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Faculteit Revalidatiewetenschappen

master in de revalidatiewetenschappen en de kinesitherapie

Masterthesis

Postural function of the diaphragm and the effectiveness of 8 weeks inspiratory muscle training in people with chronic obstructive pulmonary disease: a randomized, single-blinded, placebo-controlled trial

Chloé Hollander
Nina Jacobs

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

PROMOTOR :
Prof. dr. Lotte JANSSENS

COPROMOTOR :
Mevrouw Charlotte AMERIJCKX
dr. Nina GOOSSENS

2019
2020

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POSTURAL BALANCE IN PEOPLE WITH COPD

"Postural function of the diaphragm and the effectiveness of 8 weeks inspiratory muscle training in chronic obstructive pulmonary disease: a randomized, single-blinded, placebo-controlled trial"

Master thesis part two

Promotor: Prof. Dr. Janssens Lotte

Co-promotor: Dr. Goossens Nina

Hasselt University

Highlights:

1. Postural activation of the diaphragm is confirmed in a small sample of clinical stable COPD (n = 11). Explorative analysis revealed direction-specific tonic contractions dependent of the breathing mode.
2. Eight weeks of inspiratory muscle strength training positively influenced the magnitude of postural diaphragm activity in COPD, but balance recovery is still compromised.

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Acknowledgement

This thesis was written under the guidance of promotor Prof. Dr. Janssens Lotte. We would like to thank her for her continuous feedback and guidance throughout this process. We would also like to thank Dr. Nina Goossens for her guidance as a co-promotor.

Further, we would like to thank Prof. Langer Daniel, Dr. Saluwak Dascha, Prof. Rik Gosselink and other staff who worked on the greater framework of this study, testing and evaluating all participants. We are also grateful to the University Hospital of Gasthuisberg for providing the equipment and environment needed to execute the trials.

We would also like to thank Dr. Geraerts Marc and Dr. Baggen Remco for creating the software wherein our data processing was performed and for processing the data.

Lastly, we would like to thank the participants of this study for their time and dedication to this study.

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Context

This master thesis is part of a broad research project 'Effects of inspiratory muscle training on shortness of breath (dyspnea) and postural control in patients with COPD' (Prof. Rik Gosselink, Prof. Daniel Langer, Prof. Lotte Janssens (supervisors)), funded by KU Leuven C2 Internal Funds (C22/15/035).

This is a chronic obstructive pulmonary disease mainly known for its respiratory problems. It is associated with exacerbations and many possible comorbidities. COPD is a debilitating disease and had the fourth greatest disease burden in DALYs in the Netherlands in 2015. COPD was responsible for 2.6% of the global DALYs in 2015. Globally, it was the third greatest cause of death in 2018 [1]. With an incline in mortality due to COPD and a rising prevalence of 44% between 1990 and 2015, the economic burden keeps growing [2]. More exacerbations and comorbidities are associated with higher costs and thus a greater economic burden.

Additionally, with the rise of COVID-19, which is especially threatening for people with respiratory disease [3], the importance of researching COPD is greater than ever. Physical therapy will most likely also play an important part in the post-acute COVID-19 period.

COPD is accompanied by many other functional problems, such as an increased risk of falling, which subsequently causes increased mortality and worse quality of life [4, 5]. The diaphragm plays an important role in these functional problems [6-8]. However, altered diaphragm activation in people with COPD has been proven. Lung hyperinflation seems to flatten the position of the diaphragm, reducing the diaphragmatic movement ability [9, 10]. Moreover, a shift towards slow-twitch, oxidative type I muscle fibers has been found in people with COPD [11]. The diaphragm activation pattern in people with COPD may also be altered. Since this thesis is the first study to assess the postural role of the diaphragm in COPD with intra-abdominal electromyography, an intrinsic underlying mechanism for these postural balance deficits may be found.

Inspiratory muscle training (IMT) may strengthen the diaphragm and thus positively influence the functional problems described above. IMT has shown positive effects on postural balance in different populations [12-15], but has only been tested in COPD for pulmonary features and not for postural balance [16, 17]. By subjecting the participants to an eight-week IMT program, we hypothesized to strengthen the diaphragm and positively influence postural balance, physical performance and inspiratory muscle function. IMT is a cheap and easy-to-use intervention. If it proves to be beneficial in patients with COPD, it may reduce the global economic burden of COPD by reducing the negative attributions caused by a decreased postural balance, physical performance and inspiratory muscle function symptoms.

In this manuscript, the influence of IMT on the diaphragm activation during an increased postural demand specifically, was investigated.

The research project was already in operation for some time and participants included in this thesis were already tested. However, we were present and supported assessments of patients that were tested when we were already involved with this study. Our further contribution lies mainly in the data processing, data analysis, statistical analysis and writing of the study. We analyzed raw data files and extracted the data needed for this thesis. After further processing was done, we proceeded with the statistical analysis. The findings of last year's review in preparation of this thesis were used to critically assess and compare the results found in this thesis. Academic writing and further processing of the thesis was done by us independently with feedback of promotor Prof. Dr. Janssens Lotte.

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1. Abstract

Background Patients with Chronic Obstructive Pulmonary Disease (COPD) suffer from many extra-pulmonary functional problems, such as postural balance deficits associated with a higher risk of falls. Identifying the risk profile remains a scientific topic of interest, wherein the multifunctional diaphragm muscle plays a key role.

Objectives The aim of this study was to investigate the postural function of the diaphragm in people with COPD, followed by the effectiveness of 8 weeks of inspiratory muscle training (IMT) to modify this function, and consequently postural balance in this vulnerable population.

Participants A single-blind, randomized, placebo-controlled study design was used. Eleven eligible subjects with COPD were randomized to either an intervention group (n= 8) or a control group with placebo IMT (n= 3)

Measurements All subjects were subjected to twelve different postural tasks, varying in the following conditions: (1) support surface, (2) vision, (3) arm movement direction and frequency, (4) breathing mode. Primary outcomes were diaphragm muscle activity (electromyography) and postural balance (stabilometry). Also, functional balance performance and inspiratory muscle function were evaluated before and after the intervention.

Results Postural function of diaphragm was confirmed by both single and repetitive upper limb (UL) movements. For repetitive UL movements a direction-specific tonic contraction was shown, dependent of the breathing mode. IMT was found to significantly increase postural diaphragm activity over time in eight out of twelve trials in the intervention group ($p< 0.05$). A trend towards, but no overall treatment effect was observed for stabilometric parameters and functional balance performance.

Conclusion Diaphragm activity significantly increased when the postural demand increased in people with COPD. IMT positively influenced the identified postural-related changes in diaphragm activation, but the transfer to improvements in balance was lacking. Further research with a larger sample size and long-term effects is warranted.

2. Introduction

Chronic Obstructive Pulmonary Disease (COPD) is a degenerative disease that is characterized by persistent respiratory symptoms and chronic airflow limitation [18, 19]. Besides the disease-related pulmonary limitations documented in the Global Initiative for Chronic Obstructive Lung Disease (GOLD), non-pulmonary complications also need proper attention [20]. Fall injuries are very common in people with COPD with an estimated annual fall rate of 1.2 falls per person-year [21]. Although this fall risk may seem less important than the life-threatening consequences, falls are likely to be associated with femoral and vertebral fractures, lower physical activity levels, increased mortality and worsening of quality of life [4, 5]. Accordingly, fall prevention is a major health-care priority and identifying potential risk factors for falls in patients with COPD is important. The presence of a previous fall history, medication intake, co-morbidities, impaired mobility and muscle weakness are frequently cited as risk factors for falls in the elderly [22, 23]. These risk factors are also common in people with COPD [24, 25], but limited information is available regarding the association with the fall incidence [21, 26]. Moreover, postural balance deficits are recognized as intrinsic and modifiable risk factors for falling in COPD [4, 26]. Previous research has already shown specific balance deficits in COPD compared to age-matched healthy individuals [27-29]. This was demonstrated by both stabilometric analysis [30, 31] and functional balance performance tests [25, 32], amplifying the role of both laboratory and clinical field tests as postural balance assessment in COPD. In view of this latter, the Mini-Balance Evaluation System Test (Mini-BESTest) seems to be an accurate test for identifying postural balance deficits and predicting falls in COPD [33].

Although balance deficits are increasingly recognized in individuals with COPD, the underlying mechanisms remain largely unknown. Most studies suggest that disease-related features, such as peripheral muscle weakness [34], lower physical activity levels [34, 35], anxiety and depression [32], partially explain the difficulties with balance in subjects with COPD. Since COPD is characterized with progressive pulmonary limitations [20], deterioration of the respiratory muscle system might also amplify postural impairments (regarding the dual role of the diaphragm). In particular, individuals with weaker inspiratory muscle strength have been shown to exhibit less ability to recover postural balance [30].

However, identifying the risk profile of patients with COPD and poor balance remains a scientific topic of interest.

In accordance with Hodges' theory, the diaphragm has a multifunctional role in the human body, comprising a trunk stabilizing function in addition to inspiration [6, 8, 36]. Accordingly, chronic airway limitation might cause disease-related changes in diaphragm muscle function, thereby reducing its efficacy in the postural stabilization system. In people with COPD, lung hyperinflation seems to flatten the curve of the diaphragm, consequently reducing diaphragmatic movement during the breathing cycle [9, 10]. Previous research also established a shift toward slow-twitch, oxidative type I diaphragm muscle fibers in people with COPD, which are more resistant to muscle fatigue, but produce contractions with less power [11]. Hence, both the mechanical disadvantage of a flattened diaphragm and the reduction of fast-twitch, glycolytic type IIa fibers, are likely to decrease its force generating capacity to generate transdiaphragmatic pressure [11, 37-39]. As a result thereof, in people with COPD, these intrinsic pathophysiological processes are likely to negatively affect the postural role of the diaphragm, eventually at the expense of postural balance at rest [30] or post-exercise postural balance [31]. However, this has not been directly studied before.

Furthermore, since a diminished postural role of the diaphragm may be interpreted as a result of inspiratory muscle weakness, inspiratory muscle training (IMT) may be favorable. It is already proven that IMT affects static as well as dynamic postural balance in healthy elderly [12] and people with low back pain [13], respectively. However, in COPD, the effectiveness of IMT has only been broadly investigated for mainly pulmonary (versus extra-pulmonary) features, such as inspiratory muscle strength, endurance, functional exercise capacity and dyspnea [16, 27, 40]. To the authors' knowledge, the postural function of the diaphragm and the benefit of IMT on this muscle function and the subsequent balance capacity has never been assessed before in COPD.

Therefore, it was hypothesized that the proven positive changes in inspiratory muscle function due to IMT [40] are also accompanied by positive changes in the postural activation of the diaphragm, improving balance measures that are associated with the risk of falling in COPD.

To answer this research question, a single-blind, randomized, placebo-controlled trial that focused on the effects of 8 weeks home-based IMT on postural balance, physical performance and inspiratory muscle function in subjects with clinically stable COPD was performed. Moreover, this study was the first to assess the postural role of the diaphragm in patients with COPD by using intra-abdominal electromyography, partially clarifying the underlying mechanism of the postural balance deficits in this vulnerable population.

3. Aim of the study

3.1 Research question

The purpose of this study was to investigate the effect of IMT on the postural function of the diaphragm in people with COPD. This information can be used to define more appropriate treatment plans for this target group, limiting their risk for falls. This study attempted to provide an answer to the following research questions:

1. What is the diaphragm activation pattern when the postural demand increases in people with stable COPD?
2. What is the effectiveness of IMT on the postural activation of the diaphragm, and consequently postural balance in people with stable COPD?

3.2 Hypothesis

When the postural demand increases by performing upper limb activities in people with stable COPD, an increase in diaphragm electromyography (EMG) activity is expected. Moreover, postural-related changes in diaphragm activity will be increased for tasks with higher postural demands, such as occluded vision or an unstable support surface. A pronounced effect on the postural sway characteristics, linearly and positively correlated with the identified diaphragm activation, is hypothesized. Moreover, the expected increase in diaphragm activity is likely to be more present in postural tasks at the end of maximal expiration, since the respiratory function of the diaphragm is diminished at that time, and therefore, the postural function will be addressed more. After following an IMT program, inspiratory muscles will be strengthened, resulting in higher maximal inspiratory mouth pressure values, correlated with higher EMG values of the diaphragm over time. Also, after IMT, greater postural-related changes in diaphragm muscle activity will be observed in people with COPD, improving the ability of the diaphragm to increase intra-abdominal pressure (IAP) and hence, the ability to recover postural balance. Furthermore, a positive reflection on certain functional balance performance scores may also be shown after IMT.

4. Methods

4.1 Participants

4.1.1. Selection criteria

The study sample consisted of eleven people (7 men, 4 women) diagnosed with clinically stable COPD based on GOLD (with an average GOLD stage 2). Participants were included or excluded based on the selection criteria summarized in Table 1. All sexes and ages were eligible for the study. Spirometric measurements and measurements of respiratory muscle strength were also assessed at baseline.

International guidelines were followed for assessing *respiratory strength* [41]. The POWERbreathe®KH1, HaB International Ltd., Southam, UK with a flanged mouthpiece with a small leak incorporated to prevent glottis closure was used. One second of maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP) was recorded, and the highest value of three assessments that varied less than 10% was taken into analysis. The MIP was measured at residual volume (RV), and the MEP was measured at total lung capacity (TLC), to standardize the measurement of these assessments and to limit too much variability within and between subjects.

European Respiratory Society (ERS) guidelines were followed for *spirometric measurements* [42, 43]. Forced expiratory volume in the first second (FEV1), forced vital capacity (FVC), total lung capacity (TLC) and residual volume (RV) were assessed with the MasterScreen Body, CareFusion, Hoechberg, Germany. For the FVC, a maximal inspiration was followed by a blast of expiration, with a pause of one second before the blast of expiration. A minimum of three trials was performed, and trials were performed until the end of test criteria were completed [42]. The test procedure for FEV1 was similar, with a short maximal inspiration after a maximal inspiration. RV and TLC were derived from other spirometry measurements (functional residual capacity (FRC), expiratory reserve volume (ERV) and inspiratory vital capacity (IVC)) [43]. All spirometry tests were preceded by a testing trial, where a demonstration and detailed instructions were given.

Table 1. Selection criteria

Inclusion criteria	Exclusion criteria
1. Clinical Diagnosis of COPD based on the Global Initiative for Chronic Obstructive Lung Disease (GOLD) criteria 2. Able and willing to provide written informed consent. 3. Willing to insert an oesophageal catheter for EMGdi recordings	1. Major cardiovascular problems 2. Limiting exercise capacity more than pulmonary function impairment 3. Severe orthopaedic problem with major impact on daily activities 4. Psychiatric or cognitive disorders 5. Progressive neurological or neuromuscular 6. Long term oxygen therapy 7. Previous inclusion in rehabilitation program (< 1 year) 8. Waiting list for lung transplantation

EMGdi = diaphragm electromyography

4.1.2. Patient recruitment

One hundred twenty-eight individuals were recruited from a particular population in UZ Leuven (Campus Gasthuisberg), starting from January 2016, and specifically invited to participate in this study. A detailed overview of the patient recruitment and follow-up through the course of the study can be retrieved in Appendix: 1. Since the researchers confirmed this source population in advance, not everyone who met the selection criteria was able to be enrolled. The selection criteria were further assessed through completion of a health check questionnaire. A member of the research team met with potential participants to provide information about the study set-up prior to the start of the rehabilitation program. If the individual agreed to participate, written informed consent was obtained at that time. Recruitment will continue until the overall target population size is reached for the study.

4.2 Experimental study design

Our master thesis is part of a single-blinded placebo-controlled randomized controlled trial in cooperation with UZ Leuven Campus Gasthuisberg. After individuals were enrolled in the study, they were allocated randomly to an intervention group (Inspiratory muscle training, "IMT group") or a placebo group (Inspiratory muscle endurance training, "Sham IMT group"). Group allocation was performed by randomization on the basis of ratio 2:1 using sealed opaque envelopes. To improve adherence with the treatment in the placebo group and to ensure placebo treatment effects, all participants were led to believe that they followed an active IMT intervention. So, the training was presented as strength training in the IMT group and as endurance training in the sham-IMT group.

All measurements were performed between December 2016 and June 2019 in UZ Leuven Campus Gasthuisberg under standardized conditions. Three test moments were required for each participant. During the first visit (week 0), the main respiratory characteristics including lung function and respiratory muscle strength were recorded. Before and after the eight-week intervention, the following assessments were performed: (1) postural task-related changes in EMG of the diaphragm, other trunk and peripheral muscles, accompanied with static balance evaluation derived from force plate data, and (2) functional balance performance measured with clinical field testing (Mini-BESTest, Timed Up & Go (TUG), Sit To Stand To Sit Test). During these second (baseline) and third (week 9) testing visits, the researcher was blinded to group allocation. All measures were scheduled in one day except for the Mini-BESTest and the TUG, which were scheduled within the same week. The flow chart of the study is covered in Figure 1.

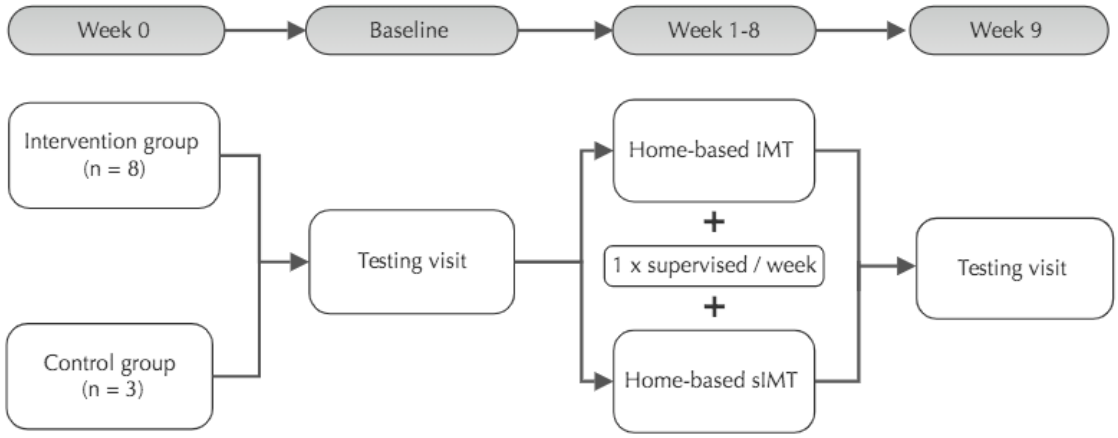


Figure 1. Study design
IMT = inspiratory muscle training; sIMT = sham-IMT (placebo training)

4.3 Ethical approval

The study was approved by the local ethics committee (Ethische Commissie onderzoek UZ/KU Leuven). The approval is encoded as s58513. The trial is registered on www.clinicaltrials.gov (NCT01900873).

4.4 Interventions

Inspiratory muscle training (IMT) in both groups was performed daily for eight weeks using an electronic tapered flow-resistive loading (TFRL) device (POWERbreathe®KH1, HaB International Ltd., Southam, UK). All participants got a loading device to take home that automatically registered the load (in cmH_2O), volume (in litres), power (in Watt) and energy (in Joule) from each training session. Adherence to the home-based training was self-reported as all participants were instructed to full in the recorded parameters in a daily training diary. The diary also tracked progresses and increased the participant's motivation.

In both groups, measurements of maximal inspiratory mouth pressure (MIP) were performed weekly during one supervised training session at the research centre. All other six training sessions were non-supervised and conducted at home.

The two interventions were only different in terms of training load as described in Table 2. This study is in keeping with the experimental design of a previous randomized controlled trial in people with COPD [40].

Table 2. Intervention programs

	IMT	**Sham IMT**
Exercise frequency, volume	2x/day, 30 breaths	2x/day, 30 breaths
Duration	8 weeks	8 weeks
Load	40-50% of MIP Incremental load	10% of MIP Fixed load
Supervision/home-based	1 supervised session/week Daily home-based exercise	1 supervised session/week Daily home-based exercise

IMT = inspiratory muscle training; MIP = maximal inspiratory pressure

4.4.1. Inspiratory muscle strength training (IMT)

The participants randomized to the "IMT group" (strength IMT) performed two daily sessions of 30 breaths at the highest tolerable intensity. The training intensity was initially set at a load of approximately 50% of the participants' MIP. Weekly, the training load continuously and gradually increased to maintain at least 40-50% of the actual MIP values achieved during that week. An objective measure used to decide on the intensity was the inspiratory volume that the participant could perform against the applied load.

This volume should be close to the participants' Forced Vital Capacity (FVC) measured at baseline. Using a Borg score was another subjective measure to make sure that the applied intensity was not too high. If a participant could not keep the inspiratory volume while breathing against the applied intensity or rated the Borg score above seven, it was considered to decrease the intensity.

