The Effect of the Use of Aquabags on Muscle Activation in Functional Strength Training

A cross-sectional observational study

Word count: 5,157

Laveyne Katrien (01601512)
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Promotors: Dr. Wezenbeek Evi & Dr. Schuermans Joke

A dissertation submitted to Ghent University in partial fulfilment of the requirements for the degree of Master in Rehabilitation Sciences and Physiotherapy

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Academic year: 2020 – 2021
Preface

This thesis is written within the scope of our Master of Science in Rehabilitation Sciences and Physiotherapy degree program. It marks the end of our five years as physiotherapy students at Ghent University. This paper is written with the aim of publishing it in a scientific American journal. We have experienced this time as intensely educational and challenging. We have learned about scientific research in general and how to set up our own research and manage it correctly.

We would like to express our gratitude to several people who were essential to complete this thesis:

First of all, our promotors, dr. Wezenbeek Evi and dr. Schuermans Joke, for their time, feedback and great expertise. Due to their trust in us as a team, we were able to conduct our experimental research completely independently. Their valuable insights and encouragement gave us guidance to complete this thesis.

Secondly, we would like to thank our participants who were willing to take part in this study. Without their cooperation, we would not have succeeded in fulfilling this research.

Furthermore, we owe a special thanks to our family and friends for their endless support, not only while writing this thesis, but during the entirety of our studies.

Lastly, we would like to thank each other for the pleasant cooperation. During the COVID-19 pandemic, the many video calls during the writing of our master’s thesis brought us closer together as friends.

Katrien Laveye
Lieze Ravelingien
Luna Verhaeghe

Ghent, May 18, 2021
# Table of contents

Preface .................................................................................................................. 4

Table of contents.................................................................................................... 5

List of figures and tables......................................................................................... 6

List of abbreviations............................................................................................... 7

Abstract .................................................................................................................... 8

English version (UGent)......................................................................................... 8

English version (Journal of Strength and Conditioning Research).................... 9

Dutch version .......................................................................................................... 10

Introduction ............................................................................................................ 11

Methods .................................................................................................................. 13

Experimental approach to the problem ................................................................ 13

Subjects .................................................................................................................. 14

Testing Procedure .................................................................................................. 15

Statistical analyses................................................................................................. 19

Results .................................................................................................................... 20

Discussion .............................................................................................................. 24

Core stability: LES & EO ....................................................................................... 24

Stabilizer of lower limb: GME ............................................................................... 26

Prime movers of lower limb & pelvis: GMA, BF & RF ........................................ 27

Limitations .............................................................................................................. 28

Conclusion and Practical applications .................................................................. 29

Acknowledgements ............................................................................................... 29

References .............................................................................................................. 30

Abstract in layman's terms (Dutch)..................................................................... 32

Ethics committee: proof of approval...................................................................... 33
List of figures and tables

Figure 1: The aquabag ........................................................................................................... 15
Figure 2: Parallel squat with stick and AB ........................................................................ 16
Figure 3: Forward lunge with stick and AB ........................................................................ 17
Figure 4: Forward step-up with stick and AB ................................................................. 17
Figure 5: Electrode placement ............................................................................................ 18
Figure 6: Electrodes and associated wireless amplifiers fixated with Hypafix tape ............ 18
Figure 7: Normalized EMG activation of the LES, EO, GME, GMA, BF and RF in the squat performed with AB and stick. ................................................................. 21
Figure 8: Normalized EMG activation of the LES, EO, GME, GMA, BF and RF in the lunge performed with AB and stick. ........................................................................... 22
Figure 9: Normalized EMG activation of the LES, EO, GME, GMA, BF and RF in the step-up performed with AB and stick. ........................................................................... 23

