase 2**: 8 min. stop- and go trials with music (30s walking on music, 5s stop) 2 min. stop- and go trials in silence (30s walking in silence, 5s stop) ↓ **Fase 3:** Idem fase 1	A familiar German folk Song without lyrics emphasized with a superimposed salient high-pitch bell sound (Hoch auf dem gelben Wagen)	Wireless headphones (Beyerdynamic RSX 700); portable MP3-Player & headphones (Sansa-Clip); Vicon MX Motion Capture System	Oval trajectory	3x/week; 30 min. (3x10min)	1 month

4.3.4 Measurements

4.3.4.1 Beat perception

Crosby, Wong et al. 2020, Ready, McGarry et al. 2019, Roberts 2017 and Leow, Parrott et al. 2014 used the perception subtest of the Beat Alignment Test (BAT). In each of these studies, the BAT was conducted differently depending on the consulted literature. Ready, McGarry et al. 2019 and Leow, Parrott et al. 2014 performed the test from Goldsmiths Musical Sophistication Index v1.0 (Müllensiefen, Gingras et al. 2014). Crosby, Wong et al. 2020 and Roberts 2017 performed the test described in (Iversen, Aniruddh 2008). Bella, Benoit et al. 2017 used other perceptual tests. The tests conducted were based on the subtests of the Battery for the Assessment of Auditory Sensorimotor and Timing Abilities (BAASTA) described in (Benoit, Bella et al. 2014).

The instruments, methods and materials are summarized in Table 7.

4.3.4.2 Gait parameters

In Crosby, Wong et al. 2020, Ready, McGarry et al. 2019, Roberts 2017 and Leow, Parrott et al. 2014 the Zeno™-Walkway was used. The Zeno™-Walkway measures the common spatiotemporal gait parameters such as step length, stride length, stride width, gait velocity, cadence, stride velocity, step time, stance time, swing time, single- support time, double-support time and percentage of gait cycle for stance phase, swing phase, single-support phase and total double-support phase (Vallabhajosula, Humphrey et al. 2019). In the study of (Bella, Benoit et al. 2017) gait parameters were measured by the Vicon MX Motion Capture System. Participants walked in an oval trajectory with small reflective markers placed in accordance with the Conventional Gait Model on the participant (Baker 2006) to measure to measure the spatiotemporal gait parameters.

Table 7: Measuring instruments of beat perception, procedure and materials

Study	Measuring instrument	Procedure	Materials
(Crosby, Wong et al. 2020)	Perception subtest BAT	17 music clip trails were overlaid with a series of tones, on or off the beat of the music clip. <u>Technique</u> Yes = on the beat No = off the beat	Computer using E-prime software
(Ready, McGarry et al. 2019)	Perception subtest BAT	Procedure from Goldsmiths Musical Sophistication Index v1.0*	/
(Roberts 2017)	Perception subtest BAT	17 music clips with a superimposed beep that was either on or off the music or the beat. <u>Technique</u> Press Y = on the beat Press N = off the beat Rate certainty of answer	Computer using E-prime software
(Bella, Benoit et al. 2017)	BAASTA: - Paced tapping to an isochronous sequence - Adaptive tapping task The motion capture system: - synchronised walking	**Paced tapping to an isochronous sequence** Tapping to an isochronous sequence of 60 piano tones. There were 3 different inter-onset intervals (IOIs). Each trial was repeated twice. **Adaptive tapping test** Sequences of 10 tones were presented. First 6 had an IOI of 600ms, the other 4 maintained or had a slower (570 or 525ms) or faster tempo (630 or 670 ms). <u>Technique</u> Tapping on percussion pad on the beat **Synchronized walking** Walk to the beat of German folk song presented at a faster (+10%) or slower tempo (−10%) relative to their comfortable gait speed. <u>Technique</u> Walking on the beat	Roland SPD-6 MIDI percussion pad controlled by MAX-MSP software (version 5.1) with 1-ms precision; IBM-compatible computer; headphones (Sennheiser HD201)
(Leow, Parrott et al. 2014)	Perception subtest BAT	17 music clips with a superimposed beep that was either on or off the music or the beat. <u>Technique</u> Press Y = on the beat Press N = off the beat Rate certainty of answer	/

4.3.4.3 Outcome measures

As shown in Table 5 the most commonly used outcome measures of gait parameters were cadence, stride/step time, stride/step length, stride length variability and speed.

To investigate the influence of beat perception on these parameters, beat perception ability had first to be measured. The BAT was conducted before the start of the experimental paradigms in Crosby, Wong et al. 2020, Ready, McGarry et al. 2019, Roberts 2017 and Leow, Parrott et al. 2014. The scores of the BAT were used to divide the participants into weak/poor or strong/good beat perceivers. The cut-off values are presented in Table 8.

Table 8: Cut-off values of beat perception

Study	Beat perception parameter	Strong perceivers	Weak perceivers
(Crosby, Wong et al. 2020)	Synchronization accuracy: mean BAT score (%):	>50	<50
(Ready, McGarry et al. 2019)	Synchronization accuracy: mean BAT score (%):	76,47-100	29,41-58,82
(Roberts 2017)	Synchronization accuracy: mean BAT perception score:	Young adults > 0,68 Old adults > 0,64	Young adults < 0,68 Old adults < 0,64
(Leow, Parrott et al. 2014)	Synchronization accuracy: mean BAT score:	>0,65	<0,65

Crosby, Wong et al. 2020 found a significant difference between the pre and metronome testing. The temporal gait asymmetry improved. The test-results are shown in Table 10.

Ready, McGarry et al. 2019 found a significant cue type by beat perception interaction. With high groove music, the stride length differed. But this wasn't observed with low grove music or with metronome cues. In addition, good beat perceivers took significantly shorter strides in comparison to poor beat perceivers. For stride time, a significant main effect of the cue type was observed. High groove music and metronome cues showed faster and longer strides than low groove music. For stride velocity, there was also a significant interaction between cue type and beat perception. Good beat perceivers decreased their velocity significantly less for high groove music and metronome cues compared to low groove music. The results for high groove music and metronome cues didn't differ. Also, poor beat perceivers decreased the velocity significantly for high groove music and metronome cues compared to low groove music. But here, the decreases with high groove music were smaller than with metronome. The test-results are shown in Table 11 and Table 12.

Roberts 2017 didn't describe specific numeric values of their gait results. They described the interaction and significance of change in the gait parameters. Roberts 2017 found significant differences when comparing the change scores to baseline. In the younger group, good and poor beat perceivers had faster strides and more steps per minute to high enjoyment music, low enjoyment music and metronome when they were instructed to synchronize. In addition, the good beat perceivers also had briefer strides to high enjoyment music, low enjoyment music and metronome. When they were instructed to freely walk, there wasn't any significant difference in the younger group. In the older group, there was a significant difference for the good beat perceivers when they were instructed to freely walk. Faster strides and more steps per minute were observed to high enjoyment music, low enjoyment music and metronome. When instructed to synchronize, both groups had shorter strides to high enjoyment music, low enjoyment music and metronome and only to the metronome, they also had more steps per minute. In the younger group, the stimuli had an effect on stride velocity and stride length. RAS induced faster strides ($p = 0.04$) and longer strides ($p = 0.006$) to both high enjoyment and low enjoyment music than to the metronome. Cadence increased to both music and metronome but similarly ($p = 0.94$). Stride length variability did not significantly change between music and the metronome ($p = 0.48$). In the older group, the main effect was on stride velocity and cadence. RAS induced slower strides ($p<0.001$) and less steps per minute ($p <0.001$) to both high and low enjoyment music compared to the metronome. Also, the stride length variability increased with music compared to metronome ($p <0.001$). There wasn't a main effect on stride length.

In the younger group of Roberts 2017, when instructed to synchronize, the cadence ($p = 0.015$) and the stride velocity ($p = 0.001$) increased, but it didn't significantly influence the stride length ($p = 0.84$). When given the instruction to freely walk, it didn't significantly influence stride length variability ($p = 0.30$). In the older group, synchronised walking, compared to freely walk, resulted in shorter stride length ($p <0.001$) and slower stride velocity ($p = 0.004$), but it did not significantly influence cadence ($p = 0.77$). There also was a significant increase in stride length variability ($p < 0.001$).

Looking at the interaction between stimulus and instruction type, there was a significant interaction in the older group. It resulted in a higher cadence to the metronome than to both high and low enjoyment music ($p < 0.001$). Also, a slower stride velocity to both high and low enjoyment music than metronome was observed ($p = 0.003$). There was no significant interaction for stride length ($p = 0.87$). Looking at the influence of beat perception ability, among the younger group, the poor beat perceivers took significantly shorter strides to all stimuli ($p = 0.02$) and had a slower stride velocity ($p = 0.04$) compared to the good beat perceivers. On cadence ($p = 0.15$) and stride length variability ($p = 0.68$) there wasn't a significant influence. At the older group, the poor beat perceivers had a slower stride velocity to the stimuli ($p = 0.04$) compared to the good beat perceivers.

Leow, Parrott et al. 2014 found a significant interaction between the cues and the tempo for stride velocity and step length. High groove music showed similar results for stride velocity and step length to metronome cues at preferred tempo but showed slower and shorter steps than metronome cues at faster tempo. Low groove music showed significantly slower and shorter steps than high-groove music and metronome (at both preferred and faster tempo). For step time, a significant interaction between beat perception, cues and tempo was observed. At preferred tempo, weak beat perceivers slowed step times more than strong beat perceivers, but only with low groove music. With high groove music and metronome cues, this was not observed. At faster tempo, weak beat perceivers sped up step times more than strong beat perceivers only with metronome cues. This was not observed with low groove music or high groove music. In addition, with metronome cues, the weak beat perceivers combined the briefer step times with reduced step length, resulting in a stride velocity increase. For stride length variability, a significant interaction between beat perception and cues were found. Weak perceivers showed greater increases in stride length variability than strong beat perceivers with low groove music as well as with metronome cues. This wasn't observed with high groove music. The test-results are shown in Table 13.