4.4.2. Inspiratory muscle endurance training (Sham-IMT)

The participants randomized to the "Sham IMT group" (endurance IMT) performed two daily sessions of 30 breaths with a constant inspiratory load. The training intensity was set at approximately 10% of the initial MIP and was not modified throughout the intervention period. Also, the participants' MIP was assessed during the weekly supervised session. Participants were also asked about their BORG score, but not instructed to maintain a certain BORG score during this training session.

4.5 Materials and procedures

4.5.1. Testing procedure

Electromyography (EMG) and postural balance measurements were assessed during different *postural stability trials* in quiet bipedal standing, as described in Table 3. Figure 4 shows the experimental set-up. The standard set-up varied in the complexity of the postural task by implementing (1) eyes open and vision-occluded (with non-transparent goggles) conditions, (2) stable and unstable support surface conditions, and (3) conditions without and with ballistic arm movements as internal postural perturbations. As postural upper limb (UL) activity, a single rapid arm anteflexion up to 90° was performed only once (trial 1,2,7,8). Later, repetitive ballistic arm movements between 15° of flexion and extension were performed as fast as possible for ten seconds while breathing normally (trial 3,5,9,11) or while holding breath at the end of the maximal expiration (trial 4,6,8,10), respectively. During the last trials (trial 13-14), dynamic postural balance was tested by performing five sit-to-stand-to-sit (STSTS) movements as fast as possible with and without vision. The trials are in accordance to the experimental set-up as previously performed in recent studies [27, 30, 36, 44, 45].

During all trials, participants were instructed to maintain their balance in upright standing at all times and the investigator stood nearby to prevent actual falls. To ensure a consistent foot position across all postural stability trials, the set-up was standardized as much as possible by placing a marked paper on the force plate or the foam. Hereby, the participants' foot length was measured and marked halfway to match the centre of the force plate. The participants' feet stood with their heels placed ten centimetres apart and with a free forefoot position.

Table 3. Postural stability trials

Trial number	Postural tasks
Condition 1: standing on the force plate (stable support surface)	
001	Upright stance, with vision 30s - one ball arm anteflexion 90° - with vision 30s
002	Upright stance, no vision 30s - one ball arm anteflexion 90° - no vision 30s
003	Upright stance, no vision: 20s - ball arm **flexion-extension** (as fast as possible & **normal breathing**): 10s - rest: 10s - ball arm anteflexion: 10s - rest: 10s - ball arm anteflexion: 10s - rest: 20s
004	Upright stance, no vision: 20s - ball arm **flexion-extension** (as fast as possible & **end-expiration**): 10s - rest: 10s - ball arm anteflexion: 10s - rest: 10s - ball arm anteflexion: 10s - rest: 20s
005	Upright stance, no vision: 20s - ball arm **abduction** (as fast as possible & **normal breathing**): 10s - rest: 10s - ball arm anteflexion: 10s - rest: 10s - ball arm anteflexion: 10s - rest: 20s
006	Upright stance, no vision: 20s - ball arm **abduction** (as fast as possible & **end-expiration**): 10s - rest: 10s - ball arm anteflexion: 10s - rest: 10s - ball arm anteflexion: 10s - rest: 20s
Condition 2: standing on the foam on the force plate (unstable support surface)	
007	Upright stance, with vision 30s - one ball arm anteflexion 90° - with vision 30s
008	Upright stance, no vision 30s - one ball arm anteflexion 90° - no vision 30s
009	Upright stance, no vision: 20s - ball arm **flexion-extension** (as fast as possible & **normal breathing**): 10s - rest: 10s - ball arm anteflexion: 10s - rest: 10s - ball arm anteflexion: 10s - rest: 20s
010	Upright stance, no vision: 20s - ball arm **flexion-extension** (as fast as possible & **end-expiration**): 10s - rest: 10s - ball arm anteflexion: 10s - rest: 10s - ball arm anteflexion: 10s - rest: 20s
011	Upright stance, no vision: 20s - ball arm **abduction** (as fast as possible & **normal breathing**): 10s - rest: 10s - ball arm anteflexion: 10s - rest: 10s - ball arm anteflexion: 10s - rest: 20s
012	Upright stance, no vision: 20s - ball arm abduction (as fast as possible & **end-expiration**): 10s - rest: 10s - ball arm anteflexion: 10s - rest: 10s - ball arm anteflexion: 10s - rest: 20s
Condition 3: sit-to-stand-to-sit (STABLE) - rest between conditions + explain	
013	Sitting, with vision: 15s - 5x controlled STSTS as fast as possible - 15s
014	Sitting, no vision: 15s - 5x controlled STSTS as fast as possible - 15s

Difference in breathing modes and postural upper limb activities across trials in **bold
Ball = ballistic; STSTS = sit to stand to sit

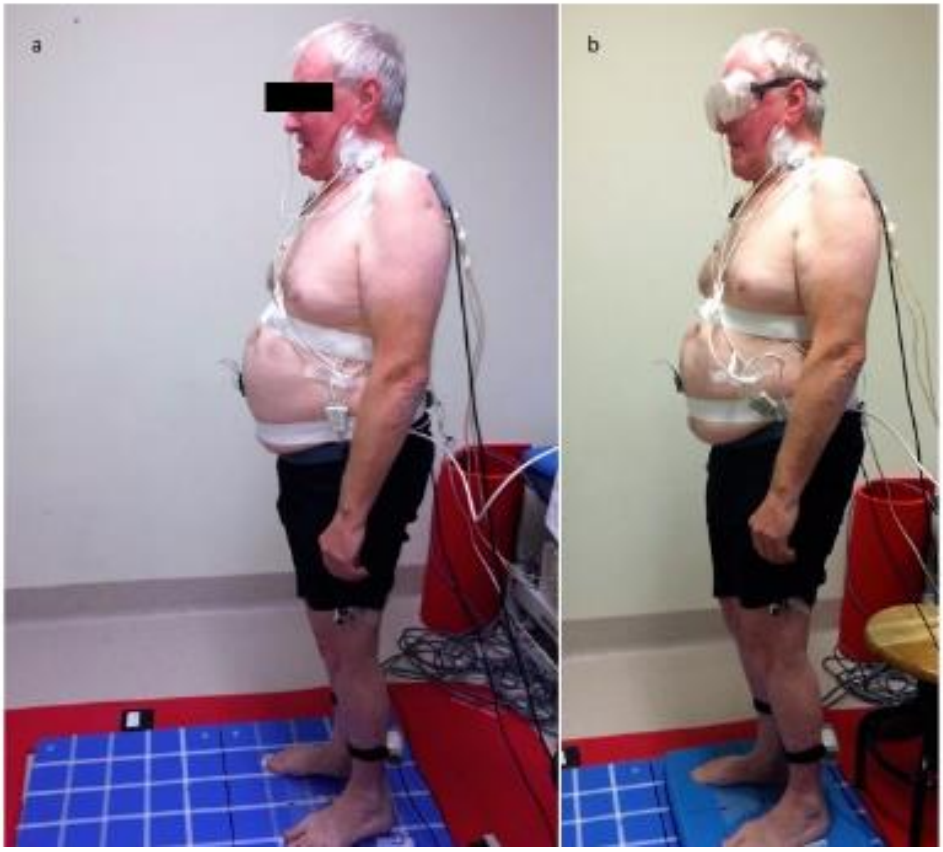


Figure 4. *(a) condition with vision on stable support surface; (b) condition without vision on foam*

4.5.2 Electromyography

4.5.2.1. Diaphragm electromyography (EMGdi)

During the postural tasks, diaphragm activation was assessed with an EMG-electrode catheter inserted in the oesophagus through the nose [17, 46]. Diaphragm function assessment is most efficient by recording both Pdi (gastric pressure - oesophageal pressure) and EMGdi [47]. More specifically, EMGdi recording was conducted with a multipair-oesophageal electrode catheter (Yinghui Medical Equipment Technology Co. Ltd., Guangzhou, China), inserted nasally into the oesophagus after topical anaesthesia [48]. It was localized in accordance by using determined methodology as previously reported in people with COPD [46].

4.5.2.2. Electromyography (EMG) of trunk and proximal peripheral muscles

Furthermore, activity of other trunk and peripheral limb muscles was assessed with EMG. More specifically, the electrical activity of the lumbar m. erector spinae, lumbar m. multifidus, m. deltoideus, and abdominal musculature (m. obliquus internus and m. rectus abdominis) was measured unilaterally (right side) using dual surface EMG electrodes with a wireless transmission system (Desktop Direct Transmission System (DTS), Noraxon USA, Inc., Scottsdale, AZ USA). All electrodes were placed on predetermined anatomical locations described in Table 4 and secured with double sided tape (Noraxon DTS USA, Inc., Scottsdale, AZ USA). Specific placement of the surface electrodes is shown in Figure 2 and 3.

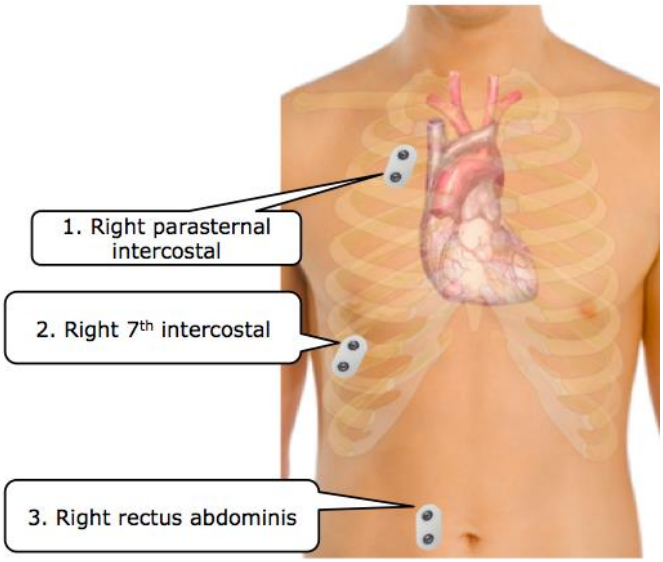


Figure 2. Placement of surface electrodes (front view)

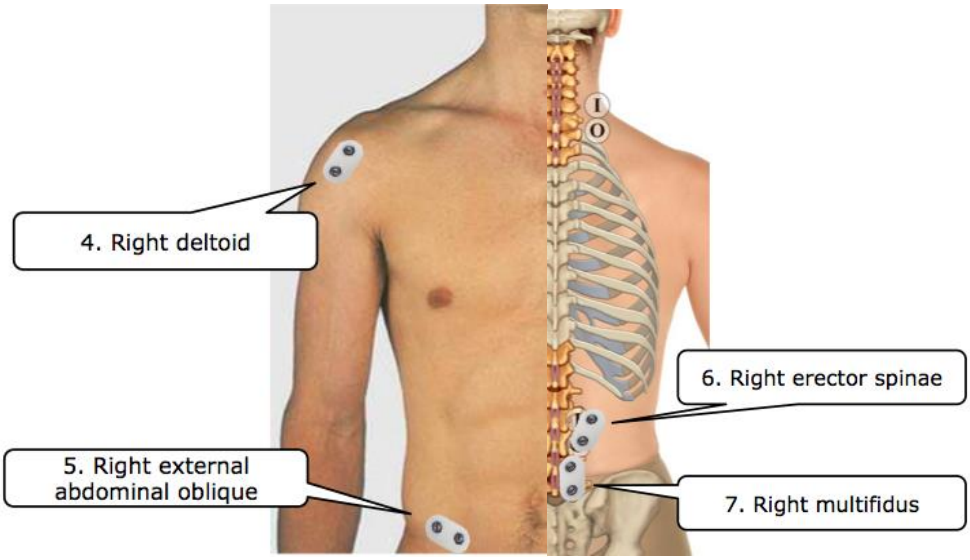


Figure 3. Placement of surface electrodes (left = front view; right = back view)

Table 4. Placement of surface electrodes

Muscle	Location surface electrodes
m. deltoideus pars anterior	One finger distal and anterior to the acromion. In the direction of the line between the acromion and the thumb.
m. rectus abdominis	2cm lateral to the umbilicus - vertical
m. obliquus abdominis internus	2cm medially and inferior to the anterior superior iliac spine (SIAS) – diagonal (oblique angle from cranio-lat to caudo-med)
m. erector spinae	2 cm lateral to the spine at L3 vertebra level, over the muscle mass – diagonal (oblique angle from cranio-lat to caudo-med)
m. multifidus	Max 1 cm lateral to the spine at L4-L5 level, vertical angle

L = lumbar vertebrae, SIAS = spina iliaca anterior superior

4.5.3 Static postural balance performance

Postural stability was measured in terms of centre of pressure (CoP) coordinates from raw force plate (Kistler, 9360AA, Winterthur, Switzerland) data.

4.5.4. Functional balance performance

4.5.4.1 The Mini-BESTest

The Mini-BESTest was used to asses both static and dynamic postural balance performance. This clinical assessment tool includes 14 different items from the section of the BESTest, related to anticipatory postural adjustments, reactive postural responses, sensory orientation and stability of gait [49, 50]. The score for each item ranges from 0 to 2, with higher scores indicating better postural balance performance. The maximal possible total score is 28 points. The Mini-BESTest has been proven to be a reliable and valid clinical assessment tool in people with COPD [51], evaluating balance in a more functional way.

4.5.4.2 The timed up and go test

The timed up and go test (TUG) was undertaken to evaluate functional mobility, dynamic balance and gait speed, both in a single and dual-task condition (i.e., cognitive timed up and go, TUG_C). The participants were instructed to rise from a standard armchair at a specific command, walk 3m at their habitual pace, turn around, walk back to the chair, and sit down [52]. During the TUG_C, participants performed the same task as in the TUG together with a three-digit countdown started from a randomly selected number between 90 and 100. No physical assistance was provided, but using a gait aid was permitted if required. The total duration to perform the TUG and TUG_C was recorded with the timing initiated on the command "3, 2, 1 and go". Before testing, a practice trial was performed for familiarisation. The TUG is a reliable and valid clinical assessment tool in people with COPD, with a change of 0.9-1.4 seconds considered as clinically meaningful [27, 53, 54] .

4.5.4.3 The Sit To Stand To Sit test

The sit-to-stand (STS) manoeuvre reflects a functional daily activity [55] and is partially depending on peripheral muscle strength [56], exercise tolerance [57] and most importantly, dynamic balance [44] in COPD. For the Sit To Stand To Sit (STSTS) test, the participants started sitting barefoot on a chair placed on the force plate, with their feet exactly flat on the force plate. The chairs' floor-to-seat height was adapted to create a 90° angle in both the hips and knees. The participants were instructed to get up and to subsequently sit back down without using support of their arms [58]. The STSTS movement was performed five times as quickly as possible with a full range of motion after fifteen seconds of sitting quietly with the arms relaxed along the body (Table 3, trial 13-14). Each participant performed the STSTS test twice, once with vision (trial 13) and once without vision (trial 14). In the vision occluded condition, non-transparent goggles were used to minimize a possible effect of vision on the performance. An investigator stood nearby the participants to prevent real falls. The total duration to perform the five STSTS repetitions was recorded and derived from raw force plate data. The STSTS test has been proven to be a reliable, valid and responsive functional assessment tool in people with COPD, with an estimated MCID of 1.7 seconds [56].

4.5.5 Inspiratory muscle function

4.5.5.1 Inspiratory muscle strength

Maximal inspiratory mouth pressure (MIP) assesses inspiratory muscle strength generated by the combined inspiratory muscles. This measurement was performed both before and after the intervention program, as well as weekly during each supervised training session. It is measured by detecting the pressure in the mouthpiece with the device (POWERbreathe®KH1, HaB International Ltd., Southam, UK) via pressure transducers [59]. Participants were seated during the MIP measurements and were instructed to maintain the generated inspiratory pressure for at least one and a half seconds, as to record the maximum pressure maintained for one second. The maximum value of three trials that varied less than 10% was then taken and used for further analysis.

4.6 Data signaling and processing

For data acquisition, the CoP displacement, recorded from the raw force plate data and EMG signals, derived from a multipair-oesophageal electrode catheter and surface electrodes, were obtained and sampled at 1000 Hz using Spike2 software (Cambridge Electronic Design, United Kingdom). Matlab 6.5 (Mathworks, Natick, MA, USA) was used for data processing and data filtering applied to the raw data removing any possible movement artefact. All EMG data (in Voltage) were filtered using a 4^{th}-order Butterworth filter and high-pass filter at 20Hz. Signals were further filtered with a zero-lag filter, rectified and smoothed using a moving average window of 100 samples. Beyond, trunk muscle EMG activity was analysed as EMG mean amplitude and EMG peak amplitude recorded before (baseline phase) and immediately after the onset of EMG deltoid (UL movement phase). More specifically, in case of trial 1-2 and 7-8, EMG amplitudes were also recorded after termination of the single UL movement task (recovery phase). The latter were based on automated cursor placement in Matlab with EMG Deltoid channel used as a reference channel. Data were also visually checked in Matlab to exclude incorrect trials with artefacts affecting the results.

The raw EMGdi signals recorded during each postural trial were sampled at 2000 Hz, filtered using a 4^{th}-order Butterworth filter, with a high-pass filter at 20Hz and a consecutive zero-lag filter, full-wave rectified and smoothed using a 100-point moving average window. Furthermore, to ensure the accuracy of the EMGdi signal, it is important to obtain the EMGdi signal without contamination of ECG signals [47]. However, the EMGdi signal recorded from the oesophageal electrode can be contaminated by the superimposed ECG [46], necessitating the implementation of the following ECG filtering: first, it was determined what response the ECG causes in the EMGdi signal during baseline periods of the subject in rest. This was performed over a number of cycles leading to an average response score. The next approach was to cut the ECG signal in cycles with a positive large peak on the ECG signal serving as a stable indicator for identifying cycles. The latter was applied with EMGdi signals serving as the basis. The normalized data of these cycles with low muscle activity was further used to extract an ‘average response’ of the ECG on the EMGdi cycle. This average response was calculated and control points were determined.

However, because both position and amplitude of the peaks of the average response do not match those of each cycle, control points were shifted horizontally and vertically in order to minimize the resulting filtered EMG signal. The resulting diaphragm EMG activity was converted into the mean and peak EMG amplitudes; the largest value of the five EMG channels in each inspiration was used for analysis.

At least, the obtained EMGdi signal was normalized by calculating the EMGdi/EMGdi-max ratio and expressed as % EMGdi-max with the EMGdi-max signal determined as the average of three peak EMGdi signals obtained from three maximal sniff manoeuvres [17, 46]. For the EMG activity of the other five trunk muscles, recorded signals were also normalized and expressed as a percentage of the average peak EMG activity produced by each muscle's MVC (Maximum Voluntary Contraction). The specific MVC manoeuvres, executed three times against manual resistance, consisted of (1) back extension from prone position; (2) trunk flexion from seated position; and (3) unilateral anteflexion from sitting position. These MVC manoeuvres respectively targeted the multifidus and erector spinae muscles, abdominal oblique muscles and the m. deltoideus.

The CoP displacement was estimated by using the following equation: CoP_{ML} = Mx/Fz and CoP_{AP} =My/Fz with Mx = moment about X-axis based on mediolateral (ML) force, My = moment about Y-axis based on anteroposterior (AP) force and Fz= vertical ground reaction force. Prior to processing, all CoP data were filtered by using a 4^{th}-order Butterworth filter with a low-pass cut-off frequency of 6 Hz. After data filtering, the following stabilometric parameters were calculated: the maximum and minimum CoP displacement (amplitude), CoP range (max – min CoP), standard deviation (std) of CoP, Root Mean Square (RMS) of CoP, CoP mean velocity, CoP max velocity, CoP total sway path and time-normalized sway, both in anterioposterior (AP) and mediolateral (ML) direction, and cumulative sway path and sway area. All aforementioned parameters were used to analyse postural stability.

4.7 Statistical analysis

Analysis for demographic features at baseline

JMP Pro 14.2.0 and SPSS Statistics 26.0 was used for the statistical analysis of the collected data, with a probability level (p-value) < 0.05 considered significant.

Baseline characteristics were compared between groups with descriptive statistics for continuous and categorical variables, to examine potential between-group differences.

In case of *continuous variables* (age, height, weight, FEV1, FVC, FEV1/FVC, TLC, RV, TLC/RV, MIP, MEP, TUG, STSTS) an independent t-test, Welch test or Wilcoxon rank sum test (equivalent to Mann-Whitney U test) were performed depending on the analysis of the following assumptions: normality, homoscedasticity and independence of the variables. The normality and the homoscedasticity were verified by using the Shapiro Wilk test and the Brown-Forsythe test, respectively. A flowchart designed by Weaver K. was used to determine the correct statistical test [60] (see Figure 5).