Table 1: Subject characteristics ......................................................................................... 14
Table 2: EMG activity recorded for the different muscles during squat.............................. 21
Table 3: EMG activity recorded for the different muscles during lunge............................... 22
Table 4: EMG activity recorded for the different muscles during step-up ......................... 23
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB</td>
<td>Aquabag</td>
</tr>
<tr>
<td>BF</td>
<td>M. biceps femoris</td>
</tr>
<tr>
<td>CI</td>
<td>Confidence interval</td>
</tr>
<tr>
<td>e.g.</td>
<td>For example (exempli gratia)</td>
</tr>
<tr>
<td>ECG</td>
<td>Electrocardiogram</td>
</tr>
<tr>
<td>EMG</td>
<td>Electromyography</td>
</tr>
<tr>
<td>EO</td>
<td>M. external oblique</td>
</tr>
<tr>
<td>FST</td>
<td>Functional strength training</td>
</tr>
<tr>
<td>GMA</td>
<td>M. gluteus maximus</td>
</tr>
<tr>
<td>GME</td>
<td>M. gluteus medius</td>
</tr>
<tr>
<td>i.e.</td>
<td>Id est</td>
</tr>
<tr>
<td>LES</td>
<td>M. lumbar erector spinae</td>
</tr>
<tr>
<td>MVC</td>
<td>Maximum voluntary isometric contraction</td>
</tr>
<tr>
<td>n</td>
<td>Sample size</td>
</tr>
<tr>
<td>RF</td>
<td>M. rectus femoris</td>
</tr>
<tr>
<td>SD</td>
<td>Standard deviation</td>
</tr>
<tr>
<td>sEMG</td>
<td>Surface electromyography</td>
</tr>
<tr>
<td>VAS</td>
<td>Visual Analogue Scale</td>
</tr>
<tr>
<td>y</td>
<td>Years</td>
</tr>
</tbody>
</table>
Abstract

English version (UGent)

Background: Recently introduced innovative equipment and training protocols cause a positive evolution in the field of strength and conditioning. For instance, training with instability devices, such as an aquabag (AB) has gained popularity. The AB is an inflatable tube that resembles a barbell and can be partially filled with a certain amount of water. This new innovative training gadget is often utilized during functional strength training (FST) by physiotherapists and (personal) trainers. Although there has been an increase of use in clinical practice, evidence concerning the effect of AB’s on muscle activation is lacking.

Objective: The aim of this study was to evaluate the effect of AB’s on muscle activity of stabilizing and mobilizing core and lower limb muscles during three functional exercises.

Study design: Cross-sectional observational study

Methods: Ten male and ten female healthy subjects (age = 21.2 years ± 1.5, height 175.8 cm ± 8.9, weight 68.4 kg ± 9.6) performed a squat, lunge and step-up while using a wooden stick (stable condition) and an AB (unstable condition). Surface electromyographic (sEMG) signals were recorded from the lumbar erector spinae (LES), external oblique (EO), gluteus medius (GME) bilaterally and gluteus maximus (GMA), biceps femoris (BF) and rectus femoris (RF) on the dominant leg. sEMG signals were normalized to the maximum voluntary isometric contraction (MVC). Linear mixed models were used to analyze the collected data. The level of significance was set at α = 0.05.

Results: When performing the exercises with an AB compared to a stick, the results showed a significant increase in muscle activity of the LES during squat (p < 0.001), lunge (p = 0.001) and step-up (p = 0.003), EO during squat (p = 0.034) and step-up (p = 0.046), BF during lunge (p = 0.008) and step-up (p = 0.008), GME and GMA during lunge (p < 0.001 and p = 0.010, respectively).

Conclusion: The AB could be an addition to FST by providing balance challenges demanding compensatory activity of stabilizing muscles, specifically in core and pelvis regions. For specific functional exercises such as lunge and step-up, prime movers of the lower limb can be targeted as well by using this device. Therefore, the AB can be utilized to enhance training and rehabilitation effects.

Key words: electromyography, aquabag, instability, functional strength exercises, muscle activity
English version (Journal of Strength and Conditioning Research)