In Bella, Benoit et al. 2017, beat perception was measured in terms of synchronization accuracy and variability.

In the tapping tasks, synchronization accuracy is determined by the mean absolute asynchrony (i.e., unsigned) between the tap times and the onset of the metronome tones. Synchronization variability was determined by the standard error of the mean (SEM) asynchrony between the tap times and the metronome tones. Both variables are presented as % of inter-onset intervals (IOI). Performance on hand tapping tasks did not differ significantly between IPD patients and controls before training (Supplementary table 1 in (Bella, Benoit et al. 2017)) (Bella, Benoit et al. 2017).

The study also examined the synchronization ability during walking. The inter-step interval, the synchronization accuracy and the variability of steps during the cued gait intervention were measured respectively at +10% and -10% of the preferred cadence. The inter-step interval is defined as the average duration between successive steps in a sequence of steps. Synchronization accuracy is defined as the mean absolute asynchrony between the step times and the musical beats. Synchronization variability is the SEM of asynchrony between the step times and musical beats (Bella, Benoit et al. 2017). Both the patients and control groups were measured at baseline, but only the patient group had a post and follow-up measurement. At pre-measurement, a significant difference in synchronization accuracy of -10% was found between the patient and control groups. At post- and follow-up measurement, there was a significant difference of inter-step interval at -10% and synchronization variability at +10%. Similarly, there was a significant difference of inter-step interval at -10% between pre and follow up. The test results and p-values are shown in Table 9.

In Bella, Benoit et al. 2017, only the patient group performed a post and follow-up measurement. Bella, Benoit et al. 2017 found significant differences between patients and controls. Patients exhibited faster cadence, shorter stride length, shorter stride time and slower speed. Also, there were significant differences between the pre, post and follow-up measurements. At the post measurement gait speed and stride length significantly increased. This was maintained at the follow-up measurement (1 month later). Stride time was significantly shorter at the post and follow-up measurements. The variability was significantly reduced at the post measurement, but it wasn't maintained at follow-up. The test-results are shown in Table 14.

All the studies used a p-value of 0.05 as a significant value.

Table 9: Results of beat perception ability (Bella, Benoit et al. 2017)

Study	Beat perception parameters	Healthy controls	Patients			P-values		
		CONTROL	PRE	POST	FOLLOW - UP	PRE-CONTROL	PRE-POST	PRE-FOLLOW UP
(Bella, Benoit et al. 2017)	Synchronization accuracy (% of IOI)	-10% cadence 10,8 (8,9) +10% cadence 18,0 (2,3)	-10% cadence 22,7 (3,1) +10% cadence 19,1 (3,4)	-10% cadence 22,4 (2,0) +10% cadence 23,3 (1,6)	-10% cadence 24,9 (2,8) +10% cadence 21,4 (1,8)	-10% cadence p < 0,01 +10% cadence p = 0,48	-10% cadence p = 0,32 +10% cadence p = 0,12	-10% cadence p = 0,24 +10% cadence p = 0,26
	Synchronization variability (% of IOI)	-10% cadence 1,3 (0,3) +10% cadence 2,3 (0,5)	-10% cadence 2,0 (0,5) +10% cadence 1,3 (0,4)	-10% cadence 2,2 (0,6) +10% cadence 3,5 (0,6)	-10% cadence 2,8 (1,0) +10% cadence 3,5 (0,6)	-10% cadence p = 0,01 +10% cadence p = 0,18	-10% cadence p = 0,27 +10% cadence p < 0,05	-10% cadence p = 0,42 +10% cadence p < 0,01
	Inter-step interval (ms)	-10% cadence 627,7 (14,0) +10% cadence 535,7 (11,0)	-10% cadence 610,3 (16,3) +10% cadence 518,6 (13,4)	-10% cadence 576,3 (15,9) +10% cadence 513,4 (11,4)	-10% cadence 572,3 (14,6) +10% cadence 500,4 (12,4))	-10% cadence p = 0,26 +10% cadence p = 0,19	-10% cadence p < 0,05 +10% cadence p = 0,31	-10% cadence p <0,01 +10% cadence p < 0,05

Table 10: Results of gait parameters (Crosby, Wong et al. 2020)

Study	Gait parameters	Patients		
		PRE	Metronome	
			Strong beat perceivers	Weak beat perceivers
(Crosby, Wong et al. 2020)	Temporal gait asymmetry (ratio)	1,38 (0,27)	1,37 (0,28)	1,42 (0,27)
	Velocity (cm/sec.)	72,5 (21,5)	77,6 (21,4)	61,5 (18,5)

Table 11: Results of gait parameters of poor beat perceivers (Ready, McGarry et al. 2019)

Study	Gait parameters	Poor/weak beat perceivers							
		Free walking				Synchronised walking			
		PRE	Experimental paradigm			PRE	Experimental paradigm		
			Low groove	High groove	Metronome		Low groove	High groove	Metronome
(Ready, McGarry et al. 2019)	Cadence (steps/min.)	111,2 (7,8)	/	/	/	112,6 (7,2)	/	/	/
	Stride time (sec.)	1,08 (0,07)	1,11 (0,08)	1,08 (0,07)	1,09 (0,07)	1,08 (0,07)	1,12 (0,12)	1,07 (0,07)	1,07 (0,06)
	Stride length (cm)	129,45 (10,7)	125,18 (11,5)	130,58 (10,7)	126,27 (11,9)	129,45 (9,7)	122,35 (8,8)	128,75 (9,0)	124,94 (9,7)
	Stride velocity (cm/sec.)	120,34 (12,7)	113,34 (14,4)	121,83 (13,3)	116,99 (13,3)	120,78 (10,4)	111,45 (14,0)	121,04 (10,2)	117,89 (9,6)

Table 12: Results of gait parameters of good beat perceivers (Ready, McGarry et al. 2019)

Study	Gait parameters	Good/strong beat perceivers							
		Free walking				Synchronised walking			
		PRE	Experimental paradigm			PRE	Experimental paradigm		
			Low groove	High groove	Metronome		Low groove	High groove	Metronome
(Ready, McGarry et al. 2019)	Cadence (steps/min.)	111,4 (6,6)	/	/	/	114,2 (8,0)	/	/	/
	Stride time (sec.)	1,09 (0,08)	1,12 (0,07)	1,10 (0,08)	1,11 (0,08)	1,05 (0,07)	1,07 (0,08)	1,04 (0,07)	1,05 (0,08)
	Stride length (cm)	128,45 (9,7)	123,89 (10,7)	125,31 (10,7)	124,71 (11,3)	127,83 (12,0)	121,35 (11,8)	125,04 (13,0)	122,70 (12,7)
	Stride velocity (cm/sec.)	118,71 (11,1)	111,70 (13,1)	114,05 (13,5)	112,86 (14,0)	122,50 (14,8)	115,09 (14,6)	120,45 (16,2)	119,94 (15,1)

Table 13: Results of gait parameters (Leow, Parrott et al. 2014)

Study	Gait parameters	Preferred tempo				Faster tempo			
		PRE	Experimental paradigm			PRE	Experimental paradigm		
			Low groove	High groove	Metronome		Low groove	High groove	Metronome
(Leow, Parrott et al. 2014)	Step time (sec.)	0,37 (0,17)	0,41 (0,18)	0,37 (0,17)	0,37 (0,17)	/	0,29 (0,24)	0,34 (0,16)	0,22 (0,25)
	Step length (cm)	31,9 (6,5)	61,0 (7,4)	59,8 (7,4)	60,8 (7,0)		61,2 (8,2)	58,8 (8,0)	59,9 (7,7)
	Stride length variability (CV)	0,051 (0,021)	0,068 (0,022)	0,062 (0,018)	0,055 (0,019)		0,070 (0,027)	0,072 (0,026)	0,067 (0,015)
	Stride velocity (cm/sec.)	95,4 (14,4)	88,4 (16,8)	95,5 (18,6)	95,2 (17,3)		93,3 (22,0)	107,7 (20,9)	103,8 (19,2)

Table 14: Results of gait parameters (Bella, Benoit et al. 2017)

Study	Gait parameters	Healthy controls			Patients		
		PRE	POST	FOLLOW - UP	PRE	POST	FOLLOW - UP
(Bella, Benoit et al. 2017)*	Cadence (steps/min.) Stride time (sec.) Stride length (cm) Stride length variability Speed (cm/sec.)	100,5 (1,8) 1,2 (0,02) 1152,0 (22,3) 964,4 (25,9)	/	/	106,3 (2,3) 1,1 (0,03) 1011,7 (44,8) 0,0048 (0,0008) 898,9 (48,1)	108,0 (2,2) 1,1 (0,02) 1057,5 (37,8) 10,4 (0,9) 952,7 (37,0)	109.5 (2.2) 1.1 (0.02) 1053.7 (38.7) 10.8 (0.6) 961.5 (39.3)

5. Discussion

5.1. Reflection on methodological quality of the included studies

Two methodological quality assessments, the PEDro scale and the STROBE checklist, were performed by two individuals. Four of the five included articles were assessed using the STROBE checklist given they were cross-sectional studies/one day experiments. Only the study of (Bella, Benoit et al. 2017) was assessed by the PEDro scale given it was a experimental study. Both checklists indicated that all the studies had a fair methodological quality. However, there was a poor reporting of study design, results and study size. The discussion section was well described in the articles.