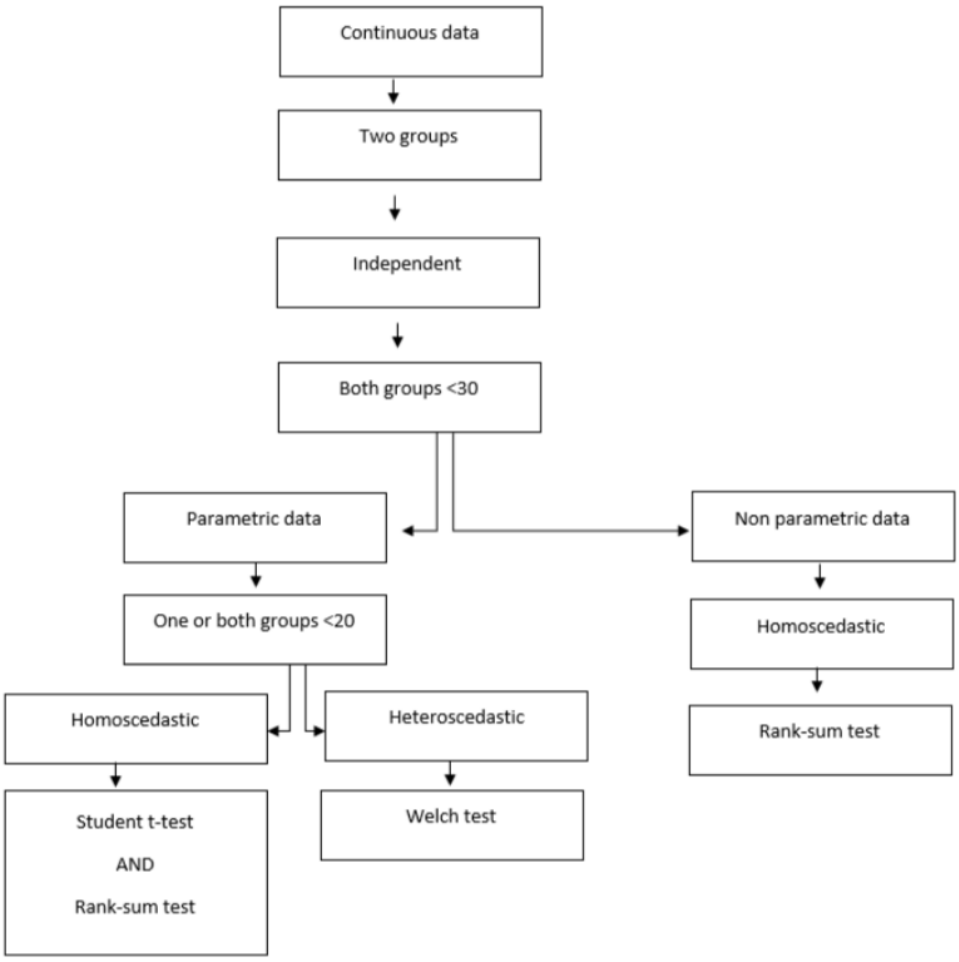


Figure 5. Flowchart continuous variables: two independent samples

In case of *categorical variables* (gender, GOLD stage, Mini BESTest) a contingency table was implemented to perform the Chi Square Pearson test (X^2 test). If 20% of all cells had an expected count less than five, the more reliable Fisher exact test was used for between-group analysis. In contrast to nominal data, the 28-point ordinal scale from the Mini-BEST was analysed as continuous data [61].

Analysis for postural task-related changes in CoP/ EMG activity at baseline

To analyse an overall difference in (i) diaphragm, ES, MF, RA, OI activation level and (ii) anteroposterior and mediolateral postural balance measures between all twelve postural trials, the following statistical tests were implemented. Change scores from postural balance measures were calculated and used as response variable. These change scores represent the amount of change in each postural balance variable by the performed task compared to baseline. In case of trials 1-2 and 7-8, the change in CoP / EMG activity caused by a single UL movement was calculated by subtracting the baseline CoP/EMG value from the mean COP/EMG value during the UL movement. Moreover, the change in CoP/EMG during the recovery phase after the UL movement was calculated by subtracting the baseline CoP/EMG value from the mean CoP/EMG value during recovery. In case of trial 3-6 and 9-12, the average CoP/EMG of all three sets of ballistic movements was calculated. This average value was used to calculate the change in CoP/EMG during repetitive ballistic UL movements, by subtracting the baseline CoP/EMG value from the average COP/EMG value during repetitive ballistic UL movements.

To determine whether the above-mentioned calculated changes in CoP/EMG activity were significantly different from zero, a paired t-test or Wilcoxon signed rank test was used. For between-trial analysis in CoP/EMG activity for trials 1, 2, 7 and 8, a two-way ANOVA for repeated measures with factors ‘vision’ and ‘surface’ was used. For trials 3-6 and 9-12, a three-way ANOVA with factors ‘surface’, ‘movement direction’ and ‘breathing mode’ for repeated measures was implemented for all change scores. This full-factorial analysis observed the main and interaction effects of the following two-level within-factors: surface (stable, foam) and vision (eyes open, vision occluded) in case of trial 1-2 and 7-8, or surface (stable, foam), movement direction (flexion-extension, abduction-adduction) and breathing mode (normal, end-expiration) in case of trial 3-6 and 9-12.

In case of not normally distributed residual values, a non-parametric test for multiple related samples was used in SPSS Statistics 26.0 (Friedman test).

Significant main and interaction effects were followed by pairwise comparisons of trials to further analyse these results in detail. For post-hoc analysis, multiple testing was corrected for controlling type I error. This was performed automatically, using Tukey test, or manually using the Bonferroni adjustment (α / amount of pairwise combinations).

The strength of association between both continuous variables CoP and EMG activity were determined by a linear Pearson correlation test. In case of non-parametric data, the Spearman's Rho test was implemented to assess the rank correlation coefficient.

Analysis for treatment effect on postural task-related changes in CoP/EMG activity, functional balance performance tests and MIP

To analyse the main treatment effects and interactions effects within a two-way design with one repeated measure, a repeated-measures analysis was performed for the following measurements: electromyography of the diaphragm (EMGdi), CoP outcome measures, functional balance performance tests and MIP. Therefore, a Mixed Model ANOVA for repeated measures was implemented in JMP with between-subjects factor 'treatment' (high IMT versus low IMT) and within-subjects factor 'time' (before versus after intervention). The statistical significance of the within-group by between-group interaction was determined a priori. In case of nonparametric data, change scores were calculated for the repeated factor 'time' (before versus after intervention). Within-group effects over time were checked for each treatment using a paired t-test or Wilcoxon signed rank test for non-parametric data. Between-group effects for change scores over time (post-pre) as well as change scores within trials pre- and post-intervention (UL movement – baseline; recovery – baseline) were checked using an independent t-test, Welch test or Wilcoxon rank sum test [60].

5. Results

Ten participants completed the training program (n= 10). One participant chose to discontinue the study after a couple of weeks, resulting in one drop out (IMT: n = 1, see Appendix 1). The baseline data of this participant were included for the within- and between-trial analysis concerning postural task-related changes in EMG and CoP variables. However, regarding the main treatment effect over time, this participant was excluded from analysis, since there were no data recorded after the training implementation. Furthermore, some data sets were incomplete because of inaccurate tests, loss of information or adjustments to the experimental protocol over time. In case of missing data of functional balance measures (n = 3), the participants were only excluded from the analysis of the related response variable. In case of incorrect or not performed postural trials with unreliable or missing data recording, the participants were only excluded from the CoP/EMG analysis of the related postural trial(s) at baseline (IMT; trial 9: n = 1, trial 10: n = 1, trial 11: n = 1, trial 12: n = 1/ Sham-IMT; trial 8: n = 1, trial 9: n = 1, trial 10: n = 2, trial 11: n = 2, trial 12: n = 2, trial 14: n = 1) and/or post-intervention (IMT; trial 9: n = 1, trial 10: n = 1, trial 11: n = 1, trial 12: n = 1, trial 14 n = 1/ Sham-IMT; trial 7: n = 1, trial 8: n = 1, trial 9: n = 1, trial 10: n = 2, trial 11: n = 2, trial 12: n = 2, trial 14 n = 1). The main reasons for data exclusion from analysis were an incorrect performing of the breathing task and loss of balance with support of the assessor.

5.1 Baseline characteristics

The baseline characteristics of both groups are displayed in Table 5. Data were presented as mean +/- standard deviation if the variables were normally distributed. In case of non-parametric variables, the median, quartile one (Q1) and quartile three (Q3) were displayed.
All participants were diagnosed with clinically stable COPD (stages 0-4). Despite the unequal distribution regarding the number of subjects (IMT n= 8; Sham-IMT n= 3), the similarity of the two groups was high at the start of the training program. Except for age ($p = 0.0064$), groups were homogeneous in terms of gender, height, weight, GOLD stage, lung function (FEV_1, FVC, TLC, RV) and respiratory muscle function (MIP, MEP) at baseline ($p > 0,05$).

Table 5. Participant characteristics at baseline

	IMT (n=8)	Sham IMT (n=3)	P-value
General characteristics			
Gender (%male)	63%	67%	1.000
Age (years)	63 ± 4	73 ± 4	0.006 *
Height (cm)	167 ± 16	169 ± 7	0.803
Weight (kg)	75 ± 21	69 ± 30	0.698
GOLD stage (0-4) (N)	3|0|2|2|1	0|0|2|1|0	0.458
GOLD stage (0-4) (%)	38|0|25|25|12	0|0|67|33|0	0.458
Lung function			
FEV1 (l/min)	1.66 ± 0.62	1.24 ± 0.46	0.315
FEV1 (%pred)	50 ± 15	60 ± 28	0.580
FVC (l)	3.68 (3.02-4.35)	2.56 (2.56-2.79)	N/A
FVC (%pred)	102 ± 25	86 ± 25	0.381
FEV1/FVC	59 ± 18	54 ± 12	0.681
TLC (l)	7.15 ± 1.79	6.36 ± 0.94	0.498
TLC (%pred)	117 ± 21	110 ± 32	0.676
RV (l)	2.60 (2.32 – 4.05)	3.80 ± 0.87	0.193
RV (%pred)	118 (100-162)	152 ± 47	0.630
RV/TLC	45 ± 10	60 ± 10	0.059
Respiratory muscle function			
MIP (cm H_2O)	80.4 ± 16.2	76 ± 7.6	0.671
MIP (pred%)	82.6 ± 15	105.3 ± 10.4	0.041*
MEP (cm H_2O)	175.3 ± 53	150 ± 57.4	0.506
MEP (pred%)	177.1 ± 54.4	155,3 ± 36.5	0.543

IMT= inspiratory muscle strength training
FEV_1 = Forced Expiratory Volume in 1 second; FVC = Forced Vital Capacity; TLC = Total Lung Capacity; RV = Rest Volume; MIP= Maximal Inspiratory Pressure; MEP= Maximal Expiratory Pressure; % pred= percentage predicted; N/A = not applicable
**Significant difference between both groups (p < 0,05)*

5.2 Electromyography

5.2.1 Task-related changes in muscle activation at baseline

The results and the corresponding baseline data with change scores for UL movement and recovery phase are covered in Table 6 and 7. The results of both within-trial analysis and between-trial analysis on the calculated change scores are described below. Multiple related-sample comparisons revealed no significant differences in UL movement-related changes in Deltoideus EMG activity across trials ($X^2_{(trial\ 1\text{-}2,7\text{-}8)} = 3.533$, $p = 0.316$, $X^2_{(trial\ 3\text{-}6,9\text{-}12)} = 3.143$, $p = 0.871$). However, change scores (UL movement phase – baseline) were positive and significantly different from zero within all twelve trials ($p < 0,01$). This confirms that both single (trial 1-2 and 7-8) and repetitive ballistic arm movements (trial 3-6 and 9-12) were executed effectively and not significantly different across trials.

Postural-related changes in EMG by single ballistic UL movement (trial 1-2 and 7-8)

For the *UL movement phase*, the paired t-test and Wilcoxon signed rank test revealed that the positive change scores (UL movement phase – baseline) were significantly greater than hypothesized value zero ($p < 0,05$) for all five core muscles within each postural trial. However, in case of the diaphragm, MF and ES, a two-way repeated-measures ANOVA showed that this increased muscle activation by ballistic arm flexion was independent from the support surface and vision condition separately ($p > 0,05$), as well as their corresponding interaction (Diaphragm: $F_{(3,37)} = 3.260$, $p = 0.102$), ES: $F_{(3,37),} = 0.087$, $p = 0.775$, MF: $F_{(3,37)} = 1.207$, $p = 0.300$). Also, the positive changes scores for RA and OI did not significantly differ between postural trials (RA: $X^2_{(3)} = 0.067$, $p = 0.996$, OI: $X^2_{(3)} = 0.600$, $p = 0.896$).

For the *recovery phase,* only the positive change scores in normalized mean EMG amplitudes of the diaphragm and the abdominal muscles (recovery – baseline) were significantly different from zero, more specifically during both unstable support surface trials (Diaphragm: $p_{(trial\ 7)} = 0.023$, $p_{(trial\ 8)} = 0.011$; RA: $p_{(trial\ 7)} = 0.046$, $p_{(trial\ 8)} = 0.032$; (OI) $p_{(trial\ 7)} = 0.031$ $p_{(trial\ 8)} = 0.044$). Between-trial factorial analysis further confirmed a significant surface effect for the proved change scores in the aforementioned muscles. Change in diaphragm activity was significantly higher during upright standing on unstable compared to stable support surfaces, regardless of the vision condition (main surface effect: $F_{(3,37),} = 11.307$, $p = 0.007$).

Similar results were found for RA by using the Friedman test ($X^2 = 8.333$, $p = 0.040$), followed by a trend towards a significantly higher change score in the unstable compared to the stable support surface condition with eyes open (Bonferroni: $0.004 < p_{(trial\ 7\text{-}1)} = 0.017 < 0.05$).

Table. 6 Baseline and change scores of EMG (% MVC) for single UL movement by support surface and vision

UL MOVEMENT PHASE - BASELINE				RECOVERY PHASE – BASELINE			
Outcome	**Baseline** **Change score**	**STABLE**	**FOAM**	**Outcome**	**Baseline** **Change score**	**STABLE**	**FOAM**
M. Diaphragm (%) *Mean ± SD* *Median (Q1 – Q3)*	**VISION**	10.21 (6.42–14.55) **4.51 ± 6.93**	12.35 (6.03–15.6) **6.89 ± 12.11**	M. Diaphragm (%) *Mean ± SD* *Median (Q1 – Q3)*	**VISION**	10.21 (6.42–14.55) 0.09 ± 1.30	12.35 (6.03–15.6) **0.75 ± 1.5** ##
	NO VISION	12.67 (4.74 –16.29) **3.80 ± 4.86**	10.30 (6.50–15.51) **3.83 ± 5.73**		**NO VISION**	12.67 (4.74 –16.29) 0.13 ± 0.10	10.30 (6.50–15.51) **0.74 ± 0.86** ##
M. Erector Spinae (%) *Mean ± SD* *Median (Q1 – Q3)*	**VISION**	4.85 (3.07–6.48) **7.30 ± 3.82**	3.94 (1.97–6.13) **7.83 ± 5.89**	M. Erector Spinae (%) *Mean ± SD* *Median (Q1 – Q3)*	**VISION**	4.85 (3.07–6.48) 0.19 ± 0.76	3.94 (1.97–6.13) 0.50 ± 1.26
	NO VISION	3.62 (2.24–7.94) **7.22 ± 3.68**	4.21 (3.01–7.49) **7.92 ± 5.42**		**NO VISION**	3.62 (2.24–7.94) 0.23 ± 0.98	4.21 (3.01–7.49) 0.29 ± 0.53
M. Multifidus (%) *Mean ± SD* *Median (Q1 – Q3)*	**VISION**	11.19 (4.53–18.43) **9.30 ± 8.94**	10.34 (3.54–21.87) **7.26 ± 6.85**	M. Multifidus (%) *Mean ± SD* *Median (Q1 – Q3)*	**VISION**	11.19 (4.53–18.43) 0.38 ± 1.57	10.34 (3.54–21.87) 0.98 ± 1.56
	NO VISION	10.32 (5.23–13.63) **7.33 ± 8.60**	12.48 (3.42–17.02) **6.30 ± 5.27**		**NO VISION**	10.32 (5.23–13.63) 0.53 ± 1.17	12.48 (3.42–17.02) 0.69 ± 1.59
M. Rectus Abdominus (%) *Median (Q1 – Q3)*	**VISION**	3.21 (1.88–6.20) **2.47 (3.31–4.95)**	2.77 (2.03–6.06) **2.52 (0.85–6.28)**	M. Rectus Abdominus (%) *Median (Q1 – Q3)*	**VISION**	3.21 (1.88–6.20) 0.03 (-0.09–0.04)	2.77 (2.03–6.06) **0.17 (0,01–0.20)** ††
	NO VISION	2.82 (2.07–5.89) **3.30 (1.14–6.83)**	3.47 (2.12–6.22) **3.42 (1.99–12.06)**		**NO VISION**	2.82 (2.07–5.89) 0.06 (-0.05–0.17)	3.47 (2.12–6.22) **0.17 (0.03–0.13)**
M.Obliquus Internus (%) *Median (Q1 – Q3)*	**VISION**	5.16 (3.31–8.30) **5.46 (2.99–12.18)**	5.02 (3.09–7.53) **7.71 (2.97–11.82)**	M.Obliquus Internus (%) *Median (Q1 – Q3)*	**VISION**	5.16 (3.31–8.30) **0.03 (0.01–0.07)**	5.02 (3.09–7.53) **0,16 (-0.06–1.87)**
	NO VISION	5.15 (3.24–7.94) **7.81 (3.09–11.49)**	5.17 (2.76–7.25) **6.79 (1.95–8.14)**		**NO VISION**	5.15 (3.24–7.94) **-0.07 (-0.30–0.33)**	5.17 (2.76–7.25) **0.11 (-0.22–0.38)**

*Significantly different from baseline phase **bold** (p < 0,05)*
Significantly different from stable support surface independent from vision (p < 0,01)
†† Significantly different from stable support surface with vision (p < 0,05)
SD = standard deviation, values are presented as % of the average peak EMG activity measured during three Maximal Voluntary Contractions (MVC)

Postural-related changes in EMG by repetitive ballistic UL movements (trial 3-6 and 9-12)

For the *UL movement phase,* the average of the mean EMG amplitude of all three sets of ballistic movements was calculated and subtracted with the corresponding baseline values. For the ES, MF, RA and OI, all EMG change scores were positive and significantly different from zero within all eight postural trials (p= < 0,05). However, a significant postural-related increase in diaphragm EMG was only observed in the trials with normal breathing ($p_{(trial\ 3)}$ = 0.002, $p_{(trial\ 5)}$ = 0.012, $p_{(trial\ 9)}$ = 0.004, $p_{(trial\ 11)}$ = 0.016). Within the end-expiration trials, however, postural-related activation was observed (i.e., positive change score), but to a lesser non-significant extent (p > 0,05).

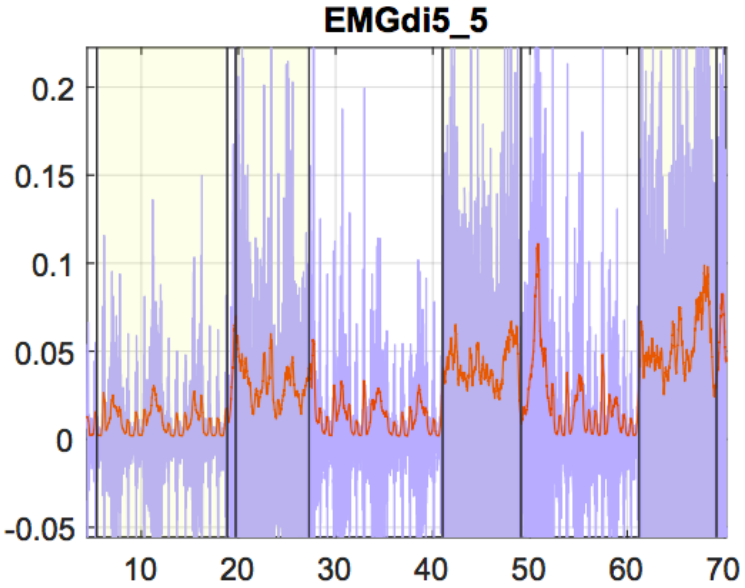
For the between-trial analysis of EMG change scores, only Friedman tests were performed, followed by Wilcoxon signed rank test due to non-normal data distribution. This multiple related-samples comparison was significant for three out of five muscles (Diaphragm: $X^2_{(7)}$ = 14.048, p= 0.042); MF: $X^2_{(7)}$ = 13.572, p= 0.049; RA: $X^2_{(7)}$ = 39.429, p= <0.001) with a trend towards a significant effect for ES ($X^2_{(7)}$ = 12.048, p= 0.059). With regards to diaphragm EMG activity, the positive change scores within the normal breathing trials were also significantly greater compared to the corresponding end-expiration trials with a mean difference of (+) 3.45% ± 1.82% ($p_{(trial\ 3>4)}$ = 0.044; $p_{(trial\ 5>6)}$ = 0.041, $p_{(trial\ 9>10)}$ = 0.018, $p_{(trial\ 11>12)}$ = 0.043). Moreover, between these four end-expiration trials, a trend towards increased diaphragm activation due to repetitive flexion-extension compared to abduction-adduction movements was found, during standing on both the stable ($p_{(trial\ 4>6)}$ = 0.062) and unstable support surface ($p_{(trial\ 10>12)}$ = 0.081). The same trend towards a movement direction-related difference in diaphragm activation was also found during standing on the unstable support surface while breathing normally ($p_{(trial\ 9>11)}$ = 0.072). In line with the latter pairwise comparison, post-hoc tests for the EMG activity of MF also revealed a strong, and statistically significant, movement direction-related difference in change scores ($p_{(trial\ 9>11)}$ 0.008). Also, when performing repetitive flexion-extension while breathing normally, standing on the unstable compared to the stable support surface caused significantly more postural-related MF activation ($p_{(trial\ 9>3)}$ = 0.045). At least, also RA EMG activity increased significantly more within the four repetitive flexion-extension trials compared to the corresponding abduction-adduction trials ($p_{(trial\ 3>5)}$ = 0.004; $p_{(trial\ 4>6)}$ = 0.003, $p_{(trial\ 9>11)}$ = 0.016, $p_{(trial\ 10>12)}$ = 0.018).