The aim of this controlled trial was to evaluate the effect of aquabag (AB) implementation on muscle activity of core and lower limb muscles during three functional exercises. Twenty healthy subjects performed a squat, lunge and step-up, while using a stick and an AB. Surface electromyographic (sEMG) signals were recorded from the lumbar erector spinae (LES), external oblique (EO), gluteus medius (GME) bilaterally and gluteus maximus (GMA), biceps femoris (BF) and rectus femoris (RF) on the dominant leg. sEMG signals were normalized to the maximum voluntary isometric contraction (MVC). Linear mixed models were used to analyze the data. The level of significance was set at α = 0.05. When performing the exercises with an AB compared to a stick, the results of this study showed a significant increase in muscle activity of the LES during all three exercises (p < 0.001 to p = 0.003), EO during squat (p = 0.034) and step-up (p = 0.046), BF during lunge (p = 0.008) and step-up (p = 0.008) and GME and GMA during lunge (p < 0.001 and p = 0.010, respectively). These results indicate that an AB could advance functional strength training by providing balance challenges demanding compensatory activity of stabilizing muscles, specifically in the core and pelvis regions. When performing a lunge and a step-up, prime movers of the lower limb can be targeted as well by using this device. The authors therefore recommend the use of an AB to enhance training and rehabilitation effects.

Keywords: electromyography, water bag, instability, functional strength exercises
Dutch version

Achtergrond: Recent en innovatieve oefenmaterialen en trainingsprotocollen zorgen voor een positieve evolutie op het gebied van kracht- en conditietraining. Trainen met destabiliserend materiaal, zoals een aquabag (AB), wint aan populariteit. Een AB is een opblaasbare cilindervormige tube gelijkend op een halter en kan gevuld worden met water. Deze nieuwe trainingstool wordt regelmatig gebruikt tijdens functionele krachttraining door kinesitherapeuten en (personal) trainers. Hoewel het gebruik in de klinische praktijk toegenomen, ontbreekt wetenschappelijk bewijs omtrent het effect van aquabags op spieractivatie.

Doelstelling: Het doel van deze studie was om het effect van aquabags op de activiteit van stabiliserende en mobiliserende spieren ter hoogte van de core en onderste ledematen te evalueren tijdens drie functionele oefeningen.

Onderzoeksdesign: Cross-sectioneel observationeel onderzoek

Methode: Tien mannelijke en tien vrouwelijke gezonde proefpersonen (leeftijd = 21.2 jaar ± 1.5, lengte 175.8 cm ± 8.9, gewicht 68.4 kg ± 9.6) voerden een squat, lunge en step-up uit met behulp van een houten stok (stabiele toestand) en een AB (onstabiele toestand). Door middel van oppervlakte-elektromyografie (EMG) werd de elektrische spieractiviteit geregistreerd van de lumbale erector spinae (LES), externus obliquus (EO), gluteus medius (GME) bilateraal en gluteus maximus (GMA), biceps femoris (BF) en rectus femoris (RF) op het dominante been. EMG-signalen werden genormaliseerd naar de maximale vrijwillige isometrische contractie (MVC). Linear mixed models werd toegepast om de gegevens statistisch te analyseren. Het significantieniveau was α = 0.05.

Resultaten: De resultaten van deze studie toonden een significante toename in spieractiviteit van de LES tijdens squat (p < 0.001), lunge (p = 0.001) en step-up (p = 0.003), EO tijdens squat (p = 0.034) en step-up (p = 0.046), BF tijdens lunge (p = 0.008) en step-up (p = 0.008), GME en GMA tijdens lunge (p < 0.001 en p = 0.010, respectievelijk) wanneer gebruik werd gemaakt van een AB in vergelijking met een stok.

Conclusie: De AB kan een aanvulling zijn op functionele krachttraining door de stabiliteit uit te dagen en zo compenserende activiteit van stabiliserende spieren uit te lokken, met name in de core- en bekkenregio. Voor specifieke functionele oefeningen zoals lunge en step-up, kunnen ook de prime movers van het onderste lidmaat geactiveerd worden door dit materiaal te gebruiken. De AB kan dus ingezet worden om de trainings- en revalidatie effecten bij het grote publiek te vergroten.

Trefwoorden: elektromyografie, aquabag, instabiliteit, functionele krachtoefeningen, spieractiviteit
Introduction

Recently introduced innovative equipment and training protocols cause a positive evolution in the field of strength and conditioning. For instance, training with instability devices, such as an aquabag (AB) has gained popularity. The hypothesis is that performing resistance exercises under unstable conditions will boost the activation of stabilizing muscles (20, 22) and therefore amplify the associated training effects. Originally, training with destabilizing devices (e.g. Swiss ball, BOSU ball, wobble board, air cushion, slash pipe) was exclusively carried out in therapeutic settings for patients, but nowadays this type of training has also has become popular in fitness training regimens for the general (non-rehabilitating) population and even athletes, to improve sports performance and enlarge the training challenge and benefits (3, 6, 13).