5.2. Reflection on BAT, BAASTA and the walkways

Two instruments were used for beat perception: The Beat Alignment Test (BAT) and the Battery for the Assessment of Auditory Sensorimotor and Timing Abilities (BAASTA). All studies except for (Bella, Benoit et al. 2017) used the BAT. The BAT is commonly used for this type of testing. But for this test, there were no studies on the test-retest reliability, internal consistency etc... This could lead to several biases and inconsistent presentation of results. Also, the fact that the BAT can be done in different ways, makes it difficult to compare studies with each other. However, this test doesn't take much time and it's easy to explain and to understand. A disadvantage of this test is that the perception is assessed by listening to different music clips with a superimposed beep that was either on or off the beat. The scores of the BAT were based on a voting system. When hearing two identical rhythms, they needed to vote correct. If not identical, they needed to vote incorrect. The scoring of the BAASTA were based on a combination of the same voting system as the BAT and also measures of fingertapping synchronisation. Thus, this does not assess the influence of beat perception ability while walking nor the ability to synchronize (Iversen, Aniruddh 2008). The BAASTA provides a more general assessment of timing skills. However, it takes longer to complete the test compared to the BAT (Della Bella, Farrugia 2016). A study was conducted on the test-retest reliability of the BAASTA. It was found that performance on most tasks remained stable. This suggests that performance is robust and not affected by a learning effect or annoyance due to repetition (Bégel, Verga et al. 2018). Moreover, both tests may reveal individual differences, particularly poor timing performance. Last, only timing perception ability and timing production ability during walking were specifically examined. Since the purpose of this study is to evaluate the influence of beat perception during walking, it would be more interesting to assess beat perception ability during walking rather than the ability to tap.

Two instruments were used to measure gait parameters: The Zeno™-Walkway and the Vicon MX Motion Capture System with small reflective markers placed on the participant according to the Conventional Gait Model. The Zeno™-Walkway is a relatively new instrument. Not much research has been done on it. The advantages of this instrument are that it is a mat which has a variety of widths and lengths and is easy to install. The walkway also capture pressure data as you walk and sends that data directly to a computer program. One disadvantage of this type of instrument is that it is a walkway. Therefore, it cannot measure continuous walking paradigms as a treadmill can. A study by (Lynall, Zukowski et al. 2016) concluded that the Zeno™-Walkway can be a reliable gait assessment tool, but further research is needed. (Bella, Benoit et al. 2017) used the Vicon MX Motion Capture System (Nexus, sd). Participants had to walk an oval trajectory with small reflective markers placed according to the Conventional Gait Model. Given this system uses markers, it can be easily placed and transported anywhere. Another advantage is that it can detect the smallest differences or movements. A disadvantage of this system is that it has to be placed exactly in the same place to compare data measured at different times.

5.3. Reflection on the results in relation to the research questions

All studies except (Bella, Benoit et al. 2017) divided their participants into two groups: good beat perceivers or poor beat perceivers. (Bella, Benoit et al. 2017) investigated the correlation between beat perception and gait parameters. Therefore, any conclusion should be taken with caution. Furthermore, only (Bella, Benoit et al. 2017) used RAS as a true training. All other studies ((Leow, Parrott et al. 2014, Crosby, Wong et al. 2020, Ready, McGarry et al. 2019 and Roberts 2017)) used one-day experimental paradigms investigating the instant effect of RAS on gait, making it difficult to conclude the effect of RAS as a long-term intervention.

However, all of studies concluded that there was a direct effect of walking to auditory cues on gait parameters. All studies found a direct effect of metronome cues, high groove/enjoyment music and low enjoyment music for all gait parameters. Low groove music is the only exception here, as it did not always have a direct effect. This could be explained by the fact that the beat is probably harder to find or the music was not as well-known compared to high-groove music.

Our hypothesis that good beat perceivers benefit most from walking to music, can be rejected as both good and poor beat perceivers experienced the same benefit of walking to auditory cues on all gait parameters. However, given that this review is based on five articles and RAS was only used in (Bella, Benoit et al. 2017), more research is needed. But then the question arises as to why there are good and poor beat perceivers. Looking at previous research, this could be explained by less musical training or musical interests compared to the good beat perceivers (Manning, Schutz 2016 & Matthews, Thibodeau et al. 2016 & Nave-Blodgett, Snyder, Hannon 2021). Also, the more familiar with a song, the better the beat perception/synchronization ability (Leow, Rinchon, Grahn 2015). When looking at the measuring of beat perception and production ability, it is measured by finger tapping. This is considered a dual task, so the cognitive load is higher here. Thus, the lower beat perception/production ability may be due to higher cognitive load or more difficulty in performing a dual task.

However, the poor beat perceivers showed the same advantages in gait parameters when walking to auditory cues. Perhaps, this can be explained by their ability focus on the beat.

5.4. Reflection on strengths and limitations of the literature review

5.4.1 Strengths

This review included not only neurological patients but also healthy adults. This is an advantage because it can show the difference of the influence of beat perception on gait between healthy adults and neurological patients.

5.4.2 Limitations

The greatest limitation was that only five articles could be included in this review because of the novelty of this topic. Also, the studies used an experimental paradigm conducted in one day, except for (Bella, Benoit et al. 2017) who used RAS as an intervention. However, immediate effects were found in these experimental paradigms. Furthermore, there was no wash-out period between the experimental conditions which may lead to a carry-over effect. Looking at the information in the articles, the studies do not provide much information about the participants. Specific medications and their side-effects on gait or more specific information about their condition were not described in any article. For example, when PD patients use Levodopa or dopamine agonists, they have less tremor and experience a more normal gait pattern. When knowing this, therapists can base their therapy and testings on it to give a specific conclusion/plan. In addition, only two databases were used to conduct the studies: PubMed and Web of Science. Finally, only studies written in Dutch or English were included, which could lead to language bias.

5.5. Clinical implications

As shown in the results section above, both good and poor beat perceivers benefit from these experimental paradigms that resulted in changes in gait when walking to music. But how can we get the poor beat perceivers to a higher/better beat perception baseline? Several studies showed the influence of music background and beat perception ((Manning, Schutz 2016 & Matthews, Thibodeau et al. 2016 & Nave-Blodgett, Snyder, Hannon 2021). This is something that can be implemented in a longitudinal study to improve beat perception skills from a young age. Knowing this at the beginning of the study, is a way to recruit participants early so that poor beat perceivers can receive musical training. Furthermore, the influence of familiarity with the music was investigated. With higher familiarity with the song, the synchronization was less demanding and gave better results on the gait parameters compared with low familiarity (Leow, Rinchon, Grahn 2015). With this knowledge, we can conclude that making poor beat perceivers more familiar with the music can lead to better performance. Also, the type of music is relevant in this case. When walking to metronome or high groove music, where the beat is more obvious, poor beat perceivers perform better ((Leow, Parrott et al. 2014) & (Ready, McGarry et al. 2019)). So, this can be implemented in music therapy as well. There is also not much research yet on synchronization ability. This could be an interesting point as to why poor beat perceivers also benefit from the experimental paradigms.
Overall, there is not much research on improving beat perception ability in adults. But with the findings described above, there is an opportunity to investigate this further and implement the findings of previous studies.

The clinical conclusion is that good beat perceivers can get an immediate benefit from walking to music, while the poor beat perceivers can benefit even more if they have been trained or if they have the opportunity to become more familiar with the cues.

5.6. Future implications

Since this review only included five studies that examined the influence of beat perception on gait parameters, more research is needed on this topic. In addition, most of the articles were about Parkinson Disease or stroke patients, but there were none about people with the neurological disease multiple sclerosis. Thus, further research should be conducted on other pathologies. Also, most of the articles used an experimental paradigm that was tested for one day instead of doing an intervention. Thus, it would be interesting to see how beat perception affects gait parameters when auditory stimulation is used as an intervention over a longer period of time, to investigate the effect of training. Finally, as described above, it would be beneficial to better train poor beat perceivers if this is possible. Perhaps this can be accomplished by doing more training with this group or letting them become more familiar with the music. Another idea might be to use more obvious cues such as walking to metronome cues instead of walking to music where the beat is often hard to find.

6. Conclusion

From our brief review of five articles, there can be concluded that beat perception has an influence on gait parameters. Studies testing an intervention effect of beat perception on walking with music are lacking. However, when subjected to a one-day experimental paradigm, a direct effect on gait can be seen. So its use in therapy may directly benefit patients. Nevertheless, there must be kept in mind that further research on this topic is needed to provide a complete specific answer to this research question.