Figure 6 presents the mean normalized EMG activity from a representative subject by different types of UL movement task varying in the movement plane (A – C) and the breathing mode (B – C).

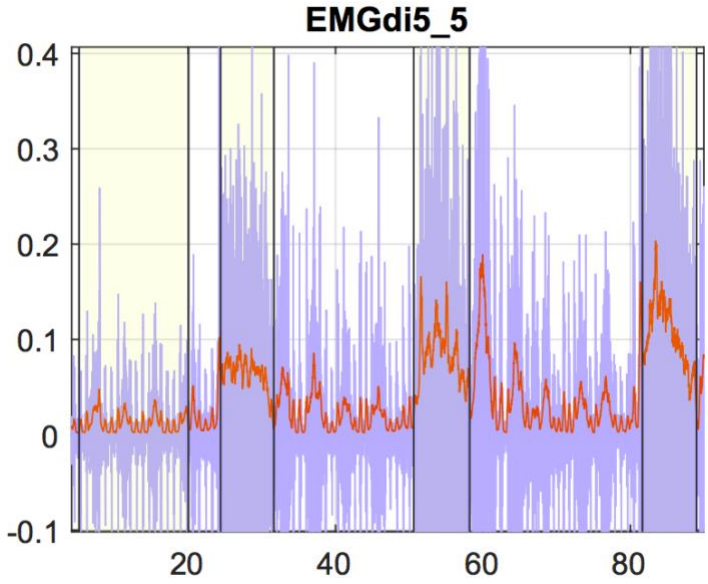
Table 7. Baseline and change scores of EMG for repetitive UL movements by support surface, movement direction and breathing condition

UL MOVEMENT PHASE - BASELINE					
Outcome	**Baseline / Change score**	**STABLE**		**FOAM**	
		FLEXION - EXTENSION	**ABDUCTION - ADDUCTION**	**FLEXION - EXTENSION**	**ABDUCTION - ADDUCTION**
M. Diaphragm (%) *Median (Q1-Q3)*	**NORMAL**	11.15 (6.11–15.03)	12.76 (6.93–17.17)	11.45 (6.19–15.05)	13.21 (7.44–16.47)
		4.30 (3.11–1.5) ##	**4.41 (-1.03–6.77) ##**	**6.75 (3.72**–10.02) **##**	**4.17 (2.54**–5.69) **##**
	END-EXPIRATION	12.64 (8.02–17.52)	12.11 (9.77–15.39)	13.50 (5.77–19.45)	15.56 (6.80–17.74)
		1.84 (-1.23–4.9)	0.74 (-1.59–3.13)	1.40 (-1.62–4.39)	0.56 (-3.18–2.16)
M. Erector Spinae (%) *Median (Q1-Q3)*	**NORMAL**	3.14 (2.22–6.72)	3.84 (2.37–5.21)	4.47 (2.56–8.15)	3.48 (2.23–6.98)
		10.79 (8.09–15)	**9.16 (4.13–13.91)**	**10.56 (5.62–14.51)**	**11 (5.25–12.14)**
	END-EXPIRATION	4.03 (2.33–7.39)	3.71 (2.41–6)	4.22 (2.23–6.29)	3.63 (2.82–5.95)
		11.17 (6.92–16.58)	**9.33 (4.45–14.25)**	**13.81 (5.15–14.72)**	**8.51 (6.15–13.22)**
M. Multifidus (%) *Median (Q1-Q3)*	**NORMAL**	9.24 (4.53–12.97)	8.54 (3.54–14.29)	11.17 (4.23–23.84)	12.70 (4.24–21.30)
		4.29 (1.38–10.54)	**2.96 (1.51–11.60)**	**6.30 (2.14–14.12) ††$$**	**2.61 (0.56–11.41)**
	END-EXPIRATION	9.97 (4.48–14.32)	9.98 (3.30–14.55)	14.34 (4.17–22.62)	13.76 (4.27–20.18)
		5.58 (1.81–10.07)	**2.96 (1.12–6.70)**	**4.47 (1.42–10.57)**	**3.08 (0.40–7.58)**
M. Rectus Abdominus (%) *Median (Q1-Q3)*	**NORMAL**	2.83 (2.12–5.77)	2.87 (2.24–6.18)	2.28 (1.94–5.89)	2.44 (1.95–3.76)
		9.71 (7.23–11.94) ††	**1.78 (0.80–3.59)**	**6.27 (4.85–10.43) ††**	**1.30 (0.59–3.11)**
	END-EXPIRATION	2.78 (2.18–5.77)	2.78 (2.19–6.31)	2.47 (1.68–3.74)	2.38 (1.85–4)
		10.58 (6.06–18.04) ††	**2.89 (1.49–5.29)**	**6.79 (4.44–12.91) ††**	**2.22 (1–4.34)**
M. Obliquus Internus (%) *Median (Q1-Q3)*	**NORMAL**	4.42 (3.05–8.03)	5.09 (3.03–5.70)	4.77 (1.82–8.95)	4.44 (1.38–5.03)
		8.02 (4–11.69)	**6.92 (6.77–8.87)**	**6.28 (2.34–6.70)**	**5.20 (3.66–6.80)**
	END-EXPIRATION	4.63 (3.06–5.33)	4.96 (3.22–6.09)	4.38 (1.98–5.20)	4.07 (1.51–5.44)
		8.38 (7.34–13.69)	**8.39 (6.13–8.84)**	**6.64 (2.22–7.41)**	**6.16 (4.03–8.50)**

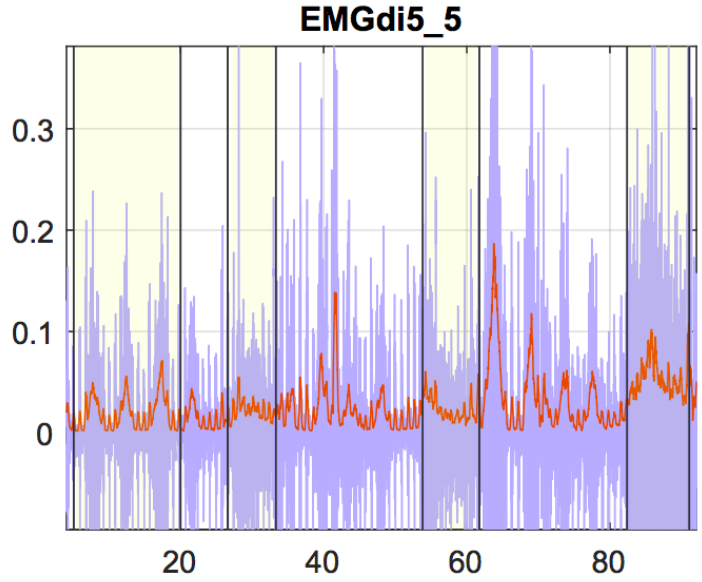
*Significantly different from baseline phase **in bold** ($p < 0.05$)*
Significantly different from end-expiration on same support surface and within same movement plane ($0.01 < p < 0.05$)
†† Significantly different from abduction-adduction on same support surface with same breathing mode ($p < 0.01$)
$$ Significantly different from flexion-extension on stable support surface with normal breathing ($p < 0.05$)
Values are presented as % of the average peak EMG activity measured during three Maximal Voluntary Contractions (MVC)



(A) repetitive UL flexion-extension with normal breathing during standing on stable support surface



(B) repetitive UL flexion-extension with breath holding at end-expiration level during standing on stable support surface



(C) repetitive UL abduction-adduction with normal breathing during standing on stable support surface.

Figure 6. *Mean normalized EMG amplitude at baseline from a representative subject for condition (A), (B), (C).*
Baseline phase = < 20 s
UL movement phase = > 20s, 10 s for each set of ballistic UL movements (total of three sets within each trial)
Y axis = mean EMG amplitude (Voltage), X axis = recording time (seconds)

5.2.2 The effect of IMT on task-related changes in Diaphragm EMG

The results and corresponding data for changes in Diaphragm EMG (EMGdi) over time and between-groups are covered in Tables 8 and 9, divided by the executed postural task. The results of the performed Mixed Model ANOVA on the calculated change scores are reported and described below.

The effect of IMT on changes in EMGdi by single UL movement (trial 1, 2, 7, 8)

Significant effects for postural-related changes in EMGdi over time with or without between-group differences were yielded for three out of four postural trials. During upright standing on the stable support surface without vision, an improvement in change scores for EMGdi over time could be observed in the IMT group (median 3.49 %, (-0.85% – 6.37%)) while not in the sIMT group (median -4.03% (-4.94% - 2%)). However, the latter increment or decrement, respectively, were not found to be significantly different (p>0,05). Pairwise comparisons further revealed a trend towards significantly greater changes over time for the IMT group compared to the sIMT group (median -2.31% $\pm$ 3.77 %) (p = 0.092). Also, for both unstable conditions after the intervention, trends towards greater postural-related EMGdi activation were observed in the IMT group compared to the sIMT group (Trial 7: p = 0.081; Trial 8: p = 0.092, see Table 8). Also, while postural diaphragm activation (EMGdi) due to single UL movement increased over time following IMT, changes in EMGdi by UL movement decreased post intervention following sIMT, reflected by negative change scores (post-pre). However, no significant interaction effect was found for mean EMGdi amplitude in both trials (Trial 7: p = 0.183; Trial 8: p = 0.182). However, the analysis of peak EMGdi revealed a trend towards significantly different within-changes over time (p = 0.057) with a significantly higher peak EMGdi for the IMT group in upright stance on foam with vision post-intervention (p = 0.028).

For the recovery phase after single UL movement on the stable support surface with vision, no significantly higher EMGdi was observed both before and after the intervention (p> 0.05). However, over time, postural-related changes in EMGdi improved slightly with 0.35 $\pm$ 0.55% in the IMT group and 0.46 $\pm$ 0.52% in the sIMT group. The latter was confirmed with a trend towards a significant time effect for both groups together ($F_{(3,16)}$ = 4.546, p = 0.065). For unstable conditions, EMGdi activation during recovery decreased over time in IMT group.

This was in contrast with positive within-changes observed in the sIMT group (see Table 8), leading to higher postural diaphragm activation during recovery in the sIMT control group compared to the IMT intervention group after the intervention (Trial 7: $p = 0.027$).

Table 8. Pre-intervention (week 1) and postintervention (week 8) values and postural-related change scores for EMG diaphragm (%MVC) by single UL movement

TASK PHASE - BASELINE				RECOVERY PHASE – BASELINE			
Postural task	**Baseline** **Change score**	**PRE**	**POST**	**Postural task**	**Baseline** **Change score**	**PRE**	**POST**
Trial 1	**IMT**	8.82 ± 3.55	6.66 ± 9.52	Trial 1	**IMT**	8.82 ± 3.55	6.66 ± 9.52
		2.67 ± 5.51	**6.93 ± 7.55**			0.72 ± 1.09	0.03 ± 1.04
	Sham-IMT	17.93 ± 6.76	11.4 (11.26 – 28.64)		**Sham-IMT**	17.93 ± 6.76	11.4 (11,26 –28,64)
		7.44 ± 10.68	5.82 ± 10.36			-0.63 ± 1.17	**1.11 ± 0.75**
Trial 2	**IMT**	9.95 ± 5.58	6.44 ± 4.01	Trial 2	**IMT**	9.95 ± 5.58	6.44 ± 4.01
		2.14 ± 4.10	**9.83 ± 11.72**			-0.01 (-0.23 – 0.16)	0.11 ± 0.28
	Sham-IMT	21.54 ± 10.3	17.91 ± 9.88		**Sham-IMT**	21.54 ± 10.3	17.91 ± 9.88
		5.47 ± 5.63	3.15 ± 9.22			0.13 ± 0.97	0.58 ± 0.84
Trial 7	**IMT**	11.82 ± 5.67	6.76 ± 5.02	Trial 7	**IMT**	10.30 ± 5.67	6.76 ± 5.02
		4.14 ± 9.17	**4.40 (0.40 – 7.42)**			1.29 (0.16 – 1.49)	**-2.51 (-7.12 – 0.03)**
	Sham-IMT	19.64 ± 7.38	27.54 ± 13.11		**Sham-IMT**	19.64 ± 7.38	27.54 ± 13.11
		13.84 ± 9.84	-3.15 ± 5.88			0.56 ± 2.04	3.34 ± 2.14
Trial 8	**IMT**	9.07 ± 4.50	6.83 ± 5.46	Trial 8	**IMT**	9.07 ± 4.50	6.83 ± 5.46
		2.83 ± 3.66	**4.47 (1.02 –8.38)**			**0.88 ± 0.87**	0.30 ± 0.93
	Sham-IMT	25.77 ± 13.38	25.70 ± 13.90		**Sham-IMT**	25.77 ± 13.38	25.70 ± 13.90
		7.40 ± 13.55	0.98 ± 2.17			0.64 ± 1.23	0.04 ± 2?01

*Significantly different from baseline phase pre-intervention **bold** ($p < 0.05$)*
*Significantly different from baseline phase post-intervention **bold** ($p < 0.05$*
Parametric values are presented as mean ± SD, non-parametric data are presented as median (Q1 – Q3)
IMT = inspiratory muscle training (intervention group); Sham-IMT = active placebo group
Type of postural trial (support surface and vision condition) with corresponding numbering is described in Table 3
Values are presented as % of the average peak EMG activity measured during three Maximal Voluntary Contractions (MVC)

The effect of IMT on changes in EMGdi by repetitive UL movements (trial 3-6, 9-12)

Significant effects for postural-related changes in EMGdi over time with or without between-group differences were only observed within the postural tasks performing repetitive ballistic arm flexion-extension (not during abduction-adduction). Especially when breathing normally (trial 3, 9), greater task-related changes in EMGdi activity were observed within the IMT group post-intervention (but not the sIMT group), both under stable (1.66 $\pm$ 3.08 %, p = 0,078) and unstable support surface conditions (1.63 $\pm$ 6.04 %, p = 0.261). However, these differences in EMGdi were not statistically different. Though, a trend towards significant difference in change scores over time (post-pre) between groups was shown by a Students' T test (trial 3: p = 0.051). Furthermore, after maximal expiration (trial 4, 10), positive changes in EMGdi activity by repetitive flexion-extension were only observed within the IMT group (see Table 9). However, the post intervention determined changes in EMGdi were not significantly greater from the hypothesized value zero (trial 4: p = 0.062; trial 10: p = 0.133), as well as not significantly greater compared to changes in EMGdi at baseline (trial 4: p = 0.375; trial 10: p = 0.472). At least, for changes in EMGdi activity caused by repetitive abduction-adduction, no main effect of 'time' or interaction effect of 'time x group' was observed within each trial (p > 0.05). Noteworthy, within all aforementioned postural trials, postural-related changes in EMGdi within the IMT group intended to increase over time while deteriorated in the sIMT group. See Table 9 for the corresponding positive and negative within-differences respectively.

Table 9. Pre-intervention (week 1) and post-intervention (week 8) values and postural-related change scores for EMG diaphragm (%MVC) by repetitive UL movements

TASK PHASE - BASELINE							
Postural task	**Baseline Change score**	**PRE**	**POST**	**Postural task**	**Baseline Change score**	**PRE**	**POST**
Trial 3	**IMT**	10.74 ± 6.77	7.15 ± 4.10	Trial 9	**IMT**	9.02 ± 4.56	8.98 ± 4.47
		5.28 ± 7.01	**6.94 ± 7.06**			**5.89 (2.78 – 16.17)**	**7.51 ± 9.39**
	Sham-IMT	14.63 ± 20.54	22.18 ± 17.62		**Sham-IMT**	26.48 ± 16.03	30.75 ± 23.29
		12.85 ± 9.27	7.46 ± 4.86			8.83 ± 2.51	**7.09 ± 1.46**
Trial 4	**IMT**	11.20 ± 5.52	8.17 ± 5.78	Trial 10	**IMT**	12.26 ± 7.09	11.72 ± 7.11
		4.10 (1.79 – 7.25)	3.04 ± 5.52			4.13 ± 6.40	3.44 ± 6.74
	Sham-IMT	15.54 ± 11.11	30.37 ± 17.30		**Sham-IMT**	*16.08 ± 0	37.35 ± 16.82
		-2.70 ± 4.49	-5.69 ± 5.10			*-2.14 ± 0	-5.65 ± 6.63
Trial 5	**IMT**	11.29 ± 6.10	7.62 ± 6.02	Trial 11	**IMT**	12.12 ± 6.22	10.43 ± 6.12
		2.17 (-1.42 –6.77)	**5.29 ± 5.26**			**4.30 (1.50 –11.42)**	**5.40 ± 4.37**
	Sham-IMT	22.44 ± 15.20	23.86 ± 17.20		**Sham-IMT**	*15.17 ± 0	*38.47 ± 0
		5.22 ± 3.05	1.96 ± 2/90			*2.46 ± 0	*-4.77 ± 0
Trial 6	**IMT**	10.59 ± 4.77	8.65 ± 6.14	Trial 12	**IMT**	12.65 ± 6.14	9.95 ± 6.50
		1.80 ± 3.64	2.48 ± 4.28			0.48 ± 2.35	3.72 ± 4.61
	Sham-IMT	15.01 (14.80 –43.78)	12.83 (12.18 –49.40)		**Sham-IMT**	*16.48 ± 0	38.07 ± 27.02
		-4 ± 0.91	-0.96 ± 2.19			*3.29 ± 0	-3.76 ± 1.39

*Significantly different from baseline phase pre-intervention **bold** (p < 0.05)*
*Significantly different from baseline phase post-intervention **bold** (p < 0.05*
Parametric values are presented as mean ± SD, non-parametric data are presented as median (Q1 – Q3)
IMT = inspiratory muscle training (intervention group); Sham-IMT = active placebo group
Type of postural trial (support surface) and UL movement task (movement plane, breathing mode) with corresponding numbering is described in Table 3
Values are presented as % of the average peak EMG activity measured during three Maximal Voluntary Contractions (MVC)
**single case data used for within (time) and between (group) analysis*

5.3 Postural Balance

5.3.1 Task-related changes in CoP coordinates at baseline

An overview of all calculated stabilometric parameters from the CoP coordinates is covered in Appendix 2. Only the within- and between-trial analysis of the significant parameters are described below.

For the *basic postural balance phase (baseline)*, a two-way repeated measures ANOVA yielded significant main effects of vision and of support surface on each stabilometric parameter in both AP and ML direction. However, the mean CoP velocity and time-normalized CoP sway path in both directions were not significantly affected by the support surface condition ($p > 0.05$). Individuals with COPD showed significantly more postural sway ($CoPmax_{AP}$, $CoPmax_{ML}$, $CoPmin_{AP}$, $CoPmax_{ML}$, CoP_{AP} RMS, CoP_{ML} RMS, CoP total sway, cumulative sway path and sway area) during upright stance on the unstable compared to the stable support surfaces ($p < 0.01$). A similar effect was observed for trials without vision compared to those with vision ($0.01 < p < 0.05$). However, no interaction effect of 'support surface x vision' was found. Following an overall significant difference in sway path across trials (AP: $X^2 = 17.933$, $p = 0.001$, ML: $X^2 = 10.333$, $p = 0.016$, total: $X^2 = 25.533$, $p = < 0.001$), simultaneous effects were further shown by the Wilcoxon signed rank test. Significantly more CoP excursion was observed during standing on the unstable compared to the stable support surface, especially with eyes open ($p = 0.005$). Finally, significantly more CoP excursion was found during standing with vision occluded relative to with eyes open, especially during upright standing on the stable support surface (AP: $p = 0.005$, ML: $p = 0.007$, total: $p = 0.003$).