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8. Appendix

Table 15: Overview of used search terms in PubMed and Web Of Science (WOS)

Databank	Search strategy
PubMed	((("Nervous System Diseases"[MeSH Terms]) OR (“Autoimmune Diseases of the Nervous System”[MeSH Terms]) OR ("neurodegenerative diseases"[MeSH Terms]) OR (“central nervous system diseases”[MeSH Terms]) OR ("demyelinating autoimmune diseases, CNS"[MeSH Terms]) OR ("demyelinating diseases"[MeSH Terms]) OR ("neurodegenerative diseases"[MeSH Terms])) AND ((auditory perception[MeSH Terms]) OR (beat perception) OR (beat alignment) OR (synchronization) OR (rhythmic skills) OR (rhythm ability) OR (rhythm perception)) AND ((cues[MeSH Terms]) OR (music therapy[MeSH Terms]) OR (Acoustic Stimulation[Mesh]) OR (beat) OR (rhythmic cued) OR (music[MeSH Terms]) OR (music cues) OR (cued gait training) OR (rhythmic cues) OR (auditory cues) OR (rhythmic auditory stimulation) OR (music cued gait training) OR (rhythmic auditory cueing) OR (auditory cueing) OR (auditory stimulation) OR (metronome)) AND ((gait[MeSH Terms]) OR (gait) OR (walking[MeSH Terms]) OR (walking)))
Web of Science	(((TS= Nervous System Diseases) OR (TS= Autoimmune Diseases of the Nervous System) OR (TS= neurodegenerative diseases) OR (TS= central nervous system diseases) OR (TS= demyelinating autoimmune diseases, CNS) OR (TS= demyelinating diseases)) AND ((TS= cues) OR (TS= music therapy) OR (TS= Acoustic Stimulation) OR (AB= beat) OR (AB= rhythmic cued) OR (TS= music) OR (AB= music cues) OR (AB= cued gait training) OR (AB= rhythmic cues) OR (AB= auditory cues) OR (AB= rhythmic auditory stimulation) OR (AB= music cued gait training) OR (AB= rhythmic auditory cueing) OR (AB= auditory cueing) OR (AB= auditory stimulation) OR (AB= metronome)) AND ((TS= auditory perception) OR (AB= beat perception) OR (AB= beat alignment) OR (AB= synchronization) OR (AB= rhythmic skills) OR (AB= rhythm ability) OR (AB= rhythm perception)) AND ((TS= gait) OR (AB= gait) OR (AB=walking) OR (TS= walking)))

Table 16: Number of hits and duplicates in PubMed and Web Of Science (WOS)

Date	PubMed	WoS	Duplicates	Total
21 Jan. ‘21	87	106	38	155
31 March ‘21	90	99	32	157
24 April ‘21	124	134	65	196

9. References

(*) references with a number before them are articles included in the literature review

Bégel, V., Verga, L., Benoit, C. E., Kotz, S. A., & Dalla Bella, S. (2018). Test-retest reliability of the Battery for the Assessment of Auditory Sensorimotor and Timing Abilities (BAASTA). *Ann Phys Rehabil Med*, *61*(6), 395-400. https://doi.org/10.1016/j.rehab.2018.04.001

(*)Bella, S. D., Benoit, C. E., Farrugia, N., Keller, P. E., Obrig, H., Mainka, S., & Kotz, S. A. (2017). Gait improvement via rhythmic stimulation in Parkinson's disease is linked to rhythmic skills. *Sci Rep*, *7*, 42005. https://doi.org/10.1038/srep42005

Cha, Y., Kim, Y., & Chung, Y. (2014). Immediate effects of rhythmic auditory stimulation with tempo changes on gait in stroke patients. *J Phys Ther Sci*, *26*(4), 479-482. https://doi.org/10.1589/jpts.26.479

(*)Crosby, L. D., Wong, J. S., Chen, J. L., Grahn, J., & Patterson, K. K. (2020). An Initial Investigation of the Responsiveness of Temporal Gait Asymmetry to Rhythmic Auditory Stimulation and the Relationship to Rhythm Ability Following Stroke. *Front Neurol*, *11*, 517028. https://doi.org/10.3389/fneur.2020.517028

Dalla Bella, S., Farrugia, N., Benoit, C. E., Begel, V., Verga, L., Harding, E., & Kotz, S. A. (2017). BAASTA: Battery for the Assessment of Auditory Sensorimotor and Timing Abilities. *Behav Res Methods*, *49*(3), 1128-1145. https://doi.org/10.3758/s13428-016-0773-6

Dalla Bella, S., & Sowiński, J. (2015). Uncovering beat deafness: detecting rhythm disorders with synchronized finger tapping and perceptual timing tasks. *J Vis Exp*(97). https://doi.org/10.3791/51761

de Bruin, N., Kempster, C., Doucette, A., Doan, J. B., Hu, B., & Brown, L. A. (2015). The Effects of Music Salience on the Gait Performance of Young Adults. *J Music Ther*, *52*(3), 394-419. https://doi.org/10.1093/jmt/thv009

Erra, C., Mileti, I., Germanotta, M., Petracca, M., Imbimbo, I., De Biase, A., Rossi, S., Ricciardi, D., Pacilli, A., Di Sipio, E., Palermo, E., Bentivoglio, A. R., & Padua, L. (2019). Immediate effects of rhythmic auditory stimulation on gait kinematics in Parkinson's disease ON/OFF medication. *Clin Neurophysiol*, *130*(10), 1789-1797. https://doi.org/10.1016/j.clinph.2019.07.013

Ghai, S., & Ghai, I. (2019). Effects of (music-based) rhythmic auditory cueing training on gait and posture post-stroke: A systematic review & dose-response meta-analysis. *Sci Rep*, *9*(1), 2183. https://doi.org/10.1038/s41598-019-38723-3

Grahn, J. A. (2009). The role of the basal ganglia in beat perception: neuroimaging and neuropsychological investigations. *Ann N Y Acad Sci*, *1169*, 35-45. https://doi.org/10.1111/j.1749-6632.2009.04553.x

Grahn, J. A., & Brett, M. (2007). Rhythm and beat perception in motor areas of the brain. *J Cogn Neurosci*, *19*(5), 893-906. https://doi.org/10.1162/jocn.2007.19.5.893

Iversen, J. a. P. A. (2008). The Beat Alignment Test (BAT): Surveying beat processing abilities in the general population. *Proceedings of the 10 th International Conference on Music Perception and Cognition (ICMPC10)*.

(*)Leow, L. A., Parrott, T., & Grahn, J. A. (2014). Individual differences in beat perception affect gait responses to low- and high-groove music. *Front Hum Neurosci*, *8*, 811. https://doi.org/10.3389/fnhum.2014.00811

Leow, L. A., Rinchon, C., & Grahn, J. (2015). Familiarity with music increases walking speed in rhythmic auditory cuing. *Ann N Y Acad Sci*, *1337*, 53-61. https://doi.org/10.1111/nyas.12658

Leow, L.-A., Waclawik, K., & Grahn, J. A. (2018). The role of attention and intention in synchronization to music: effects on gait. *Experimental Brain Research*, *236*(1), 99-115.

https://doi.org/10.1007/s00221-017-5110-5
Lynall, R. C., Zukowski, L. A., Plummer, P., & Mihalik, J. P. (2017). Reliability and validity of the protokinetics movement analysis software in measuring center of pressure during walking. *Gait Posture*, *52*, 308-311. https://doi.org/10.1016/j.gaitpost.2016.12.023

Manning, F. C., & Schutz, M. (2016). Trained to keep a beat: movement-related enhancements to timing perception in percussionists and non-percussionists. *Psychol Res*, *80*(4), 532-542. https://doi.org/10.1007/s00426-015-0678-5

Matthews, T. E., Thibodeau, J. N., Gunther, B. P., & Penhune, V. B. (2016). The Impact of Instrument-Specific Musical Training on Rhythm Perception and Production. *Front Psychol*, *7*, 69. https://doi.org/10.3389/fpsyg.2016.00069

Merchant, H., Grahn, J., Trainor, L., Rohrmeier, M., & Fitch, W. T. (2015). Finding the beat: a neural perspective across humans and non-human primates. *Philos Trans R Soc Lond B Biol Sci*, *370*(1664), 20140093. https://doi.org/10.1098/rstb.2014.0093

Moon, Y., Sung, J., An, R., Hernandez, M. E., & Sosnoff, J. J. (2016). Gait variability in people with neurological disorders: A systematic review and meta-analysis. *Hum Mov Sci*, *47*, 197-208. https://doi.org/10.1016/j.humov.2016.03.010

Moseley, A. M., Elkins, M. R., Van der Wees, P. J., & Pinheiro, M. B. (2020). Using research to guide practice: The Physiotherapy Evidence Database (PEDro). *Braz J Phys Ther*, *24*(5), 384-391. https://doi.org/10.1016/j.bjpt.2019.11.002

Moumdjian, L., Moens, B., Maes, P. J., Van Nieuwenhoven, J., Van Wijmeersch, B., Leman, M., & Feys, P. (2019). Walking to Music and Metronome at Various Tempi in Persons With Multiple Sclerosis: A Basis for Rehabilitation. *Neurorehabil Neural Repair*, *33*(6), 464-475. https://doi.org/10.1177/1545968319847962

Müllensiefen, D., Gingras, B., Musil, J., & Stewart, L. (2014). The musicality of non-musicians: an index for assessing musical sophistication in the general population. *Plos One*, *9*(2), e89642. https://doi.org/10.1371/journal.pone.0089642

Nave-Blodgett, J. E., Snyder, J. S., & Hannon, E. E. (2021). Hierarchical beat perception develops throughout childhood and adolescence and is enhanced in those with musical training. *J Exp Psychol Gen*, *150*(2), 314-339. https://doi.org/10.1037/xge0000903

Patterson, K. K., Wong, J. S., Knorr, S., & Grahn, J. A. (2018). Rhythm Perception and Production Abilities and Their Relationship to Gait After Stroke. *Arch Phys Med Rehabil*, *99*(5), 945-951. https://doi.org/10.1016/j.apmr.2018.01.009

(*)Ready, E. A., McGarry, L. M., Rinchon, C., Holmes, J. D., & Grahn, J. A. (2019). Beat perception ability and instructions to synchronize influence gait when walking to music-based auditory cues. *Gait Posture*, *68*, 555-561. https://doi.org/10.1016/j.gaitpost.2018.12.038

(*)Roberts, B. S. (2017). Comparing the influence of music enjoyment and beat perception ability on spatiotemporal gait parameters among healthy young and older adults.

Shahraki, M., Sohrabi, M., Taheri Torbati, H. R., Nikkhah, K., & NaeimiKia, M. (2017). Effect of rhythmic auditory stimulation on gait kinematic parameters of patients with multiple sclerosis. *J Med Life*, *10*(1), 33-37.

Sowiński, J., & Dalla Bella, S. (2013). Poor synchronization to the beat may result from deficient auditory-motor mapping. *Neuropsychologia*, *51*(10), 1952-1963. https://doi.org/10.1016/j.neuropsychologia.2013.06.027

Vallabhajosula, S., Humphrey, S. K., Cook, A. J., & Freund, J. E. (2019). Concurrent Validity of the Zeno Walkway for Measuring Spatiotemporal Gait Parameters in Older Adults. *J Geriatr Phys Ther*, *42*(3), E42-e50. https://doi.org/10.1519/jpt.0000000000000168

von Elm, E., Altman, D. G., Egger, M., Pocock, S. J., Gøtzsche, P. C., & Vandenbroucke, J. P. (2014). The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: guidelines for reporting observational studies. *Int J Surg*, *12*(12), 1495-1499.

https://doi.org/10.1016/j.ijsu.2014.07.013
Wittwer, J. E., Webster, K. E., & Hill, K. (2013). Rhythmic auditory cueing to improve walking in patients with neurological conditions other than Parkinson's disease--what is the evidence? *Disabil Rehabil*, *35*(2), 164-176. https://doi.org/10.3109/09638288.2012.690495
Yoo, G. E., & Kim, S. J. (2016). Rhythmic Auditory Cueing in Motor Rehabilitation for Stroke Patients: Systematic Review and Meta-Analysis. *J Music Ther*, *53*(2), 149-177. https://doi.org/10.1093/jmt/thw003

Part 2: Protocol

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1. Introduction

Gait disorders are a major problem in many neurological disorders and increase the risk of falls and physical disability (Moon et al., 2016). One of the ways to improve gait parameters such as speed, stride length and cadence, is the use of rhythmic auditory stimulation (RAS) (Cha et al., 2014). Rhythmic auditory stimulation (RAS) is a method of gait rehabilitation in which patients synchronize their footsteps to a metronome or musical beats (Leow et al., 2015).

Considering the results of the literature review above, beat perception ability can play a role in the effects of auditory based training on gait performance. There are many studies which describe the benefits of auditory stimuli on gait performance in neurological disorders, such as Parkinson Disease (PD) ((Erra et al., 2019); (Wittwer et al., 2013)), stroke ((Ghai & Ghai, 2019);(Cha et al., 2014); (Yoo & Kim, 2016)) and Multiple Sclerose (MS) ((Shahraki et al., 2017); (Ghai & Ghai, 2018); (Moumdjian et al., 2019)). However, the beat perception ability of the participants in these studies were never measured. Nevertheless there is evidence that rhythm perception is impaired in stroke (Patterson et al., 2018) and discrimination of beat-based rhythms in Parkinson disease (Grahn & Brett, 2009). Therefore, an assessment of beat perception when timing skills play an important role in rehabilitation strategies in neurological population, such as rhythmic auditory stimulation, should be implemented (Patterson et al., 2018).

The review above described some studies which studied the influence of beat perception in stroke (Crosby et al., 2020), persons with PD (Simone Dalla Bella et al., 2017) and healthy controls ((Leow et al., 2014); (Roberts, 2017); (Ready et al., 2019)). Unfortunately, there aren't any references available to investigate this influence of beat perception on effects of auditory based stimuli in persons with MS. That is also the reason for writing this protocol.

2. Aim study

The aim of this study is to investigate the influence of beat perception on the benefits on gait using a music-based intervention in people with MS.

2.1 Research question

Two main research questions are formulated as followed:

- ➢ What is the influence of beat perception ability on a six-week music-based walking intervention on walking performance in persons with MS?
- ➢ Can a six-week music-based walking intervention improve the beat perception ability in persons with MS?

Four other sub-questions are formulated as followed:

- ➢ Does beat perception ability have an effect on fatigue after a music-based walking intervention in persons with MS?
- ➢ Will good perceivers be less tired compared to poor beat perceivers after a music-based walking training in persons with MS?
- ➢ Does beat perception ability have an effect on balance after a music-based walking intervention in persons with MS?
- ➢ Will good perceivers have a less impact on day-to-day life after a music-based walking intervention in persons with MS compared to poor perceivers?

2.2 Hypothesis

For the first main research question, we expect that beat perception ability will play a significant role, especially in the groups that followed the intervention with music. So, participants who will score better at the beat perception tests, hereafter named as good perceivers, will have a more positive effect on gait performance (improvements in one or multiple tests: 6MWT, spatiotemporal parameters or MSWS). For the second main research question we assume a positive effect on beat perception ability in both groups, although we expect a greater effect in the poor perceiver group (seen in better scores on BAT).

Secondly, we expect a positive effect on fatigue for both good and poor perceivers. However, we suppose that good perceivers will be experience less fatigue than bad perceivers (seen in lower scores of MFIS). Also, we expect that good perceivers will be less tired after a single music-based training than poor perceivers (seen in lower scores on the BORG RPE- scale).

Further we expect a positive effect on balance for both good and poor perceivers. However, we also suppose here that the effect on balance will be greater in de group of good perceivers (seen in better score on TUG and DGI).

Finally, we expect that good perceivers will experience less impact on day-to-day life after a music-based walking intervention compared to poor perceivers (seen in lower scores on the MSIS)).

3. Methods

3.1 Study design

Forty persons with MS will be participating in this randomized single blinded controlled pilot study. These 40 participants will be randomly divided, using stratified randomisation on motor disability, over two arms: a synchronised walking on music group and a non-synchronised walking on music control group. Each group will contain 20 participants and will be subdivided into two subgroups based on their scores of the beat perceptual tests: good or poor perceivers. Both subgroups, good and poor perceivers, will contain 10 participants (see Figure 2). The participants of the synchronised group will be instructed to synchronise their steps on the beat. The participants of the control group will get no instructions. Every walking intervention will be done at preferred cadence of the participant.

The interventions will be on top of their usual rehabilitation and will be performed prior to their therapy session.

After randomisation in two arms, a perceptual subtest of the Battery for the Assessment of Auditory Sensorimotor and Timing Abilities (BAASTA) will be performed. This test will be the Beat Alignment Test (BAT). The score of this test will determine whether you are a good or a poor perceiver. The determination will be done based on a cut-off score, dependent on the acquired scores. This way both groups will contain 10 participants. This test will be executed at the same day as the baseline measurement.

Both the intervention group and control group will undergo a baseline and post measurement (see Figure 3). The baseline measurement consists of following measurements:

- ➢ Demographic data and musical background (self-made questionnaire)
- ➢ Gait performance and perceived ability (6MWT and MSWS)
- ➢ Gait parameters (portable APDM sensors ((OPAL, USA, https://www.apdm.com/wearable-sensors/)) (Washabaugh et al., 2017)
- ➢ Walking and balance (DGI and TUG)
- ➢ Impact of fatigue (MFIS)
- ➢ Impact of day-to-day life (MSIS)

- ➢ Beat perception ability (BAT)

The post-measurement will include the same tests as the baseline, except the self-made questionnaire.

The baseline measurement will be performed one week before the intervention will start. One week after the intervention the post-testing will be performed.

During the six weeks of intervention a BORG RPE-scale will be used to measure fatigue of the participants. This will be conducted before and after training.

The whole intervention, including pre- and post-measurement, will last eight weeks and will be conducted in Noorderhart, Revalidation & MS centre in Pelt. Participants will be training two times a week for twenty minutes per training session.

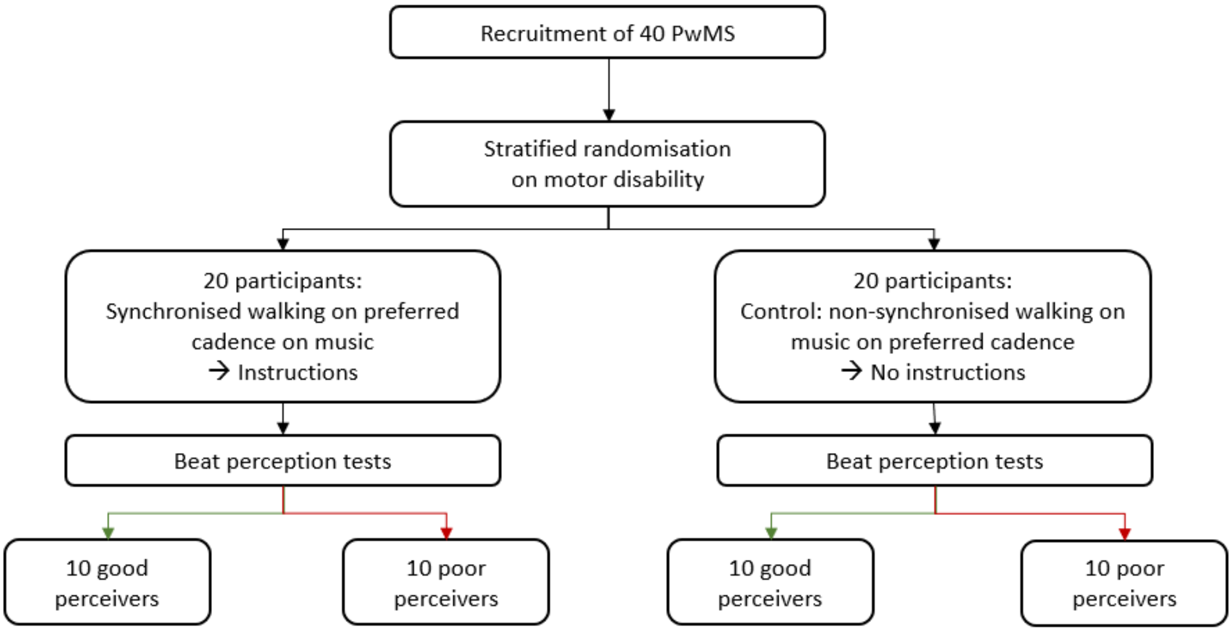


Figure 2: recruitment

Figure 3: Procedure

3.2 Participants

3.2.1 Inclusion criteria

Participants can be included in the study when: (1) a diagnosis of MS longer than 1 year with no relapses in the past month; (2) older than 18 years (3) ability to walk independently on a treadmill; (4) walking speed of 2-6 km/h.