Changes in CoP coordinates by single ballistic UL movement (trial 1, 2, 7, 8)

For the *UL movement phase*, sixteen out of all nineteen stabilometric parameters showed positive change scores relative to basic postural balance phase, with a significant difference from zero in at least one trial ($p<0.05$). Moreover, in line with the ballistic UL movement in AP direction, five out of eight CoP parameters in AP direction were significantly greater within each trial and with a higher probability change compared to the corresponding ML variable ($p < 0.01$). A two-way repeated measures ANOVA further confirmed that UL movement-related changes in AP mean velocity were also dependent from both the support surface and vision conditions (Interaction effect 'support surface x vision': $F_{(3,38)} = 6.198$, $p = 0.015$). Post-hoc tests showed a trend towards faster AP CoP sway under unstable relative to stable support surface conditions with vision (mean difference 48.47 cm/s, p = 0,054). Also, a significant main surface effect was found for CoP range, with more UL movement-related changes in CoP range during upright stance on unstable relative to stable support surface regardless of vision (mean difference 24.08 +/ 6.27 cm, main effect support surface: $F_{(3,38)} = 14.864$, $p = 0.003$).

For the *recovery phase*, all significant changes scores were positive and confirmed in fourteen out of nineteen stabilometric parameters ($p<0.05$), with the majority in AP direction. Compared to baseline postural sway, posteriorly- (CoPmax) and anteriorly-directed (CoPmin) CoP displacement and calculated CoP range significantly increased within each trial ($p<0.05$). The highest change scores were observed in the most challenging balance condition (i.e., upright standing on an unstable support surface with the removal of vision (trial 8) (CoPmax: 9.61 cm $\pm$ 14.84, CoPmin: -9.98 cm $\pm$ 14.23; CoP range; 11.65 cm $\pm$ 39.89). However, repeated measures ANOVA yielded that the increased within-trial changes in aforementioned parameters were not significantly different between-trials (CoPmax: $F_{(3,37)} = 0.612$, $p = 0.453$; CoPmin: $F_{(3,37)} = 1.130$, $p = 0.314$; CoP range: $F_{(3,37)} = 0.750$, $p = 0.412$). Also, in line with UL movement phase effects, significant within-trial changes in AP mean velocity were observed ($p<0.05$), except for upright stance on foam with vision. Moreover, a main effect of vision was found for the change scores, indicating a more difficult recovery when vision was occluded ($F_{(3,37)} = 10.271$, $p = 0.012$). The same trend was observed in ML mean velocity, but with a simultaneous effect of vision by surface ($F_{(3,37)} = 7.539$, $p = 0.02$).

Within the more difficult vision occluded condition, COPD participants also showed faster postural sway during upright stance on the unstable relative to the stable support surface (mean difference 20.03 $\pm$ 4.76 cm/s, p = 0.011).

Changes in CoP coordinates by repetitive ballistic UL movements (trial 3-6, 9-12)

For *the UL movement phase,* 10 seconds of repetitive ballistic arm movements in both AP and ML direction caused significantly greater changes in all nineteen stabilometric parameters within each trial ($p < 0.01$)**.** For flexion-extension as well as abduction-adduction, significant changes caused by the aforementioned movements were found for both AP and ML CoP outcome measures. However, descriptive statistics revealed higher change scores for the movement in the corresponding plane, e.g. changes in AP mean velocity by flexion-extension (84.2 (61.91 – 122.1) cm/s) were greater than during abduction (40.2 (31.05 – 5.86) cm/s), whereas changes in ML mean velocity were greater during abduction-adduction (30.5 (13.98- 43.13) cm/s) compared to flexion-extension (24.8 (19.47 – 51.79) cm/s) (see Appendix 3).

Between-trial analysis for repeated measures further confirmed this main effect of movement direction on the following parameters: CoP max velocity AP ($F_{(7,64)} = 39.779$, p = < 0.001), RMS of CoP ($F_{(7,64)} = 23.931$, p = 0.007), standard deviation of CoP ($F_{(7,64)} = 23.929$, p = 0.007) and posterior CoP displacement (CoPmax) (($F_{(7,64)} = 26.570$, p = 0.006). Moreover, the superior effect of flexion-extension on CoP sway area was observed within normal breathing trials (1245 $cm^2 \pm 186$, p = 0.002), within end-expiration trials (830 $\pm$ 191 cm^2, p = 0.015) and within unstable support surface trials (1703 $\pm$ 296 cm^2, p = 0.001), confirming the interdependence. A same trend of results was found by Friedman test for AP changes in CoP mean velocity ($X^2 = 28.571$), time-normalized sway path ($X^2 = 28.571$) and total sway path ($X^2 = 26.476$) ($p<0.001$). Similar effects of all three factors were only found for anterior CoP displacement (CoPmin) (($F_{(7,64)} = 26.570$, p = 0.006). Post-hoc test revealed that the anterior sway caused by repetitive flexion-extension during upright stance on an unstable support surface and at the end of maximal expiration was significantly greater relative to the corresponding task with normal breathing (19,2 $\pm$ 4 cm, p = 0.009).

In contrast with overall between-trial effect in AP direction, less effects were found for the parameters in ML direction. Only a significant overall effect for changes in CoP mean velocity was observed by Friedman test (X^2 = 20.571, p = 0.004). Change in CoP velocity simultaneously caused by repetitive abduction-adduction, upright stance on foam and maximal end-expiration was significantly greater compared to the corresponding task with flexion-extension (p = 0.002), with normal breathing (p = 0.018) and on the unstable support surface (p = 0.016). However, taken into account Bonferroni adjustment of significance level (α / 12), the latter two results are no longer considered significant (0.004 < p < 0.05).

5.3.2 The effect of IMT on task-related changes in CoP coordinates

The effect of IMT on changes in Cop coordinates by single UL movement (trial 1,2,7,8)

For the *UL movement phase,* a significant interaction effect of 'group x time' was observed for sway area ($F_{(3,13)} = 9.528$, $p = 0.018$) when performing a single UL movement on a stable support surface with vision. The Post-hoc test revealed a trend towards less movement-related changes in sway area within the IMT group post-intervention. However, it must be noticed that the amount of change in CoP sway area was already significantly greater in the sIMT group (2224 $cm^2 \pm 691$) prior to the start of the training program ($p = 0.038$).

For *the recovery phase*, a significant interaction effect of 'group x time' was shown for CoP mean velocity (ML) after performing a single UL movement on an unstable support surface with vision ($F_{(3,13)} = 9.836$, $p = 0.019$). However, a negative trend for recovery in CoP mean velocity (ML) was observed with increment over time within both the IMT group (6.25 ± 2.15 cm/s, $p = 0.071$) and the sIMT groups (6.77 ± 3.74 cm/s, $p = 0.086$). However, the greater post-intervention change scores were still not significantly different from hypothesized value zero in both groups ($p_{IMT} = 0.500$, $p_{sIMT} = 0.219$). In contrast, changes in CoP range during recovery significantly decreased over time within the IMT group (-13.06 cm ± 3.77, p = 0,0388), but no such differences were found in the sIMT group (5.39 cm ± 6.23, $p = 0.807$).

The effect of IMT on changes in Cop coordinates by repetitive UL movement (trial 3-6, 912)

At baseline, the greatest movement direction-related changes in sway area on the stable support surface were found during repetitive flexion-extension. For the latter task, on stable support surface and and the end of maximal expiration, a positive trend for an interaction effect of 'group x time' was observed ($F_{(3,15)} = 4.192$, $p = 0.079$). Absolute values indicated a decrease in change scores for CoP sway area over time in the IMT group (- 328 cm^2 ± 227), while within-difference in the sIMT group were increased and more sway was likely to be observed post-intervention. With regards to anterior displacement of CoP, the greatest change at baseline was simultaneously caused by repetitive flexion-extension, unstable support surface and normal breathing.

After intervention, within the same postural task, less increment in anterior sway was observed over time (-12 ± 4 cm, p = 0.022), independently from the intervention groups ($F_{(3,15)}$ = 9.381, p = 0.022). Also, a main effect of time was observed for the following changes in AP CoP coordinates caused by repetitive abduction-adduction during standing on the stable support surface while breathing normally: CoP mean velocity AP (mean difference 12 ± 4,97 cm/s; $F_{(3,16)}$ = 5.688, p = 0.044), and total sway path AP (mean difference 142 ± 55 cm; $F_{(3,16)}$ = 6.637, p = 0.032). Moreover, within the latter postural task, significant between-group differences over time were found for CoP range. However, it must be noticed that similar, significant within-differences were observed in both intervention groups ((IMT) -21 ± 3 cm, p = < 0.001; (sIMT) -29 ± 5 cm, p = < 0.001).

5.4 Clinical field tests

5.4.1. The effect of IMT on functional balance performance

In both groups, the MiniBESTest total score was not significantly different after the intervention, with an average score of 25.5 (23.5 - 27) points in the IMT group (p = 0.317) and 21 (21-26) points in the sham-IMT group (p = 1,00). In contrast to the sham-IMT group (Δ = 0 points), the score of the IMT group increased post intervention (Δ = 1.4 points), indicating a slightly better balance performance. However, there was no statistically significant interaction effect of 'group x time' (p = 0.668). Also, the subscores of the anticipatory, reactive, sensory and dynamic domain showed no significant difference within-participants (p > 0.05) or between-groups over time (p > 0.05) (See Table 10).

When performing the TUG without and with a cognitive dual task (TUG_C) (Table 10), no significant difference in performance time (s) was observed between-groups over time (TUG p = 0.844; TUG_C p = 0.545). Within both groups, the TUG duration (IMT 8.9 +/- 2.4 seconds; sIMT 11.4 +/- 2.7 seconds) and TUG_C duration (IMT 10.0 +/- 2.5 seconds; sIMT 13.1 +/- 5.1 seconds) did not significantly differ after the intervention compared to before the intervention (IMT p_{TUG}= 0.835 p_{TUGC} = 0.558; sIMT p_{TUG}= 0.816 p_{TUGC} = 0.831). Also, in both groups, the mean change in TUG duration did not seem to be clinically meaningful as it did not exceed the determined MCID values (0.9-1.4 seconds) [53, 54].

Meantime, the STSTS test without vision (Table 6) was performed faster in the IMT group (13.4 +/- 2.3 seconds) compared to the sham-IMT group (17.5 +/- 4.2 seconds) following the intervention (p = 0.036). However, considered the repeated measures, the interaction effect of 'group x time' was not significant (p = 0.434). In other words, the within-differences in both groups were similar, but it must be taken into account that the total STSTS duration was already significantly shorter in the IMT group (15.2 +/- 1.5 seconds) prior to start of the training program (p = 0.014). Statistically, no significant within-differences were found in IMT group (p = 0.108), neither in sham-IMT group (p = 0.134). However, clinically, the treatment resulted in meaningful within-changes in performance time in both groups (IMT Δ = 1.8 seconds; sIMT Δ = 3.2 seconds > 1.7 seconds)[56].

Figure 7 presents the average change in all functional balance performances tests over time in both intervention groups.

5.4.2 The effect of IMT on inspiratory muscle function

Within-participants analysis revealed significant improvements in MIP post intervention for the IMT group (Δ = 17 cmH_2O, p = 0.012), with an average value of 95 +/- 22 cmH_2O (100 +/- 22 % predicted). No such difference was apparent in the sham-IMT group (p = 0.899). Also, marginal significance between-groups over time was detected (p = 0.058). See Table 6. Figure 8 presents the average MIP in both groups pre- and postintervention.

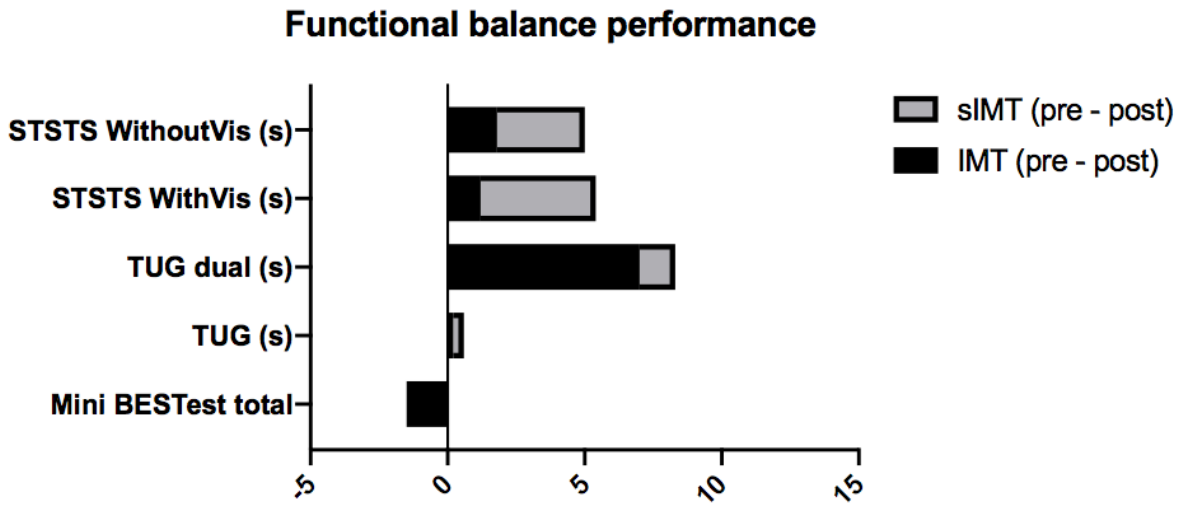


Figure 7. Change scores in functional balance performances over time in IMT and sham-IMT group.

IMT = inspiratory muscle training; sIMT = sham- inspiratory muscle training (active placebo group)
TUG = Timed Up & Go (with or without dual task); STSTS = Sit To Stand To Sit Test (with or without) in seconds.
Mini-BESTest has a maximum total score of 28 points.
TUG, TUG dual, STSTSwith vision, STSTSwithout vision: (+) change scores indicates better performance over time
Mini-BESTest: (-) change scores indicates better performance over time

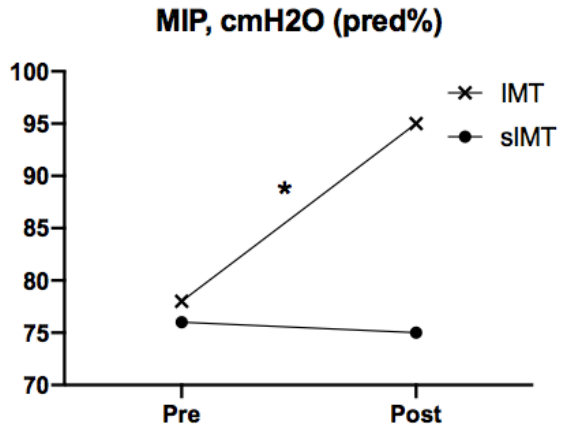


Figure 8. Group mean changes in inspiratory muscle strength (MIP) over time in IMT and sham-IMT group
IMT = inspiratory muscle training; MIP = maximal inspiratory mouth pressure (in %pred)
**Significantly different from baseline (p<0,05)*

Table 10. Baseline (week 1) and post-intervention (week 8) values/scores for inspiratory muscle function and functional balance performance

Outcomes	Time	Treatment IMT	P-value within	Treatment sIMT	P-value within	Interaction effect between groups over time
			Inspiratory muscle function			
MIP, cmH2O (%pred)	Pre	78 ± 16 (82 ± 16)	0,012*	76 ± 8 (105 ± 10)	0.899	0,058
	Post	95 ± 22 (100 ± 22)		75 ± 14 (104 ± 7)		
			Functional balance performance			
Mini-BESTest total	Pre	24 (22 - 25)	0.317	21 (21 - 25)	1.000	0.668
	Post	26 (24 - 27)		21 (21 - 26)		
Anticipatory domain	Pre	5 (3 - 5)	0.102	4 (4 - 5)	1.000	0.553
	Post	5 (5 - 5)		5 (4 - 5)		
Reactive domain	Pre	6 (5 - 6)	0.224	4 (3 - 6)	1.000	0.239
	Post	5 (4 - 6)		4 (4 - 6)		
Sensory domain	Pre	5 (5 - 6)	0.250	5 (5 - 5)	1.000	0.171
	Post	6 (5 - 6)		5 (5 - 5)		
Dynamic domain	Pre	9 (8 - 10)	0.500	9 (7 - 10)	1.000	0.121
	Post	10 (9 - 10)		8 (7 - 10)		
STSTS WithVis (s)	Pre	13.8 ± 1.9	0.236	20.5 ± 8.2	0.251	0.199
	Post	12.6 ± 3.3		16.3 ± 5.1		
STSTS WithoutVis (s)	Pre	15.2 ± 1.5	0.108	20.7 ± 4.4	0.134	0.434
	Post	13.4 ± 2.3		17.5 ± 4.2		
TUG (s)	Pre	9.1 ± 1.5	0.835	11.8 ± 0.3	0.816	0.844
	Post	8.9 ± 2.4		11.4 ± 2.7		
TUGdual (s)	Pre	10.9 ± 2.7	0.558	14.4 ± 4.0	0.831	0.545
	Post	10.2 ± 2.5		13.1 ± 5.1		

MIP= Maximal Inspiratory Pressure; % pred= percentage predicted; STSTS = Sit To Stand To Sit test (with vision or without vision); TUG = Timed Up & Go (without or with dual task)
*IMT = inspiratory muscle training; sIMT = sham-IMT (placebo training); *Significant different from baseline within-groups (p< 0.05)*
The mini-BESTest has a maximum score (MS) of 28 points and it is constructed of four subcomponents; Anticipatory MS 6, Reactive postural balance MS 6; sensory orientation MS 6; Dynamic gait MS 10

5.5 Correlations between outcomes

5.5.1 Correlation between EMGdi and CoP

At *baseline*, a reasonable strong association was observed between the postural-related changes in CoP mean velocity (AP) and EMGdi activity during the most difficult condition: upright stance on an unstable relative to stable surface without vision ($\varrho = 0.636 > 0.50$, $p = 0.048$). The significant changes in the following CoP variables (AP) caused by repetitive instead of single flexion-extension movements were also linearly and positively related to the corresponding changes in EMGdi activity: CoP mean velocity ($\varrho = 0.673$, $p = 0.023$), CoP sway path AP ($\varrho = 0.682$, $p = 0.021$) and cumulative sway path ($\varrho = 0.558$, $p = 0.045$). Noteworthy, within end-expiration trials, changes in EMGdi amplitude were positive, but to a smaller extent, compared to corresponding normal breathing trials. However, for three out four end-expiration trials, a moderate to strong association was still found between the determined changes in EMGdi and the following CoP variables: CoP posterior sway (trial 8: $\varrho = 0.846$, $p = 0.001$), CoP anterior sway (trial 16: $\varrho = 0.756$, $p = 0.052$; trial 18: $\varrho = 0.943$, $p = 0.005$), CoP max velocity (trial 8: $\varrho = 0.709$, $p = 0.015$; trial 18: $\varrho = 0.943$, $p = 0.005$). Such associations were not observed while breathing normally. Further, after an intervention period, the positive change scores in EMG activity within groups over time were not linearly correlated to any of the identified positive changes in CoP variables for the corresponding task ($\varrho < 0.25$, $p > 0.05$).

5.5.2 Correlation between EMGdi and EMG RA, OI, ES and MF

During upright standing on a stable support surface, postural-related changes in muscle activation of the diaphragm and MF were statistically and strongly correlated when performing a single UL postural task, both with vision ($\varrho = 0.733$, $p = 0.016$) and without vision ($\varrho = 0.729$, $p = 0.012$). During upright standing on an unstable support surface, a similar trend of results was confirmed for the changes in the aforementioned core muscles by repetitive ballistic UL flexion after breath holding at end-expiration ($\varrho = 0.794$, $p = 0.032$). However, while breathing normally, a shift towards a statistically strong association between changes in diaphragm and M. Erector Spinae activity was observed ($\varrho = 0.738$, $p = 0.037$).

5.5.3 Correlation between EMGdi and functional balance performance

Pearson's correlation test revealed that none of the four functional balance test scores were linearly correlated to the positive changes in EMGdi activity over time ($p < 0.05$). A moderate to poor strength of association was observed ($r < 0.25$).

5.5.4 Correlation between EMGdi and inspiratory muscle function

After the intervention, the identified improvements for MIP within the IMT group were moderately correlated with the increment in overall EMGdi activity over time ($\varrho = 0.411$). A trend for a positive, statistically strong association was yielded by the Spearman's Rho test ($p = 0.08$)

6. Discussion

6.1 Importance of the study

Fall injuries are common in people with COPD and lead to lower physical activity levels, an increased mortality and a worse quality of life [4, 5]. Many comorbidities may lead to this increased risk of falling, with postural balance deficits being one of them. COPD patients have been proven to have a decreased postural balance when compared to healthy age-matched adults [27, 29]. Diaphragm activity has been shown to play an important part in postural balance [6, 8], and diaphragm activity is diminished in COPD patients [10]. Therefore, the diaphragm activation pattern during increased postural demand in people with stable COPD was researched as first objective.

For the second objective, the effectiveness of IMT on the postural activation of the diaphragm and consequently postural balance in people with COPD was investigated. IMT has previously shown positive effects on inspiratory muscle function in people with COPD. It has also been proven to positively influence postural balance of healthy adults, but has not been tested in people with COPD [12, 16]. This study is thus among the first ones regarding this topic and may therefore set the grounds for the use of IMT in a clinical setting, as a rehabilitation tool for postural balance on top of the known respiratory benefits.

6.2 The main findings of the study

6.2.1 Basic postural balance and diaphragm activity

Previous research has already established balance deficits in people with COPD compared to age-matched healthy during upright standing on an unstable support surface with removal of vision [30]. However, these findings only recorded deficits for balance control in anteroposterior (AP) direction. In line with Smith et al. (2010), mediolateral (ML) stabilometric parameters were also analyzed in our study, since CoP displacement in this direction is more closely related to fall incidents compared to AP CoP displacements [31, 62]. Results showed both AP and ML balance control was increasingly challenged by unstable support surfaces and vision occluded conditions. The latter may be caused by (1) a decreased postural strategy variability due to proprioceptive impairments [30] or (2) a decreased stabilizing function of the trunk muscles due to respiratory demands [31]. Taken together, previously observed disease-related reduction in force generating and endurance capacity of the diaphragm [37, 39] might cause this identified postural balance disturbances in people with COPD. Subsequently, in our study, postural diaphragm activity was specifically established when postural demands were increased by UL movements tasks. For basic postural balance in quiet standing, the defined changes in postural disturbances by unstable support surface and vision occlusion separately were not accompanied with corresponding significantly changes in diaphragm EMG activity.

6.2.2 The effect of a UL movement task on EMG activity and postural balance

More simple balance perturbations associated with single or repetitive UL movement were sufficient to increase (I) baseline postural sway in people with COPD, both in AP and ML directions, and (II) postural activity of all trunk muscles (diaphragm, ES, RA, OI and MF) above that required for normal breathing and basic postural control. More specifically, this is the first study to confirm these postural-related modulations in the magnitude of the diaphragm activation in people with moderate to severe COPD. Due to lack of a healthy control group or subdivision of COPD patients based on their MIP performance [30] or disease severity [63], it was difficult to explore whether the identified postural contribution of the diaphragm was reduced by pathophysiological processes or not, subsequently explaining the previously observed compromised balance in people with (more severe) COPD [27-31, 63]

However, within this small sample (n = 11), additional exploratory analysis further examined whether the defined postural-related diaphragm activation increased for baseline conditions with higher postural demands such as occluded vision or unstable foam [64]. Unfortunately, the latter could not be confirmed and postural activity caused by UL movements was independent from the support surface and vision condition for all trunk muscles.

In addition, regarding the type of performed UL movement task, single as well as repetitive ballistic UL movements targeted the postural function of the diaphragm in the same way with similar results for magnitude of activity. This is consistent with previously findings in healthy establishing a tonic diaphragm activity, irrespective of the respiration phase, and with an anticipatory activation pattern prior to onset of the peripheral muscle responsible for the postural task (i.e., deltoideus) [36, 65]. Evidence for an anticipatory feedforward mechanism of postural diaphragm activity was also expected in people with COP, but could not be determined since the sequence of trunk muscle EMG activity associated with rapid UL movement was not yet analyzed. Anyway, the magnitude of postural-related changes in EMGdi were linearly related to changes in deltoid EMG activity amplifying a stronger diaphragm activation with more powerful UL movements.

Beyond, subsequent investigations further investigated the postural trunk muscle activity for different UL movement tasks varying in frequency of movement repetitions (single or repetitive ballistic movement) [36, 65], movement direction (flexion-extension and/or abduction-adduction) [7, 66] and breathing mode (normal breathing and breath holding at end-expiration level) [36]. More specifically, in people with COPD, the aforementioned factors are likely to interact with the amount of postural contribution of the diaphragm in to postural control.

6.2.2.1 Type of repetitive UL movement task: influence movement plane

Postural-related modulations in EMG activity of the diaphragm were established for both UL movement tasks in the frontal (abduction – adduction) and sagittal plane (flexion-extension) with tidal breathing (TB). However, for unstable surfaces, a trend was established for more postural activity of diaphragm by repetitive ballistic flexion-extension, which also caused greatest postural disturbances in AP direction. Also, for stable surfaces, only faster and greater AP sway by repetitive flexion-extension was positively and linearly related to the corresponding changes in EMGdi. Both findings postulate a direction-specific postural contraction of the diaphragm in COPD, in line with direction-specific EMG activity of MF.
The latter finding suggests an interesting link between these two deep, stabilizing trunk muscles both showing higher EMG activities accompanied by more postural sway disturbances. Together with contraction of the transversus abdominus muscle, both trunk muscles generate intra-abdominal pressure (IAP) forming a corset around the mid area, which indirectly stabilizes the spine and consequently guards postural balance [6].

In addition, results showed that greatest postural activity of the ES, RA and MF was caused by ballistic UL movements in the sagittal plane, which also primarily challenged AP postural balance. These findings regarding the superficial trunk muscles are consistent with previous findings of excessive ES and RA activity caused by a similar AP directed UL movement task in people with moderate to severe COPD [63]. Moreover, subgrouping of COPD revealed the postural response in RA EMG activity was greater in more severe COPD. In our study, the higher EMG activity of ES and RA was also simultaneously accompanied by faster and greater changes in AP postural sway, identifying increased superficial trunk muscle activity might compromise the ability to recover from postural disturbances.

More specifically, this increased trunk stiffness may be a maladaptive compensation from insufficient postural activity of the diaphragm in COPD. Subgroup comparisons are lacking, but increment in postural activity of the diaphragm for the same executed UL task after 8 weeks of IMT, suggests the defined postural diaphragm activity was diminished at baseline.

6.2.2.2 Type of repetitive UL movement task: influence breathing mode

The diaphragm has a multifunctional role in the human body [8]. Both respiratory- and postural-related muscle activity can occur concurrently, modulating intrathoracic pressures, in association with breathing, and intra-abdominal pressure, in association with postural challenging tasks [7, 65, 67]. Previous research explained the coordinated organization of this dual function by different inputs to phrenic motor units descending from ponto-medullary respiratory centers and non-respiratory supraspinal structures separately [68]. The respiratory activity of the diaphragm is mainly raised from the respiratory centers [69]. With simple balance perturbations caused by single or repetitive UL movement, respiratory-related modulations in EMG activity are still maintained, but superimposed postural-related modulations in diaphragm EMG activity are observed. Moreover, in healthy subjects performing a similar UL movement task, the diaphragm activity contracted throughout breath holding at end-expiration level was found to be greater than the magnitude of diaphragm EMG activity recorded during normal breathing, established in percentage of inspiratory activity at rest [36]. This suggests that postural drive of the diaphragm might be addressed more when the respiratory drive is diminished at the same time.

On the one hand, this proposed hypothesis was not confirmed for people with COPD, since the magnitude of postural diaphragm activity was higher when breathing normally compared to breath-holding at end-expiration level. Though, the increased respiratory demand progressively caused by COPD [20] might induce prioritizing of the respiratory drive over other diaphragm functions to maintain homeostasis. As suggested in Hodges et al. (2001), the postural activity will inevitably be declined by ‘occluding’ the postural inputs to the phrenic motor neurons [70]. This, in combination with the decreased force generating capacity in COPD due to mechanical and physiological changes, might explain less magnitude of diaphragm EMG activity for trials solely addressing the postural function.

In addition, when performing the same task with tidal breathing, a summation of both the postural and high disease-related respiratory drive takes place in COPD, resulting in an overall higher diaphragm EMG activity. Noteworthy, instructions to execute breath-holding at end-expiration level are quite difficult to understand and, consequently, to execute, causing inaccurate trial performances. The latter were excluded for analysis afterwards, whereby the total number of analyzed trials with normal tidal breathing was greater and more likely to show significant effects statistically.

On the other hand, the minor postural-related diaphragm EMG activity recorded during breath holding at end-expiration was still increased compared to the resting inspiratory EMG activity, with a more direction-specific contraction pattern (in favor of flexion-extension). More specifically, a moderate to strong association was still found between these determined changes in diaphragm EMG activity and the postural sway disturbances. The latter amplifies the postural contribution of the diaphragm in to postural control irrespective of the respiratory drive in people with COPD.

6.2.3 The effect of IMT on diaphragm activity and postural balance

In contrast with previous research evaluating the effectiveness of a home-based IMT program in people with COPD [71], our study showed an increase in both MIP and peak diaphragm EMG activity over time, which were also positively and linearly correlated. In comparison with this study, our IMT training program was implemented over a longer period of time. Also, weekly training load was gradually increased to maintain at least 40-50% of the actual MIP achieved during that supervised session, while previous research monitored and encouraged load increment by phone calls and based on predetermined values.

6.2.3.1 The effect of IMT on diaphragm activity and postural balance

Diaphragm activation during a postural task significantly increased over time for all the single UL movement trials, and half of the repetitive UL movement trials. Increased postural diaphragm activity over time was only present in the IMT group, except for trial 9, which showed significantly increased diaphragm activation in both the IMT and sIMT group. Indirectly, it can be concluded that postural diaphragm activity in people with COPD was insufficient at baseline, as it can be modified by following a respiratory-related intervention. However, this increased diaphragm activation during postural tasks did not transfer to a significantly improved static postural balance performance and balance recovery still seems compromised when performing ballistic arm movements. Although significant effects were found in some parameters, for instance the decrease in anterior sway when standing on a foam performing a flexion-extension repetitive movement while breathing normally (trial 9), these findings were not significantly correlated with any of the positive change scores in diaphragm EMG activity for the corresponding task.

However, concerning the basic postural balance in COPD regardless of performed UL movement tasks, more postural sway was found during upright standing on unstable surface. This increased sway is still present over time in the sIMT group, but not in the IMT group. For instance, the range of CoP displacement decreased after IMT when standing on an unstable support surface without vision (trial 8), which was the most difficult condition and showed most disturbance before the intervention. This decrease was not found in the sIMT group.

In addition to the hypothesis that expected an increase in postural diaphragm activity increasing IAP and thereby directly improving postural disturbances by UL movements, an indirect mechanism may be at play. During upright standing on an unstable surface, ankle proprioceptive signals become less reliable. However, people with COPD experienced an increased reliance on proprioceptive signals from ankle musculature, while the reliance on proprioceptive signals from back musculature decreased [30]. Since IMT ameliorates oxygenation in resting and exercising peripheral muscles in COPD [72] and muscles spindles display a dense network of intramuscular blood vessels [73], proprioceptive function of the lumbar muscles spindles may be favored. This may influence the postural strategy variability in people with COPD, making it possible to switch from an ankle-steered to a more multi-segmental proprioceptive strategy when standing on an unstable surface [30]. However, no vibration trials were performed to prove an actual shift in postural strategies after IMT, such as has been proven before in LBP [13].

6.2.3.2 The effect of IMT on functional balance performance

On top of CoP stabilometric values, more functional balance performance assessments were investigated. Improvement in these outcomes (STSTS test, Mini-BESTest and TUG) were expected following IMT. A slightly better performance on the mini-BESTest and STSTS test without vision was found in the IMT group, but no significantly effects were established. However, the STSTS test and Mini-BESTest may present a floor effect and ceiling effect respectively [74, 75], subsequently reducing the validity of the measurement, but has not been directly studied before in COPD. Also, clinically, the treatment resulted in meaningful changes in performance time for STSTS in both groups (> 1,7 seconds)[56]. Tough, the mean change in Mini-BESTest total score seemed not to be clinically meaningful as it did not exceed the MCID values determined for elderly with balance deficits (< 4 points) [76].

Yet, other studies found significant effects of an eight-week IMT program on (functional) balance performance in terms of mini-BESTest [12], Berg Balance Scale [14], Biodex Balance System [15] and stabilometry [13]. A similar IMT training implementation protocol with a total duration of 8-weeks was used in aforementioned studies, so other factors must be found to explain the discrepancy in the results.

However, different effects may be found in different targeted populations. In the previously mentioned studies, the benefit for IMT has thus been proven for healthy older adults [77], chronic stroke patients [14], people with low back pain [13] and children with cystic fibrosis [15], but has never been directly studied before in people with COPD. These studies attributed their significant findings to an increase in generated IAP [77] or similarly, an increased stabilization of the thoracic spine [14], a change in proprioceptive strategy [13] and an increase in MEP and abdominal muscle strength thereby directly improving lumbopelvic stability [15]. However, no (intra-abdominal) EMG measurements for postural diaphragm activity were performed in any of the aforementioned studies, and it can therefore thus not be directly concluded that the identified postural balance improvements are due to an improved function of the diaphragm. The sample size of this study was also too small to have enough statistical power for significant finds, which may explain why other studies with bigger sample sizes did find significant improvements in postural balance.

Further, the IMT intervention program may have to be included in a broader multidimensional intervention to show an improvement on both static and functional balance performances. Lee et al. (2016) included ten minutes of abdominal strengthening exercises next to 20 minutes of IMT, while Zeren et al. (2019) implemented IMT alongside other respiratory training aspects including diaphragmatic breathing exercises, incentive spirometer exercises and thoracic expansion exercises. Abdominal strengthening exercises have been proven to significantly increase postural balance in chronic stroke patients [78, 79]. Breathing exercises have further also shown to positively influence postural balance [80, 81]. Further, an additional positive effect may be achieved by adding stabilization exercises rather than just strengthening exercises. Also, a significant increase in diaphragm thickness has been established for patients with LBP after performing core stability training [82]. This intervention consisted of stabilization exercises including motor control training, while the control group performed regular strengthening exercises of the trunk muscles. Taken together, more focus on stabilization and motor control exercises may thus be granted.

In conclusion, it may thus be that these studies' findings of an improved postural balance after the intervention was mostly due to the additional intervention on top of the IMT, or due to a different population that was investigated, and not solely due to IMT on its own. It should therefore not necessarily directly be concluded that IMT can never work to improve postural balance in patients with COPD, but future research should be done with a bigger sample size and with IMT implemented into a broader intervention program involving both postural and respiratory training of the trunk muscles.

6.3 Strengths and weaknesses

The study design was set up to avoid biases by blinding the participants and the assessor. The participants of the study were randomly assigned to an intervention or control group by someone who was not a part of the trial to avoid allocation and attribution bias. Both groups were homogeneous with no significant differences in baseline characteristics apart from age. The mean GOLD stage was the same in both the IMT group and the sham group. However, the IMT group showed more variety between participants in GOLD stage, with a range of stage zero to stage four between participants. When analyzing results per participant, this must be taken into analysis for the postural-changes observed at baseline and post-intervention.

Further, the participants themselves did not know which group they were assigned to, reducing the risk of demotivation and lack of adherence in the sham-IMT control group. Training adherence and motivation was optimized in both groups by having the participants fill out a daily training diary, tracking their parameters and following their progress. Since the assessor was blinded as to which participant was part of which group, confirmation bias was avoided. Further, all participants were recruited from the same hospital, so not everyone who met the selection criteria was able to enroll, resulting in a selection bias. Only patients with a low to mild progression of COPD were referred for the study, leading to a sampling/inclusion bias and making the investigated population smaller and more specific.

The results found may however be influenced by several weaknesses of the study and have to be interpreted with caution. Regarding the testing procedure, an order effect may for instance be present, due to not randomizing the fourteen postural trials between participants. This means that during the last trial, participants may already be tired of the previous postural tasks, or may have improved balance scores due to a small learning curve.

Preceding the postural trials, the MVC's of several muscle groups were assessed. However, cognitively, it is challenging to maximally contract a specific group of muscles, especially postural muscles. Executing MVC's is also tiring, especially for people with COPD who already have a decreased muscle strength [20]. A large number of motor units are required for executing MVC's and EMG activation may be higher after the contraction due to excitation subsequently [83]. The interpretation of the EMG activity data of the erector spinae may be distorted. The ES is a postural muscle that is active when standing erect [84, 85]. Therefore, the later postural trials may show more erector spinae activation, not due to a sudden increased need for postural balance, but due to fatigue of the erector spinae. EMG quality is influenced by body composition and subcutaneous fat [86]. People with COPD tend to have a higher fat percentage and decreased muscle mass [87], thus EMG activity of the erector spinae, multifidus, rectus abdominus and obliquii muscles must be interpreted with care and may be of subpar quality due to increased fat tissue around the abdomen. To combat this problem, a different data analysis, such as the one used by Baggen et al. (2019) may be of interest [88]. In aforementioned study, EMG activation during trials was normalized to the maximum obtained contraction within that trial, instead of the MCV value.

The included sample size was very small due to the difficult equipment used and the experimental set-up that required long testing visits. The number of chosen participants then further reduced because not all were willing to implant a multipair-esophageal electrode catheter intranasally. Additionally, not every participant completed every trial. Six trials pre-intervention and seven trials post intervention had missing data due incorrect signal processing or due to lack of performance, mostly within the more difficulty postural balance (trial 10,11 and 12).

Based on previous studies [13], it was calculated that fourteen participants would be needed to have enough statistical power to detect significant changes in CoP data, or seventeen participants when taking a drop-out rate of 20% into account. Data of maximum eleven participants was analyzed, thus, a clinically important difference may be present, but the statistical power in this study was not great enough to establish these hypothesized findings. The limited data may also explain the lack of findings regarding the effect of IMT on postural balance.

Statistical analysis was further influenced by the small sample sizes: the majority of the data had no normal distribution. A different statistical model, the Friedman test, had to be used. However, this test has less statistical power than nonparametric tests such as the Wilcoxon signed rank test [89] and interaction and group effects cannot be assessed using the Friedman test. When plotting the data, difference scores were used instead of using 'zone' as a factor. This may lead to information getting lost in the process. `

This study is the first to assess the postural role of the diaphragm in COPD with intra-abdominal electromyography, partially clarifying the underlying mechanism for the increasing postural balance deficits in this vulnerable population. Diaphragm activity is often measured with surface or needle electrodes intercostally. However, gastric and oesophageal pressure and diaphragm intra-abdominal EMG, such as used in this study, are the most efficient ways to measure diaphragm function assessment [47].

Furthermore, the additional use of functional outcome measures regarding postural balance and the analysis of the linear correlation are important for transferal to clinical practice. However, to optimize our clinical findings for future research, materials and data analysis regarding functional balance measures can be improved. For a more accurate data analysis, automatic recognition of the phases of the STSTS test would be beneficial. A promising study [90] has already found that sensors and a force plate could detect the different phases (stand up, seat off, end stand up, start sitting down, seat on and end sitting down) based on sensors on the spine and forces of the chair and feet acting on the force plate. Adding this to a future protocol may lead to more accurate data.

Taken together, results found in this study must thus be interpreted with care. Especially generalizing these results to the rest of the population may be difficult due to the small and specific sample size.

6.4 Implications clinical practice and future

This study confirmed the postural role of the diaphragm in people with COPD for both single and repetitive upper limb movements. Repetitive upper limb movements were associated with a direction-specific activation of the diaphragm that was dependent of the used breathing mode. Since it is proven that people with COPD have mechanical and physiological alterations in the diaphragm [9, 10], transdiaphragmatic force generating capacity and therefor the postural function will be reduced. In addition, the identified higher respiratory demand associated with COPD [20] may also limit the postural drive to the diaphragm. This may be one of the influencing factors for the compromised balance recovery that is observed within this population when postural demand increases [30]. However, healthy control groups or subdivision of COPD was lacking, making it difficult to explore whether the identified postural contribution of the diaphragm was reduced by pathophysiological processes or not. Further disease progression with more symptoms and comorbidities are a greater economic burden for society [2]. Higher GOLD stages are more affected and have a worse postural balance when compared to lower GOLD stages [25]. Therefore, in future research, it may be of interest to sort the groups according to stage of disease progression. Comparing the diaphragm activation during postural challenging tasks between several GOLD stages and possibly healthy controls could provide interesting new findings regarding the influence of the progression of the disease on postural diaphragm activity and postural balance.