3.2.2 Exclusion criteria

Participants will be excluded if they meet the following criteria: (1) having a hearing impairment; (2) being pregnant; (3) having a cognitive impairment hindering understanding of study instructions; (4) not able to walk.

3.2.3 Recruitment

Self-made flyers will be distributed in Noorderhart, Revalidation & MS centre in Pelt for recruiting participants.

3.3 Medical ethics

An ethical application will be submitted to Hasselt University as the head centre and to Noorderhart, Revalidation & MS centre in Pelt as the local centre. All participants will be informed in detail about the content of the interventions and testings. They will be asked to sign a written informed consent.

3.4 Intervention

This RCT consists of two arms: synchronised walking on music and walking in silence (control). Both intervention arms will last six weeks in total, where the participants will be training two times a week. Every training session will take a total of 30 minutes and will consist of two times 10 minutes walking on their preferred cadence with rest in between. Before and after the training the fatigue will be assessed. The preferred cadence will be measured at the first training session.

Arm 1: synchronised walking on music

The participants are instructed to walk on their preferred cadence on the rhythm of the music on a treadmill. The music consists of songs with lyrics and will be played by the treadmill. The tempo (bpm) will be adapted at the baseline cadence measured at the beginning of the first training session. A variance in tempo of maximum of 6% less or more than preferred cadence will be used. The genre of the music can be freely chosen by the participant. The choices of music could be pop, soft pop, electro or rock.

Arm 2: control intervention

The participants are asked to walk on music on their preferred cadence on a treadmill. Preferred cadence will be measured at the beginning of the first training. The music will be played by the treadmill at a tempo of 20% above the preferred cadence. No instructions will be given at the participant.

3.5 Outcome measures

3.5.1 Beat perception

Beat alignment test (BAT)

The BAT measures the beat perception inherent in a musical stimulus. In the BAT participants get 17 music clip trails overlaid with a series of tones, on or off the beat of the music clip. After each music clip participants need to say whether the series of tones were on the beat or off the beat. Participants will do that to say: yes, if on the beat, or no, if off the beat.

The BAT records an excellent test-retest reliability (94%). (Bégel et al., 2018) This makes this test appropriate to measure beat perception ability.

This perceptual test is a test of the Battery for the Assessment of Auditory Sensorimotor and Timing Abilities (BAASTA). This test will take a total of 15 minutes. (S. Dalla Bella et al., 2017)

3.5.2 Primary outcome measures

The primary outcome measure will be gait. Gait performance will be examined with the 6MWT and MSWS. The gait parameters, such as cadence, stride length and walking speed will be measured with portable APDM sensors.

3.5.2.1 Gait performance

6MWT

In the 6MWT, participants are asked to walk at a comfortable pace for six minutes. After six minutes, the examiner writes down the total number of meters established.

The 6MWT is a feasible, reproducible and reliable measure in persons with MS. It records an excellent inter-rater reliability (ICC = 0.91) and excellent intra-rater reliability (ICC= 0.95). (Goldman et al., 2008) The test-retest variability is excellent as well (ICC = 0.965). (Bennett et al., 2017)

Multiple Sclerosis Walking Scale (MSWS)

The MSWS is a rating scale to assess the participant's perception of their walking ability. This scale consists of 12 questions and must be scored on a scale of 1 (no problem) to 5 (extremely problematic). The higher the score, the more limitations MS brings on the walking capacity. This scale would be taken home by the participant and filled in at home.

This test has a good test-retest reliability (ICC = 0.863) in persons with MS. (Bennett et al., 2017)

3.5.2.2 Gait parameters

During the 6MWT participants will be wearing APDM sensors which are strapped around the ankle and forefoot like a watch around a wrist. These sensors measure the following spatiotemporal gait parameters: stride length, walking speed and cadence. The ICC and MDC of these sensors are comparable to the existing gold standard gait evaluation techniques. (Washabaugh et al., 2017)

3.5.3 Secondary outcome measures

The secondary outcomes that will be examined are fatigue, walking and balance, music experience and impact on day-to-day life. The fatigue will be registered with the MFIS and during the intervention with the BORG RPE- scale. Balance will be assessed with the TUG and DGI, the music experience with a self-made questionnaire and impact on daily activities with MSIS.

3.5.3.1 Fatigue

Modified Fatigue Impact Scale (MFIS)

The MFIS asses the effects of fatigue on quality of life in persons with chronic diseases, especially MS. It consists of a 21-item questionnaire divided in three different domains: physical, cognitive and psychosocial. (Larson, 2013) This scale would be taken home by the participant and filled in at home.

The internal consistency of the overall score of MFIS is excellent (α = 0.81). For the different parts, the internal consistency is physical, 0.91, cognitive 0.95 and psychosocial, 0.81. The test-retest of this test is excellent (ICC = 0.91). (Larson, 2013)

BORG rating of perceived exertion scale (BORG RPE-scale)

The BORG RPE is a 15-point scale used to rate the subjective perception of fatigue of participants. Before and after the training the participants will be asked to rate their fatigue on a scale of 6 to 20. A score of six would mean that the participant experienced no fatigue at all and a score of 20 would indicate extreme fatigue.

The BORG RPE-scale is a reliable and valid instrument to measure exertion in persons with MS. It records a good test-retest reliability (ICC = 0.870). (Cleland et al., 2016)

3.5.3.2 Walking and balance

Dynamic Gait Index (DGI)

The DGI tests the ability to maintain balance under various dynamic walking conditions, such as stepping over an obstacle or looking around while walking. This test consists of eight different items and each item is scored on a scale from 0 (severe impairment) to 3 (normal function). The higher the score on the DGI, the better the better a participant's functional walking ability.

DGI records an excellent test-retest reliability (ICC= 0.955) in persons with MS. (Bennett et al., 2017)

Time Up and Go (TUG)

The TUG is a test designed to measure fall risk. Participants are instructed to stand up from a chair, walk three meters, turn around, walk back to the chair and sit back down. The goal is to do this as quickly as possible. Participants are given three attempts, of which the best time counts. The longer it takes to perform this procedure, the greater the risk of falling.

TUG has an excellent test-retest reliability (ICC= 0.973) in persons with MS. (Bennett et al., 2017)

3.5.3.3 Music experience

Self-made questionnaire

To get an idea of the musical background, a small questionnaire is made. This questionnaire would be taken home by the participant and filled in at home.

3.5.3.4 Impact on day-to-day life

Multiple Sclerosis Impact Scale (MSIS)

MSIS is a scale which describes the physical and psychological impact of MS from patient's perspective. This scale consists of 29 items and is divided into 20 physical items and 9 psychological items. Both parts must be scored on a scale of 1 (no problem) to 5 (extreme problem). The total score of the 29 items will be transformed to a 0-100 scale. The higher the score, the more impact of the disease has on daily life.

The test-retest reliability of the MSIS is excellent for the physical part (ICC = 0.94) and good for the psychological part (ICC= 0.87). The internal consistency is for both parts excellent (α = 0.96 and 0.91). (Hobart et al., 2001)

3.6. Materials

Following materials will be used in all arms:

- Treadmill (BIODEX)
- Laptop with customized software linked to BIODEX

3.7 Data analysis

A first analysis will be on the patients' beat perception results. Next there will be a statistic analysis of the demographic data and the patients' pre-testing results (sex, age, EDSS, spatiotemporal gait parameters, 6MWT, DGI,TUG and MSWS). During the intervention, dropouts will be noted. Every drop-out will be asked about a reason. The collected data of participants will be summarized in tables. To do the statistical analyses of this data, the SAS JMP Pro software will be used. The effects within patients and between good and poor perceivers within every group will be investigated. To do so, a statistical mixed model will be used. Also, the overall effect between the intervention arm and control arm will be investigated. This will be done with ANOVA. The following influencing factors will also be investigated: severity of MS; musically background; gender ; age and sex. The probability of <5% will be used and confidence intervals will be set at 95%.

4. Time planning

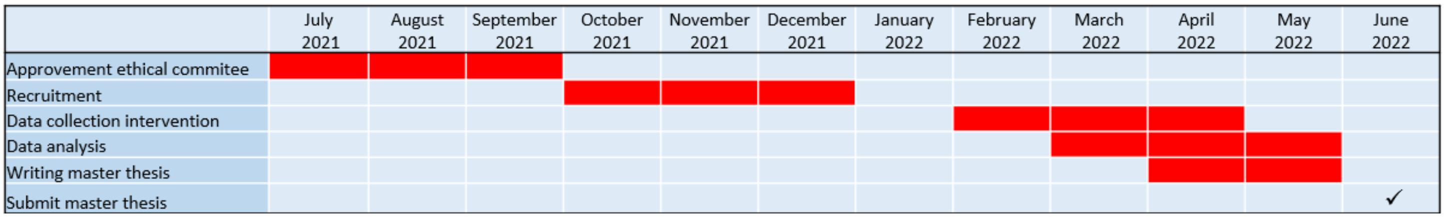


Figure 4: Time planning

5. References

Bégel, V., Verga, L., Benoit, C. E., Kotz, S. A., & Dalla Bella, S. (2018). Test-retest reliability of the Battery for the Assessment of Auditory Sensorimotor and Timing Abilities (BAASTA). *Ann Phys Rehabil Med*, *61*(6), 395-400. https://doi.org/10.1016/j.rehab.2018.04.001

Bennett, S. E., Bromley, L. E., Fisher, N. M., Tomita, M. R., & Niewczyk, P. (2017). Validity and reliability of four clinical gait measures in patients with multiple sclerosis. *International journal of MS care*, *19*(5), 247-252.

Cha, Y., Kim, Y., & Chung, Y. (2014). Immediate effects of rhythmic auditory stimulation with tempo changes on gait in stroke patients. *J Phys Ther Sci*, *26*(4), 479-482. https://doi.org/10.1589/jpts.26.479

Cleland, B. T., Ingraham, B. A., Pitluck, M. C., Woo, D., & Ng, A. V. (2016). Reliability and Validity of Ratings of Perceived Exertion in Persons With Multiple Sclerosis. *Arch Phys Med Rehabil*, *97*(6), 974-982. https://doi.org/10.1016/j.apmr.2016.01.013

Crosby, L. D., Wong, J. S., Chen, J. L., Grahn, J., & Patterson, K. K. (2020). An Initial Investigation of the Responsiveness of Temporal Gait Asymmetry to Rhythmic Auditory Stimulation and the Relationship to Rhythm Ability Following Stroke. *Front Neurol*, *11*, 517028. https://doi.org/10.3389/fneur.2020.517028

Dalla Bella, S., Benoit, C.-E., Farrugia, N., Keller, P. E., Obrig, H., Mainka, S., & Kotz, S. A. (2017). Gait improvement via rhythmic stimulation in Parkinson's disease is linked to rhythmic skills. *Scientific Reports*, *7*. https://doi.org/10.1038/srep42005

Dalla Bella, S., Farrugia, N., Benoit, C. E., Begel, V., Verga, L., Harding, E., & Kotz, S. A. (2017). BAASTA: Battery for the Assessment of Auditory Sensorimotor and Timing Abilities. *Behav Res Methods*, *49*(3), 1128-1145. https://doi.org/10.3758/s13428-016-0773-6

Erra, C., Mileti, I., Germanotta, M., Petracca, M., Imbimbo, I., De Biase, A., Rossi, S., Ricciardi, D., Pacilli, A., Di Sipio, E., Palermo, E., Bentivoglio, A. R., & Padua, L. (2019). Immediate effects of rhythmic auditory stimulation on gait kinematics in Parkinson's disease ON/OFF medication. *Clin Neurophysiol*, *130*(10), 1789-1797. https://doi.org/10.1016/j.clinph.2019.07.013

Ghai, S., & Ghai, I. (2018). Effects of Rhythmic Auditory Cueing in Gait Rehabilitation for Multiple Sclerosis: A Mini Systematic Review and Meta-Analysis. *Front Neurol*, *9*, 386. https://doi.org/10.3389/fneur.2018.00386

Ghai, S., & Ghai, I. (2019). Effects of (music-based) rhythmic auditory cueing training on gait and posture post-stroke: A systematic review & dose-response meta-analysis. *Sci Rep*, *9*(1), 2183. https://doi.org/10.1038/s41598-019-38723-3

Goldman, M. D., Marrie, R. A., & Cohen, J. A. (2008). Evaluation of the six-minute walk in multiple sclerosis subjects and healthy controls. *Mult Scler*, *14*(3), 383-390. https://doi.org/10.1177/1352458507082607

Grahn, J. A., & Brett, M. (2009). Impairment of beat-based rhythm discrimination in Parkinson's disease. *Cortex*, *45*(1), 54-61. https://doi.org/10.1016/j.cortex.2008.01.005

Hobart, J., Lamping, D., Fitzpatrick, R., Riazi, A., & Thompson, A. (2001). The Multiple Sclerosis Impact Scale (MSIS-29): A new patient-based outcome measure. *Brain*, *124*(5), 962-973. https://doi.org/10.1093/brain/124.5.962

Larson, R. D. (2013). Psychometric properties of the modified fatigue impact scale. *Int J MS Care*, *15*(1), 15-20. https://doi.org/10.7224/1537-2073.2012-019

Leow, L.-A., Rinchon, C., & Grahn, J. (2015). Familiarity with music increases walking speed in rhythmic auditory cuing. In E. Bigand, B. Tillmann, I. Peretz, R. J. Zatorre, L. Lopez, & M. Majno

(Eds.), *Neurosciences and Music V: Cognitive Stimulation and Rehabilitation* (Vol. 1337, pp. 53-61). https://doi.org/10.1111/nyas.12658

Leow, L. A., Parrott, T., & Grahn, J. A. (2014). Individual differences in beat perception affect gait responses to low- and high-groove music. *Front Hum Neurosci*, *8*, 811. https://doi.org/10.3389/fnhum.2014.00811

Moon, Y., Sung, J., An, R., Hernandez, M. E., & Sosnoff, J. J. (2016). Gait variability in people with neurological disorders: A systematic review and meta-analysis. *Hum Mov Sci*, *47*, 197-208. https://doi.org/10.1016/j.humov.2016.03.010

Moumdjian, L., Moens, B., Maes, P. J., Van Nieuwenhoven, J., Van Wijmeersch, B., Leman, M., & Feys, P. (2019). Walking to Music and Metronome at Various Tempi in Persons With Multiple Sclerosis: A Basis for Rehabilitation. *Neurorehabil Neural Repair*, *33*(6), 464-475. https://doi.org/10.1177/1545968319847962

Patterson, K. K., Wong, J. S., Knorr, S., & Grahn, J. A. (2018). Rhythm Perception and Production Abilities and Their Relationship to Gait After Stroke. *Arch Phys Med Rehabil*, *99*(5), 945-951. https://doi.org/10.1016/j.apmr.2018.01.009

Ready, E. A., McGarry, L. M., Rinchon, C., Holmes, J. D., & Grahn, J. A. (2019). Beat perception ability and instructions to synchronize influence gait when walking to music-based auditory cues. *Gait Posture*, *68*, 555-561. https://doi.org/10.1016/j.gaitpost.2018.12.038

Roberts, B. S. (2017). Comparing the influence of music enjoyment and beat perception ability on spatiotemporal gait parameters among healthy young and older adults.

Shahraki, M., Sohrabi, M., Taheri Torbati, H. R., Nikkhah, K., & NaeimiKia, M. (2017). Effect of rhythmic auditory stimulation on gait kinematic parameters of patients with multiple sclerosis. *J Med Life*, *10*(1), 33-37.

Washabaugh, E. P., Kalyanaraman, T., Adamczyk, P. G., Claflin, E. S., & Krishnan, C. (2017). Validity and repeatability of inertial measurement units for measuring gait parameters. *Gait Posture*, *55*, 87-93. https://doi.org/10.1016/j.gaitpost.2017.04.013

Wittwer, J. E., Webster, K. E., & Hill, K. (2013). Rhythmic auditory cueing to improve walking in patients with neurological conditions other than Parkinson's disease--what is the evidence? *Disabil Rehabil*, *35*(2), 164-176. https://doi.org/10.3109/09638288.2012.690495

Yoo, G. E., & Kim, S. J. (2016). Rhythmic Auditory Cueing in Motor Rehabilitation for Stroke Patients: Systematic Review and Meta-Analysis. *J Music Ther*, *53*(2), 149-177. https://doi.org/10.1093/jmt/thw003

6. Attachments

1. Voortgangsformulier
2. Verklaringen op eer: Anne Ceulemans and Febe Schuurmans
3. Inschrijvingsformulieren verdediging thesis: Anne Ceulemans en Febe Schuurmans
4. Akkoord promotor
5. Zelfevaluatierapport

VOORTGANGSFORMULIER WETENSCHAPPELIJKE STAGE DEEL 1

DATUM	INHOUD OVERLEG	HANDTEKENINGEN
2/11/2020	Introductions and motivations - the thesis: Part 1 and Part 2 -- in part 1 to not forget the protocol! - the intervention study: a short explanation of the study - partnerships with Gent - method of working together -> I don't mind having meetings, but would like them to be efficient. More details: Breakdown of part 1 -> e.g. by end of Jan/Feb- to have a finalised search strategy When you have the thesis deadlines, please inform me By May -> to anticipate that Prof. Feys can also read it Discussing Content - scooping what is there for now; Setting up a next meeting (at the end of meetings) - + a short summary of action points, so that we're aligned.	Promotor: Copromotor/begeleider: Student(e): Student(e):
10/11/2020	Documents for ethical committee + protocol → instructions translating them to dutch	Promotor: Copromotor/begeleider: Student(e): Student(e):
1/12/2020	Results of first scooping → we need to make our scooping more specific. Feedback about what we did wrong and what we should do.	Promotor: Copromotor/begeleider: Student(e): Student(e):