Further, this study confirmed postural diaphragm function is modifiable with a respiratory-related intervention, IMT, whereof the pulmonary benefits are already confirmed. However, evidence for improvements in balance recovery is lacking. IMT can be a promising tool for future rehabilitation in people with COPD. It is a cheap and easy instrument that can lower the economic burden of the disease by modifying disease-related changes in diaphragm function, positively influencing both respiration and postural balance. To maximize the effectiveness of IMT on postural diaphragm activity and subsequently postural balance in COPD, more quality research and adapted training modalities for IMT may be necessary.

In this study, a very small sample size was investigated. Future research should include a bigger sample size to have enough statistical power to find significant differences. The intervention program may also have to be increased over time and a follow-up period should be included. Even though eight-week IMT intervention programs have proven to be beneficial for postural balance in other populations [12-15], people with COPD may require a longer intervention period to show significant improvements in postural balance. Further, in this study, IMT strength training was compared with an active placebo group. However, comparing IMT strength training with IMT endurance training could be of interest to show which training modality is superior. Additionally, implementing IMT in a broader multi-modal intervention program with both respiratory and postural training of the trunk muscles may be of interest, as it has proven to show significant improvements in the past [14, 15] Thus, more research on IMT should be performed before it can be fully carried out into clinical practice. However, results are promising and implementation into clinical practice may happen in the near future.

7. Conclusion

This study identified the role of the of the diaphragm in response from postural perturbations by showing an increment in direction-specific postural contraction depending on the breathing mode. Inspiratory muscle strength training positively influenced the identified postural diaphragm activity, but the transfer to postural balance improvements was lacking. Further, more quality research is warranted to further investigate these findings and the association with other trunk muscles activity, postural recovery and risk of falls.

8. References

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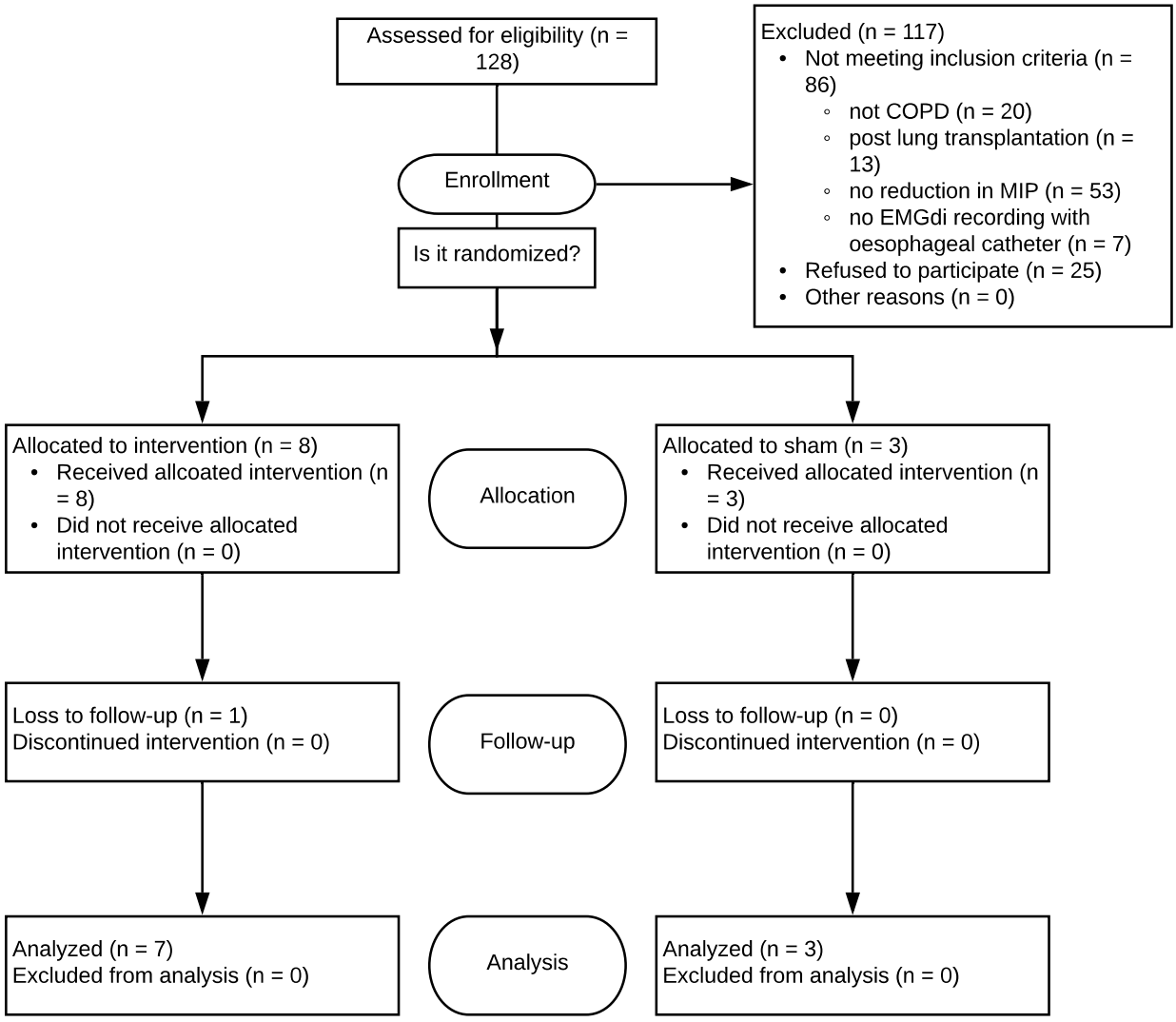
9. Appendix



Appendix 1 PRISMA Flow diagram showing participant pathways through the study.

Appendix 2 - Baseline and change scores of CoP coordinates for single UL movement by support surface and vision

TASK PHASE - BASELINE				RECOVERY PHASE – BASELINE			
Outcome	**Baseline** **Change score**	**Surface STABLE**	**Surface FOAM**	**Outcome**	**Baseline** **Change score**	**Surface STABLE**	**Surface FOAM**
COPmax AP (cm) *Mean ± SD*	**VISION**	9.79 ± 3.06 **8.84 ± 10.69**	24.96 ± 13.43 2.97 ± 14.05	COPmax AP (cm) *Mean ± SD*	**VISION**	9.79 ± 3.06 **9.59 ± 11.72**	24.96 ± 13.43 **8.43 ± 17.67**
	NO VISION	16.02 ± 3.06 **5.41 ± 7.76**	33.94 ± 14.35 2.55 ± 16.77		**NO VISION**	9.79 ± 3.06 **8.60 ± 11.74**	24.96 ± 13.43 **9.61 ± 14.84**
COPmax ML (cm) *Mean ± SD*	**VISION**	7.58 ± 4.61 4.04 ± 9.33	21.89 ± 11.19 **-12.48 ± 7.77**	COPmax ML (cm) *Mean ± SD*	**VISION**	7.58 ± 4.61 5.75 ± 10.72	21.89 ± 11.19 4.44 ± 23.72
	NO VISION	8.71 ± 6.23 3.25 ± 6.07	26.95 ± 9.53 **-8.71 ± 14.62**		**NO VISION**	8.71 ± 6.23 3.55 ± 9.39	26.95 ± 9.53 2.72 ± 7.88
COPmin AP (cm) *Mean ± SD*	**VISION**	-10.62 ± 3.34 -6.31 ± 12.69	-21.86 ± 8.03 -6.13 ± 12.80	COPmin AP (cm) *Mean ± SD*	**VISION**	-10.62 ± 3.34 **-9.84 ± 8.01**	-21.86 ± 8.03 **-7.49 ± 11.21**
	NO VISION	-14.57 ± 6.73 **-13.81 ± 13.94**	-28.04 ± 10.55 **-9.73 ± 6.25**		**NO VISION**	-14.57 ± 6.73 **-6.97 ± 8.74**	-28.04 ± 10.55 **-9.98 ± 14.23**
COPmin ML (cm) *Mean ± SD*	**VISION**	-7.11 ± 3.87 -3.22 ± 6.63	-19.93 ± 8.68 **9.73 ± 7.40**	COPmin ML (cm) *Mean ± SD*	**VISION**	-7.11 ± 3.87 -2.57 ± 8.97	-19.93 ± 8.68 -7.20 ± 16.66
	NO VISION	-8.64 ± 3.94 -2.54 ± 7.01	-24.63 ± 6.99 3.42 ± 12.97		**NO VISION**	-8.64 ± 3.94 **-2.62 ± 4.12**	-24.63 ± 6.99 -5.80 ± 13.33

COPrange (cm) *Mean ± SD*	**VISION**	14.70 ± 7.16 **7.26 ± 14.02**	41.83 ± 18.38 **-22.22 ± 13.14**	COPrange (cm) *Mean ± SD*	**VISION**	14.70 ± 7.16 **9.95 ± 10.69**	41.83 ± 18.38 **9.53 ± 17.78**
	NO VISION	17.36 ± 9.45 5.80 ± 11.86	51.59 ± 15.01 -12.14 ± 14.91		**NO VISION**	17.36 ± 9.45 **6.17 ± 12.49**	51.59 ± 15.01 **11.65 ± 39.89**
COPmaxvel AP (cm/s) *Mean ± SD*	**VISION**	74.73 ± 31.71 **131.21 ± 158.09**	180.52 ± 116.68 **145.49 ± 194.16**	COPmaxvel AP (cm/s) *Mean ± SD*	**VISION**	74.73 ± 31.71 **78.51 ± 59.55**	180.52 ± 116.68 70.41 ± 134.01
	NO VISION	182.40 ± 151.08 **118.40 ± 216.40**	217.22 ± 158.70 **209.55 ± 140.48**		**NO VISION**	182.40 ± 151.08 9.25 ± 121.49	217.22 ± 158.70 **127.51 ± 125.65**
COPmaxvel ML (cm/s) *Mean ± SD*	**VISION**	50.56 ± 20.23 **87.22 ± 115.66**	119.99 ± 59.75 21.03 ± 100.71	COPmaxvel ML (cm/s) *Mean ± SD*	**VISION**	50.56 ± 20.23 **36.48 ± 20.74**	119.99 ± 59.75 43.79 ± 152.19
	NO VISION	109.27 ± 93.65 52.07 ± 171.92	135.86 ± 48.71 **43.03 ± 74.06**		**NO VISION**	109.27 ± 93.65 -3.03 ± 90.41	135.86 ± 48.71 **67.93 ± 84.37**
COPmeanvel AP (cm/s) *Mean ± SD*	**VISION**	16.65 ± 8.00 **46.09 ± 44.15**	33.55 ± 19.70 **87.96 ± 74.83**	COPmeanvel AP (cm/s) *Mean ± SD*	**VISION**	16.65 ± 8 **3.69 ± 3.48**	33.55 ± 19.70 1.16 ± 11.94
	NO VISION	47.34 ± 49.32 **86.79 ± 45.72**	39.28 ± 22.31 **97.39 ± 42.12**		**NO VISION**	20.17 ± 29.32 **10.29 ± 12.94**	42.18 ± 22.31 **14.61 ± 13.59**
COPmeanvel ML (cm/s) *Mean ± SD*	**VISION**	10.42 ± 3.47 **27.98 ± 24.09**	22.86 ± 10.49 **19.01 ± 20.90**	COPmeanvel ML (cm/s) *Mean ± SD*	**VISION**	10.42 ± 3.47 2.84 ± 3.63	22.86 ± 10.49 0.02 ± 7.41
	NO VISION	30.45 ± 30.17 12.07 ± 37.56	29.84 ± 12.03 **34.14 ± 20.45**		**NO VISION**	30.45 ± 30.17 -9.36 ± 23.48	29.84 ± 12.03 3.45 ± 15.56

COPnorm sway AP (cm^2/s)	**VISION**	16.65 ± 8.00	33.55 ± 19.70	COPnorm sway AP (cm^2/s)	**VISION**	16.65 ± 8	33.55 ± 19.70
		46.09 ± 44.15	**87.96 ± 74.83**			**3.69 ± 3.48**	1.16 ± 11.94
Mean ± SD	**NO VISION**	47.34 ± 49.32	39.28 ± 22.31	*Mean ± SD*	**NO VISION**	20.17 ± 29.32	42.18 ± 22.31
		86.79 ± 45.72	**97.39 ± 42.12**			**10.29 ± 12.94**	**14.61 ± 13.59**
COPnorm sway ML (cm^2/s)	**VISION**	10.42 ± 3.47	22.86 ± 10.49	COPnorm sway ML (cm^2/s)	**VISION**	10.42 ± 3.47	22.86 ± 10.49
		27.98 ± 24.09	**19.01 ± 20.90**			2.84 ± 3.63	0.02 ± 7.41
Mean ± SD	**NO VISION**	30.45 ± 30.17	29.84 ± 12.03	*Mean ± SD*	**NO VISION**	30.45 ± 30.17	29.84 ± 12.03
		12.07 ± 37.56	**34.14 ± 20.45**			-9.36 ± 23.48	3.45 ± 15.56
COPrms AP (cm)	**VISION**	4.02 ± 1.14	8.88 ± 3.88	COPrms AP (cm)	**VISION**	4.02 ± 1.14	8.88 ± 3.88
		5.49 ± 6.36	**8.14 ± 7.68**			**1.56 ± 1.09**	1.67 ± 3.67
Mean ± SD	**NO VISION**	5.99 ± 2.73	11.90 ± 3.52	*Mean ± SD*	**NO VISION**	5.99 ± 2.73	11.90 ± 3.52
		8.15 ± 4.68	**8.54 ± 4.81**			**1.45 ± 2.53**	1.94 ± 4.68
COPrms ML (cm)	**VISION**	2.91 ± 1.35	7.91 ± 3.07	COPrms ML (cm)	**VISION**	2.91 ± 1.35	7.91 ± 3.07
		3.09 ± 3.87	**-1.84 ± 2.84**			**1.18 ± 1.69**	2.19 ± 6.24
Mean ± SD	**NO VISION**	3.37 ± 2.05	10.46 ± 3.16	*Mean ± SD*	**NO VISION**	3.37 ± 2.05	10.46 ± 3.16
		3.04 ± 2.84	1.37 ± 9.10			0.60 ± 2.13	1.09 ± 3.64
COPstd AP (cm)	**VISION**	4.02 ± 1.14	8.88 ± 3.88	COPstd AP (cm)	**VISION**	4.02 ± 1.14	8.88 ± 3.88
		5.49 ± 6.36	**8.15 ± 7.68**			**1.56 ± 1.09**	1.67 ± 3.67
Mean ± SD	**NO VISION**	5.99 ± 2.73	11.90 ± 3.52	*Mean ± SD*	**NO VISION**	5.99 ± 2.73	11.90 ± 3.52
		8.16 ± 4.69	**8.55 ± 4.81**			**1.45 ± 2.53**	1.94 ± 4.68

	VISION	2.91 ± 1.35	7.91 ± 3.07		**VISION**	2.91 ± 1.35	7.91 ± 3.07
COPstd ML (cm)		**3.09 ± 3.87**	**-1.84 ± 2.84**	COPstd ML (cm)		**1.18 ± 1.69**	2.19 ± 6.24
Mean ± SD	**NO VISION**	3.37 ± 2.05	10.46 ± 3.16	*Mean ± SD*	**NO VISION**	3.37 ± 2.05	10.46 ± 3.16
		3.044 ± 2.85	1.37 ± 9.10			0.60 ± 2.13	1.09 ± 3.64
	VISION	118.93 (63.50-225.25)	844.94 (312.04-1770.84)		**VISION**	118.93 (63.50-225.25)	844.94 (312.04-1770.84)
Sway area (cm^2)		**386.51 (114.34-1253.07)**	**-306.99 (-677.15- -66.73)**	Sway area(cm^2)		**161.22 (66.64-649.08)**	327.81 (-231.77-1212.8)
Median (Q1-Q3)	**NO VISION**	194.19 (84.16-373.88)	1293.93 (861.21-2085.7)	*Median (Q1-Q3)*	**NO VISION**	194.19 (84.16-373.88)	1293.93 (861.21-2085.7)
		391.03 (181.01-592.94)	579.68 (-160.63-5788.98)			**270.86 (46.91-308.45)**	-16.69 (-156.67-1735.6)
	VISION	244.20 (198.91-352.45)	583.44 (426.19-774.16)		**VISION**	244.20 (198.91-352.45)	583.44 (426.19-774.16)
Sway path AP (cm)		**-170 (-294.83- -123.96)**	**-382.91 (-593.62- -311.4)**	Sway path AP(cm)		**77.65 (17.67-134.01)**	-19.32 (-117.35-211.40)
Median (Q1-Q3)	**NO VISION**	403.100 (291.11-1140.55)	714.14 (547.90-1025.69)	*Median (Q1-Q3)*	**NO VISION**	403.100 (291.11-1140.55)	714.14 (477.80)
		-358.61 (-973.26- -141.6)	**-520.27 (-792.20- -424.17)**			-31.92 (-477.28-184.56)	32.01 (-129.93-462.96)
	VISION	170.26 (149.49-200.16)	406.39 (288.59-516.34)		**VISION**	170.26 (149.49-200.16)	406.39 (288.59-516.34)
Sway path ML (cm)		**-122.27 (-138.74- -110.4)**	**-388.90 (-540.69- -258.57)**	Sway path ML (cm)		**60.19 (17.50-90.02)**	4.66 (-75.31-92.38)
Median (Q1-Q3)	**NO VISION**	301.29 (164.43-1105.34)	505.93 (344.83-682.40)	*Median (Q1-Q3)*	**NO VISION**	301.29 (164.43-1105.34)	505.93 (344.83-682.40)
		-213.87 (-1072.83- -121)	**-434.15 (-537.15- -316.60)**			-11.57 (-410.35-42.08)	-29.71 (-96.23-174.54)
	VISION	303.71 (254.62-403.19)	711.03 (515.09-922.89)		**VISION**	303.71 (254.62-403.19)	711.03 (515.09-922.89)
Sway path total (cm)		**-193.85 (-272.59- -154.5)**	**-584.48 (-779.94- -470.54)**	Sway path total(cm)		**103.34 (32.27-148.04)**	-55.36 (-106.90-179.03)
Median (Q1-Q3)	**NO VISION**	741.16 (346.34-1522.15)	906.90 (655.78-1250.06)	*Median (Q1-Q3)*	**NO VISION**	741.16 (346.34-1522.15)	906.90 (655.78-1250.06)
		-653.42 (-1424.67- -181)	**-697.66 (-971.64- -518.09)**			-57.00 (-810.88-181.03)	60.99 (-163.66-498.68)

*Significant different from baseline phase **in bold** (p<0,05)*
COP = centre of pressure, AP= anterior-posterior, ML= medio-lateral, maxvel= maximum velocity, meanvel= mean velocity, normsway= time-normalized sway pat, rms= root mean square, std= standard deviation, swaypath= total sway path, COP max AP= backward displacement, COP min AP= forward displacement, COP max ML= right displacement, COP min ML= left displacement, cm = centimeter, s = seconds
Values are presented as mean ± standard deviation (SD) or as median (Quartile 1 – Quartile 3)

Appendix 3 - Baseline and change scores of CoP coordinates for repetitive UL movement by support surface. movement direction and breathing condition

UL MOVEMENT PHASE - BASELINE					
Outcome	**Baseline / Change score**	**Surface STABLE**		**Surface FOAM**	
		FLEXION - EXTENSTION	**ABDUCTION - ADDUCTION**	**FLEXION - EXTENSION**	**ABDUCTION - ADDUCTION**
COPmax AP (cm) *Mean ± SD*	**NORMAL**	14.02 ± 6.37	11.70 ± 4.56	24.96 ± 9.65	27.98 ± 14.51
		12.30 ± 8.61	**5.91 ± 3.95**	**25.07 ± 11.99**	**8.96 ± 8.80**
	END-EXPIRATION	14.64 ± 8.45	11.75 ± 5.04	32.55 ± 10.02	28.33 ± 8.58
		12.08 ± 11.32	**6.59 ± 5.37**	**13.82 ± 17.23**	**9.48 ± 7.78**
COPmax ML (cm) *Mean ± SD*	**NORMAL**	6.71 ± 3.81	7.90 ± 3.67	23.76 ± 12.34	22.55 ± 10.12
		13.34 ± 6.23	**12.99 ± 6.34**	**17.00 ± 8.99**	**14.62 ± 8.51**
	END-EXPIRATION	10.29 ± 9.15	6.68 ± 3.15	23.70±5.65	22.37 ± 6.14
		11.67 ± 10.78	**13.08 ± 4.96**	**16.52±14.13**	**9.63 ± 8.15**
COPmin AP (cm) *Mean ± SD*	**NORMAL**	-11.91 ± 6.24	-11.04 ± 4.11	-25.15 ± 7.08	-27.47 ± 8.46
		-21.19 ± 9.32	**-11.36 ± 4.54**	**-27.88 ± 9.97**	**-14.84 ± 9.36**
	END-EXPIRATION	-15.21 ± 5.97	-11.76 ± 6.03	-28.36 ± 10.26	-31.65 ± 14.49
		-20.61 ± 11.21	**-5.23 ± 3.03**	**-10.39 ± 8.38**	**-7.40 ± 10.05**
COPmin ML (cm) *Mean ± SD*	**NORMAL**	-6.86 ± 3.30	-7.71 ± 4.61	-20.01±13.11	-20.84 ± 9.59
		-10.69 ± 3.69	**-13.41 ± 6.60**	**-16.11 ± 13.53**	**-13.48 ± 9.12**
	END-EXPIRATION	-8.31 ± 4.19	-6.45 ± 3.12	-22.71 ± 5.71	-20.57±8.29
		-12.19 ± 5.89	**-13.87 ± 5.53**	**-15.23 ± 11.27**	**-13.36±7.29**
COPrange (cm) *Mean ± SD*	**NORMAL**	13.58 ± 7.04	15.62 ± 8.12	43.78 ± 25.18	43.39 ± 18.79
		24.04 ± 8.83	**26.41 ± 12.37**	**33.12 ± 21.90**	**28.11 ± 15.45**
	END-EXPIRATION	18.61 ± 11.44	13.14 ± 6.11	46.42 ± 11.05	42.94 ± 13.06
		23.87 ± 14.31	**26.96 ± 9.90**	**22.21 ± 16.85**	**23 ± 13.87**