11/12/2020	Discussing results of second scooping → Scooping was accepted and we could start with finding our search strategy and research question.	Promotor: Copromotor/begeleider: Student(e): Student(e):
16/12/2020	1. Search strategy → We had all the necessary terms. We need to combine our different search strategies/ research questions to one & look at what we would find. 2. Joint student meeting → More information about where and how we are going to do the measurements. We are going to start our measurements in february in the MS center in Pelt.	Promotor: Copromotor/begeleider: Student(e): Student(e):
12/01/2021	Meeting neuroteam: launching study ● Feedback about search strategy: ○ Why splitted in 4 pieces (influencing factors)? ○ Why not more specific terms? (mesh-termen) ○ Add title/ abstract in outcome measures	Promotor: Copromotor/begeleider: Student(e): Student(e):
18/01/2021	1. Giving more information about progress with the ethical committee/ the meeting on the 5th 2. What to do after finalising search strategy? More information about: ● screening of all the articles ○ include/exclude? Why? ○ quality check ○ Which information do we need to collect from our included articles? ● filling in the diagram ● begin of writing thesis part 1 ● setting up to-do-list: ○ trying our search strategy in SCOPUS ○ make a scheme with deadlines.	Promotor: Copromotor/begeleider: Student(e): Student(e):

05/02/2021	Joint student meeting ● More info about the testing strategy, protocol etc. ● setting dates for next meetings Meeting about thesis 1 ● 19 feb.: email with written methodology, flowchart & table about characteristics articles	Promotor: Copromotor/begeleider: Student(e): Student(e):
31/03/2021	Meeting about thesis 1 ● discussing data extraction, results, written methodology ○ tables more in detail, chose a couple of outcome measures to do in detail ○ update our searchstrategy ● In two weeks: email with all tables ● End of april: sketch of our final review (text, tables, figures…) so we can get feedback on it	Promotor: Copromotor/begeleider: Student(e): Student(e):
13/04/2021	Meeting about thesis 1 and 2: <u>Thesis 2</u> Feedback about the intervention, problem solving and fine tuning. <u>Thesis 1</u> Discussing data extraction, results and tables → getting some tips about lay-out. Definitive GO for start writing Set up a meeting with prof. Feys for discussing introduction, discussion and protocol	Promotor: Copromotor/begeleider: Student(e): Student(e):
29/04/2021	Meeting about thesis 1: ● Feedback about everything from (co)promotor ○ More specific writing (articles, interventions…) ○ Need to use other words ○ More info to put in our introduction/exclusion ● Sending draft to copromotor on 13/05/2021 ● Sending draft to promotor on 24/05/2021	Promotor: Copromotor/begeleider: Student(e): Student(e):
	<u>Niet-bindend advies:</u> 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 RWS 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 mijn opleiding mee te werken aan onderzoek van de faculteit RWS aan de UHasselt. Dit onderzoek wordt beleid door Prof. Peter Feys en kadert binnen het opleidingsonderdeel Wetenschappelijke stage/masterproef deel 1. Ik zal in het kader van dit onderzoek creaties, schetsen, ontwerpen, prototypes en/of onderzoeksresultaten tot stand brengen in het domein van Neurorehabilitation (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. Peter Feys/Mevr. Lousin moumdjian.

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,

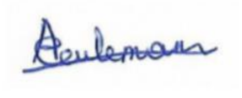
Naam: Ceulemans Anne

Adres: Mortel 22, 3930 Achel

Geboortedatum en –plaats : 08/04/1999 te Lommel

Datum: 04/11/2020

Handtekening:



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   - 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.

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Gelezen voor akkoord en goedgekeurd,

Naam: Schuurmans Febe

Adres: Apotheker Hendrixstraat 13 3990 Peer

Geboortedatum en –plaats : 05/04/1999 te Hasselt

Datum: 03/11/2020

Handtekening:

Inschrijvingsformulier verdediging masterproef academiejaar 2020-2021,
Registration form jury Master's thesis academic year 2020-2021,

GEGEVENS STUDENT - *INFORMATION STUDENT*

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

Stamnummer + naam: **1746586 Ceulemans Anne**
Student number + name

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

INSTRUCTIES - *INSTRUCTIONS*

Neem onderstaande informatie grondig door.

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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*: A REVIEW ON BEAT PERCEPTION ABILITY AND ITS INFLUENCE ON GAIT PARAMETERS WITH RAS ON PATIENTS WITH NEUROLOGICAL DISORDERS.

☒ behouden - *keep*

O wijzigen - *change to*:

?:

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)*: SCHUURMANS FEBE

X 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) PROF. FEYS

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)

03/06/2021

Heulemans

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

Peter Feys

04/06/2021

UHASSELT
KNOWLEDGE IN ACTION

Inschrijvingsformulier verdediging masterproef academiejaar 2020-2021,
Registration form jury Master's thesis academic year 2020-2021,

GEGEVENS STUDENT - *INFORMATION STUDENT*

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

Stamnummer + naam: **1747358 Schuurmans Febe**
Student number + name

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

INSTRUCTIES - *INSTRUCTIONS*

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Zonder dit inschrijvingsformulier krijg je geen toegang tot upload/verdediging van je masterproef.

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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:* A REVIEW ON BEAT PERCEPTION ABILITY AND ITS INFLUENCE ON GAIT PARAMETERS WITH RAS ON PATIENTS WITH NEUROLOGICAL DISORDERS.

● behouden - *keep*

O wijzigen - *change to:*

/:

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)*: CEULEMANS ANNE

● behouden - *keep*

O wijzigen - *change to:*

LUIK B - VERPLICHT - IN TE VULLEN DOOR DE PROMOTOR(EN) PROF. FEYS
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)

Schuurmans
03/06/'21

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

Peter Feys
04/06/2021

Re: Approval defense thesis 1

PF Peter FEYS <peter.feys@uhasselt.be>
Aan Febe Schuurmans
CC Lousin MOUMDJIAN; Anne Ceulemans

Beantwoorden | Allen beantwoorden | Doorsturen | ...

vr 4/06/2021 16:50

Als er problemen zijn met de weergave van dit bericht, klikt u hier om het in een webbrowser te bekijken.
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PDF Inschrijvingsformulier Anne Ceulemans.pdf 1 MB

PDF Inschrijvingsformulier Febe Schuurmans.pdf 3 MB

Dear Febe and Anne

Given the provided documents, I give permission to submit the thesis.
I may be able to provide comments at a later date.

Regards
Peter

Op do 3 jun. 2021 om 09:52 schreef Febe Schuurmans <febe.schuurmans@student.uhasselt.be>:

> Dear Prof. Feys
>
> With this e-mail we would like to ask approval to defend our thesis 1.
> In the attachments, you can find the registration documents.
>
> Kind regards,
>
> Anne Ceulemans and Febe Schuurmans

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Peter Feys
Decaan - Hoogleraar
Faculteit 'Revalidatiewetenschappen'

Dean - Professor

ELFEVALUATIERAPPORT **WETENSCHAPPELIJKE STAGE - DEEL 1** **RWK**

LITERATUURSTUDIE	**Gestelde deadline**	**Behaald op**	**Reflectie**
De belangrijkste concepten en conceptuele kaders van het onderzoekdomein uitdiepen en verwerken	01/12/2020	30/11/2020	Globale scooping was goed. Er moet dieper/specifieker gezocht worden naar beat perceptie & invloed op gang.
De belangrijkste informatie opzoeken als inleiding op de onderzoeksvraag van de literatuurstudie	11/12/2020	11/12/2020	/
De opzoekbare onderzoeksvraag identificeren en helder formuleren in functie van de literatuurstudie	16/12/2020	15/12/2020	De opgestelde onderzoeksvraag werd bijgesteld o.b.v. de feedback.
De zoekstrategie op systematische wijze uitvoeren in relevante databanken	05/02/2021	28/01/2021	/
De kwaliteitsbeoordeling van de artikels diepgaand uitvoeren	29/04/2021	29/04/2021	Na feedback werd er bij 3 artikels een nieuwe beoordeling toegepast.
De data-extractie grondig uitvoeren	01/04/2021	30/03/2021	/
De bevindingen ïntegreren tot synthese	17/05/2021	17/05/2020	/

ONDERZOEKSPROTOCOL een	**Gestelde deadline**	**Behaald op**	**Reflectie**
De onderzoeksvraag in functie van het onderzoeksprotocol identificeren	16/04/2021	14/04/2021	/
Het onderzoeksdesign bepalen en/of kritisch reflecteren over bestaande onderzoeksdesign	30/04/2021	30/04/2021	/
De methodesectie (participanten, interventie, uitkomstmaten, data-analyse) uitwerken	30/04/2021	30/04/2021	/

ACADEMISCHE SCHRIJVEN	**Gestelde deadline**	**Behaald op**	**Reflectie**
Het abstract tot he point schrijven	17/05/2021	10/05/2021	/
De inleiding van de literatuurstudie logisch opbouwen	17/05/2021	12/05/2021	/
De methodesectie van de literatuurstudie transparant weergegeven	17/05/2021	29/04/2021	Dit werd, samen met de resultaten, als eerste geschreven en gepresenteerd waardoor deze deadline eerder werd behaald.
De resultatensectie afstemmen op de onderzoeksvragen	17/05/2021	29/04/2021	Dit werd, samen met de methodesectie, als eerste geschreven en gepresenteerd waardoor deze deadline eerder werd behaald.
In de discussiesectie de bekomen resultaten in een wetenschappelijke tekst integreren en synthetiseren	17/05/2021	16/05/2021	/
Het onderzoeksprotocol deskundig technisch uitschrijven	17/05/2021	16/05/2021	/

Referenties correct en volledig weergeven	17/05/2021	16/05/2021	Endnote werd hiervoor gebruikt.

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