COPmaxvel AP (cm/s)	**NORMAL**	115.10 ± 76.30	96.20 ± 46.25	161.66 ± 39.55	200.01 ± 83.76
		292.29 ± 139.67	**157.36 ± 78.69**	**338.40 ± 148.58**	**192.18 ± 136.80**
Mean ± SD	**END-EXPIRATION**	144.98 ± 106.76	80.87 ± 43.18	191.71 ± 60.80	191.97 ± 58.72
		367.47 ± 197.49	**119.95 ± 96**	**301.63 ± 61.76**	**103.36 ± 122.94**
COPmaxvel ML (cm/s)	**NORMAL**	67.65 ± 21.76	70.69 ± 44.05	110.73 ± 61.07	111.09 ± 40.53
		111.40 ± 81.22	**135.63 ± 87.09**	**143.79 ± 84.55**	**135.52 ± 94.76**
Mean ± SD	**END-EXPIRATION**	86.87 ± 57.96	52.18 ± 28.55	111.82 ± 33.18	108.64 ± 31.75
		109.69 ± 100.69	**135.96 ± 81.43**	**157.33 ± 127.19**	**123.30 ± 73.22**
COPmeanvel AP (cm/s)	**NORMAL**	21.71 (16.62-38.11)	19.31 (13.23-27.92)	34.44 (31.25-53.79)	38.05 (32.46-65.98)
		72.76 (57.93-110.33)	**39.75 (28.06-53.91)**	**94.42 (83.60-130.27)**	**47.97 (32.83-67.78)**
Median (Q1-Q3)	**END-EXPIRATION**	19.50 (14.56-59.35)	14.56 (11.51-24.75)	44.95 (31.43-51.75)	41.61 (27.47-43.20)
		85.47 (48.00-112.52)	**32.35 (29.10-50.44)**	**83.77 (62.88-140.28)**	**37.13 (31.85-57.46)**
COPmeanvel ML (cm/s)	**NORMAL**	16.07 (12.67-17.58)	12.47 (9.08-21.70)	18.85 (15.87-29.55)	21.85 (19.62-31.65)
		22.01 (13.94-27.90)	**37.53 (20.03-63.95)**	**31.47 (21.12-45.23)**	**43.20 (15.11-52.19)**
Median (Q1-Q3)	**END-EXPIRATION**	13.81 (9.16-28.08)	11.60 (7.69-19.52)	23.36 (17.43-28.51)	20.49 (19.42-24.66)
		24.70 (17.45-42.17)	**34.91 (25.83-42.89)**	**52.91 (15.06-55.44)**	**-20.48 (-24.66- -19.42)**
COP norm sway AP (cm^2/s)	**NORMAL**	21.71 (16.62-38.11)	19.31 (13.23-27.92)	34.44 (31.25-53.79)	38.05 (32.46-65.98)
		72.76 (57.93-110.33)	**39.75 (28.06-53.91)**	**94.42 (83.60-130.27)**	**47.97 (32.83-67.88)**
Median (Q1-Q3)	**END-EXPIRATION**	19.50 (14.56-59.35)	14.56 (11.51-24.75)	44.95 (31.43-51.75)	41.61 (27.47-43.20)
		85.47 (48.46-112.52)	**32.35 (29.10-50.44)**	**83.77 (62.88-140.28)**	**37.13 (31.85-57.46)**
COP norm sway ML (cm^2/s)	**NORMAL**	16.07 (12.67-17.58)	12.47 (9.08-21.70)	18.85 (15.87-29.55)	21.85 (19.62-31.65)
		22.01 (13.94-27.90)	**37.53 (20.03-63.95)**	**31.47 (21.12-45.23)**	**43.21 (15.11-52.19)**
Median (Q1-Q3)	**END-EXPIRATION**	13.81 (9.16-28.08)	11.60 (7.69-19.52)	23.36 (17.43-28.51)	20.49 (19.42-24.66)
		24.70 (17.45-42.17)	**34.91 (25.83-42.89)**	**52.91 (15.60-55.44)**	**20.48 (-24.66 - -19.42)**

COP rms AP (cm)	**NORMAL**	4.98 ± 1.96	4.62 ± 1.46	10.97 ± 3.54	12.07 ± 4.54
		8.68 ± 4.03	**4.91 ± 2.13**	**11.66 ± 4.79**	**5.04 ± 2.21**
Mean ± SD	**END-EXPIRATION**	5.51 ± 2.45	4.52 ± 1.70	13.55 ± 4.50	11.82 ± 4.36
		8.88 ± 4.12	**4.77 ± 2.22**	**7.55 ± 6.32**	**4.78 ± 3.61**
COP rms ML (cm)	**NORMAL**	2.68 ± 1.37	3.24 ± 1.74	9.69 ± 5.01	9.30 ± 4.30
		5.15 ± 1.85	**5.35 ± 2.51**	**6.51 ± 3.31**	**5.67 ± 4.19**
Mean ± SD	**END-EXPIRATION**	3.37 ± 1.95	2.82 ± 1.58	10.20 ± 3.51	9.30 ± 3.35
		5.27 ± 2.48	**5.55 ± 2.20**	**6.65 ± 3.98**	**4.57 ± 2.03**
COP std AP (cm)	**NORMAL**	4.98 ± 1.96	4.62 ± 1.46	10.97 ± 3.54	12.07 ± 4.55
		8.68 ± 4.03	**4.91 ± 2.13**	**11.66 ± 4.79**	**5.04 ± 2.21**
Mean ± SD	**END-EXPIRATION**	5.50 ± 2.45	4.52 ± 1.70	13.55 ± 4.50	11.82 ± 4.36
		8.88 ± 4.12	**4.77 ± 2.22**	**7.55 ± 6.32**	**4.78 ± 3.62**
COP std ML (cm)	**NORMAL**	2.68 ± 1.37	3.24 ± 1.74	9.69 ± 5.01	9.30 ± 4.30
		5.15 ± 1.85	**5.35 ± 2.51**	**6.51 ± 3.31**	**5.67 ± 4.19**
Mean ± SD	**END-EXPIRATION**	3.37 ± 1.95	2.82 ± 1.58	10.21 ± 3.51	9.30 ± 3.35
		5.45 ± 2.60	**5.55 ± 2.20**	**6.65 ± 3.98**	**4.57 ± 2.03**
COP sway path AP (cm)	**NORMAL**	298.17 (194.19-527.83)	264.70 (188.17-418.35)	440.12 (404.66-746.20)	467.66 (380.80-886.27)
		609.27 (432.90-745.39)	**194.15 (121.24-334.46)**	**719.97 (668.87-869.01)**	**303.63 (65.63-575.89)**
Median (Q1-Q3)	**END-EXPIRATION**	291.84 (217.45-828.41)	168.65 (173.22-338.88)	476.11 (428.75-662.47)	631.44 (357.40-660.08)
		583 (35.85-880.91)	**232.56 (182.44-326.06)**	**617.70 (452.87-1029.83)**	**140.43 (81.08-239.89)**
COP sway path M (cm)	**NORMAL**	230.35 (187.49-259.04)	186.89 (128.30-268.11)	236.44 (185.45-316.59)	308.14 (246.58-421.23)
		151.10 (42.43-211.75)	**251.62 (103.08-459.95)**	**236.37 (134.74-307.88)**	**297.17 (97.7-365.61)**
Median (Q1-Q3)	**END-EXPIRATION**	206.82 (137.51-394.31)	168.31 (115.39-263.74)	256.94 (238.88-350.53)	345.38 (260.21-362.26)
		133.31 (14.13-279.99)	**273.35 (147.27-318.12)**	**336.83 (125.08-386.02)**	**159.50 (82.88-252.83)**

COP sway path total (cm) *Median (Q1-Q3)*	**NORMAL**	370.01 (301.28-561.08)	311.96 (214.26-562.96)	508.33 (475.25-785.09)	581.08 (459.99-919.93)
		620.16 (432.07-718.33)	**319.61 (196.44-615.34)**	**746.33 (705.57-809.34)**	**311.92 (109.71-680.46)**
	END-EXPIRATION	369.71 (284.95-976.05)	248.57 (199.55-520.26)	560.66 (496.35-710.55)	698.17 (401.74-788.55)
		561.70 (46.28-958.29)	**356.13 (246.80-423.40)**	**624.66 (463.30-1152.58)**	**200.02 (145.59-347.70)**
Sway area (cm^2) *Mean ± SD*	**NORMAL**	125.12 ± 63.07	140.59 ± 79.19	1265.23 ± 1058.45	1348.77 ± 1016.95
		1130.45 ± 650.13	**798.30 ± 473.66**	**3084.07 ± 1352.82**	**875.63 ± 676.38**
	END-EXPIRATION	188.85 ± 314.70	104.83 ± 56.22	1499.56 ± 967.53	1056.95 ± 777.98
		1186.62 ± 772.76	**764.94 ± 406.64**	**2580.61 ± 1631.86**	**1395.29 ± 784.25**

*Significant different from baseline phase **in bold** (p<0,05)*
COP = centre of pressure, AP= anterior-posterior, ML= medio-lateral, maxvel= maximum velocity, meanvel= mean velocity, normsway= time-normalized sway pat, rms= root mean square, std= standard deviation, swaypath= total sway path, COP max AP= backward displacement, COP min AP= forward displacement, COP max ML= right displacement, COP min ML= left displacement, cm = centimeter, s = seconds
Values are presented as mean ± standard deviation (SD) or as median (Quartile 1 – Quartile 3)

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KNOWLEDGE IN ACTION

INVENTARISATIEFORMULIER WETENSCHAPPELIJKE STAGE DEEL 2

DATUM	INHOUD OVERLEG	HANDTEKENINGEN
08/10/2019	Overleg MP2	Promotor: Copromotor/Begeleider: Student(e): Student(e):
14/11/2019	Data analyse overleg Spike2	Promotor: Copromotor/Begeleider: Student(e): Student(e):
21/01/2020	Toelichting ECG filter + overleg exploratieve dataverwerking	Promotor: Copromotor/Begeleider: Student(e): Student(e):
27/02/2020	Dataverwerking + uitleg MatLab	Promotor: Copromotor/Begeleider: Student(e): Student(e):
02/03/2020 Dra. Amerijckx Charlotte	Feedback: resultaten secundaire uitkomstmaten	Promotor: Copromotor/Begeleider: Student(e): Student(e):
16/03/2020	ECG filter: Dr. Marc Geraerts	Promotor: Copromotor/Begeleider: Student(e): Student(e):
27/03/2020	EMG data: Skype meeting Dr. Marc Geraerts	Promotor: Copromotor/Begeleider: Student(e): Student(e):
02/04/2020	Feedback: suggestie statistische analyse	Promotor: Copromotor/Begeleider: Student(e): Student(e):
07/05/2020 - 15/05/2020	Feedback Dr. Nina Goossens: statische verwerking + data analyse via e-mail communicatie + 1 Skype gesprek	Promotor: Copromotor/Begeleider: Student(e): Student(e):
20/05/2020	Feedback: finale versie	Promotor: Copromotor/Begeleider:

		Student(e): Student(e):

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

Naam Student(e): ……
Datum:…….....

Titel Masterproef:
……

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

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

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

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

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

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

Verklaring op Eer

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

1. Ik ben ingeschreven als student aan de UHasselt in de opleiding Revalidatiewetenschappen & kinesitherapie, waarbij ik de kans krijg om in het kader van mijn opleiding mee te werken aan onderzoek van de faculteit Revalidatiewetenschappen aan de UHasselt. Dit onderzoek wordt beleid door Prof. Dr. Janssens Lotte en kadert binnen het opleidingsonderdeel masterproef deel 2. Ik zal in het kader van dit onderzoek creaties, schetsen, ontwerpen, prototypes en/of onderzoeksresultaten tot stand brengen in het domein van de musculoskeletale revalidatie. (hierna: "De Onderzoeksresultaten").

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

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

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

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

6. In zoverre De Onderzoeksresultaten auteursrechtelijk beschermd zijn, omvat bovenstaande overdracht onder meer de volgende exploitatiewijzen, en dit steeds voor de hele beschermingsduur, voor de gehele wereld en zonder vergoeding:

   - het recht om De Onderzoeksresultaten vast te (laten) leggen door alle technieken en op alle dragers;
   - het recht om De Onderzoeksresultaten geheel of gedeeltelijk te (laten) reproduceren, openbaar te (laten) maken, uit te (laten) geven, te (laten) exploiteren en te (laten) verspreiden in eender welke vorm, in een onbeperkt aantal exemplaren;

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

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

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

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

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

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,

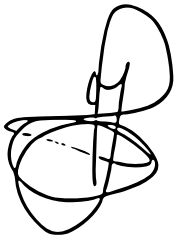
Naam: Jacobs Nina

Adres: Eikenenpad 37 3520 Zonhoven

Geboortedatum en –plaats : 05/08/1997 te Hasselt

Datum: 25/05/2020

Handtekening:



Verklaring op Eer

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

1. Ik ben ingeschreven als student aan de UHasselt in de opleiding MSK - sport, Revalidatiewetenschappen en kinesitherapie, waarbij ik de kans krijg om in het kader van mijn opleiding mee te werken aan onderzoek van de faculteit Revalidatiewetenschappen en kinesitherapie aan de UHasselt. Dit onderzoek wordt beleid door Prof. Dr. Lotte Janssens en kadert binnen het opleidingsonderdeel musculoskeletale revalidatie. Ik zal in het kader van dit onderzoek creaties, schetsen, ontwerpen, prototypes en/of onderzoeksresultaten tot stand brengen in het domein van musculoskeletale revalidatie (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").

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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.

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[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 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;
- 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;
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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.

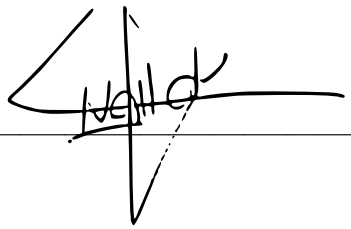
Gelezen voor akkoord en goedgekeurd,

Naam: Chloé Hollander

Adres: Heiveld 45, 3980 Tessenderlo

Geboortedatum en –plaats : 13/07/1997, Halle

Datum: 25/05/2020

Handtekening: 

AFSPRAKENNOTA

1. Organisatie

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

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

Naam	… Lotte Janssens
Functie	… Professor
Tel. - GSM	… +3211 292 174

2. De vrijwilliger: student-onderzoeker

Naam	… Nina Jacobs, Chloé Hollander
Correspondentieadres	… Eikenenpad 37, 3520 Zonhoven / Heiveld 45, 3980 Tessenderlo
Tel. - GSM	… 0497 39 45 09 / 0470 39 50 40

3. Verzekeringen

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

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

4. Vergoedingen

De organisatie betaalt geen vergoeding aan de vrijwilliger.

5. Aansprakelijkheid

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

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

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

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

6. Geheimhoudingsplicht – verwerking persoonsgegevens

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

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

7. Concrete afspraken

Functie van de vrijwilliger

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

De vrijwilliger zal deze taak op volgende tijdstippen uitvoeren:

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

Begeleiding

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

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

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

Certificaat

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

8. Einde van het vrijwilligerswerk.

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

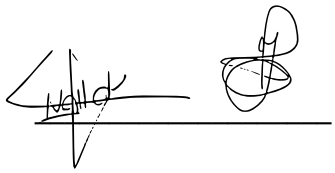
- bij onderlinge overeenstemming;
- op vraag van de vrijwilliger zelf;
- op verzoek van de organisatie.

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

Datum: ..28/05/2020

Naam en Handtekening decaan

Naam en Handtekening vrijwilliger



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

Bijlage 1

Reglement betreffende het statuut van student-onderzoeker[1]

Artikel 1. Definities

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

Artikel 2. Toepassingsgebied

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

Artikel 3. Selectie en administratieve opvolging

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

Artikel 4. Preventieve maatregelen en verzekeringen

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

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

Artikel 5. Vergoeding van geleverde prestaties

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

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

Artikel 6. Dienstverplaatsingen

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

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

Artikel 7. Afsprakennota

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

Artikel 8. Certificaat

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

Artikel 9. Geheimhoudingsplicht

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

Artikel 10. Intellectuele eigendomsrechten

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

Artikel 11. Geschillenregeling

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

Artikel 12. Inwerkingtreding

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

COVID-19 Addendum - Masterproef 2

Gelieve dit document in te laten vullen door de promotor en ingevuld toe te voegen aan je masterproef.

Naam promotor(en) ……Prof. Lotte Janssens, Dr. Nina Goossens, Dra. Charlotte Amerijckx ……...

Naam studenten ……Nina Jacobs & Chloé Hollander…….
……...

1) Duid aan welk type scenario is gekozen voor deze masterproef:

☐ scenario 1: masterproef bestaat uit een meta-analyse - masterproef liep door zoals voorzien
☒ scenario 2: masterproef bestaat uit een experiment - masterproef liep door zoals voorzien
☐ scenario 3: masterproef bestaat uit een experiment - maar een deel van de voorziene data is verzameld
    ☐ 3A: er is voldoende data, maar met aangepaste statische procedures verder gewerkt
    ☐ 3B: er is onvoldoende data, dus gewerkt met een descriptieve analyse van de aanwezige data
☐ scenario 4: masterproef bestaat uit een experiment - maar er kon geen data verzameld worden
    ☐ 4A: er is gewerkt met reeds beschikbare data
    ☐ 4B: er is gewerkt met fictieve data

2) Geef aan in hoeverre de student(e) onderstaande competenties zelfstandig uitvoerde:

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

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

Datum

20/5/2020

UHASSELT

Nina Jacobs <nina.jacobs@student.uhasselt.be>

Inschrijvingsformulier MP2

2 berichten

Lotte JANSSENS <lotte.janssens@uhasselt.be> 19 mei 2020 om 14:41
Aan: Jorn Claes <jorn.claes@student.uhasselt.be>, Sebastiaan Gijbels <sebastiaan.gijbels@student.uhasselt.be>, Nina Jacobs <nina.jacobs@student.uhasselt.be>, Chloé Hollander <chloe.hollander@student.uhasselt.be>
Cc: Nina GOOSSENS <nina.goossens@uhasselt.be>

Beste studenten,

Van de coördinatoren van de MP2 kregen we door dat ik jullie als promotor geen handtekening moet bezorgen op het inschrijvings- en voortgangsformulier, maar dat een email reply in deze omstandigheden volstaat. Bij deze bezorg ik jullie een akkoord voor het ingediende voortgangsformulier en de toelating om jullie MP2 te verdedigen.

Verder vraag ik jullie nog 2 zaken:
- Graag naast de formele indiening ook een finale Word-versie van jullie MP2 aan de (co)promotoren per e-mail te bezorgen
- Graag ook alle finale documentatie van de data- en statistische verwerking bezorgen, bij voorkeur wat gelabeld (of met wat toelichting) zodat we eraan uit kunnen (vb. Excel files, output JMP of SPSS, etc). Dit zodat we met hiermee verder kunnen gaan wanneer we nog bijkomende subjecten rekruteren in de toekomst.

De oefenpresentaties zullen zoals gepland op 23 juni blijven doorgaan, maar dan wel via Google Meet.

Verder wens ik jullie veel succes toe in deze laatste (en ongewone) fase van jullie opleiding. Zet nog even door met jullie masterproef, examens, eventuele stages. En dan kunnen we jullie hopelijk binnenkort als volwaardig collega beschouwen. Succes.

MVG,

Lotte Janssens