The AB is an inflatable tube that resembles a barbell and can be partially filled with a certain amount of water. This new innovative training gadget is often utilized during functional strength training (FST) by physiotherapists and (personal) trainers. These bags are available in different sizes and similar products are produced by different brands. The creators of the AB (Ultimateinstablity, 2013) claim that due to the unstable mass of water inserted within the inflatable tube, training with this device can improve (core) stability and strength gains of “large and small muscle groups” when used in FST. Because of the claimed advantages of AB’s and positive effects of common instability devices, AB’s are regularly employed in clinical practice with the idea that this device will positively affect the rehabilitation of several pathologies such as chronic ankle instability (9, 11), (chronic) low back pain (23) or scapular dyskinesis (21).

The use of instability devices (balance discs, BOSU ball, T-bow, power board, balance cone) results in the following additional beneficial effects when applied in FST protocols: neuromuscular adaptations and force exertion during unstable exercises and unstable circumstances in sport specific performance, neuromuscular coordination of agonist, antagonist, synergist and stabilizing muscle patterns of neuromuscular recruitment, non-hypertrophic strength achievements, limb muscle activation, trunk musculature responses and core stability (1, 2, 6, 10, 17, 22).

As previously stated, the use of AB’s during FST protocols in rehabilitation and strength and conditioning training to activate stabilizing core and limb muscles has recently become an attractive and common method for physiotherapists and (personal) trainers. However, popularity is not always associated with evidence based practice. Despite the increasing use of AB’s in clinical practice, it is striking that only one previous study investigated the effect of the use of this device on muscle activity and this solely in a clean and jerk weight lifting exercise (4). This lack of evidence concerning this commonly used device stresses the need to examine the effect of the use of AB’s on muscle activation while performing functional training exercises.
Therefore the aim of this study is to evaluate the effect of AB’s on muscle activity of the lumbar erector spinae (LES), external oblique (EO), gluteus medius (GME), gluteus maximus (GMA), biceps femoris (BF) and rectus femoris (RF) during several functional exercises (squat, lunge and step-up) in a sample of healthy individuals. It was hypothesized that in healthy individuals, the use of AB’s would increase the muscle activity amplitudes of the stabilizing musculature (LES, EO and GME) and prime movers (GMA, BF and RF) during functional exercises compared to the use of a wooden stick without inertial properties.
Methods

Experimental approach to the problem

This cross-sectional observational study was conducted at the department of Rehabilitation Sciences and Physiotherapy at Ghent University (Belgium). A within-subject study design was used to compare muscle activity between a stick and AB condition performing a squat, lunge and step-up.

The testing procedure consisted of one session per subject during autumn 2020. It involved filling in a questionnaire, measurement of maximum voluntary isometric contractions (MVC) and the performance of three exercises during the experimental conditions. The measurement protocols were always strictly controlled by the same evaluators. The questionnaire was completed to obtain more information concerning demographic data (sex and age), injury history, experience with destabilizing material, VAS-score and sports activity, which might potentially bias between-conditions effects and were therefore included in the analyses. Then, body mass and height were measured. To define leg dominance, the subject was asked which leg they use to kick a ball, as this is a frequently applied method in preceding literature (24). Afterwards, MVC collection was conducted for each muscle on the dominant side (LES, EO, GME, GMA, BF and RF) and the stabilizing muscles of the non-dominant side (LES, EO and GME) to make inter-individual comparison of the condition-related effects between subjects possible.

After completing the MVC protocol, participants performed three repetitions of each exercise under two conditions, using a non-inertial wooden stick and a destabilizing AB, while electromyographic (EMG) data of the aforementioned muscles was collected. This was conducted in a non-randomized order with focus on the dominant side.

During the exercises, timing (i.e. duration of the exercises or the exact timeframe the participant was granted to execute each exercise) was standardized and detailed instructions on positioning the stick and AB were given, as well as how to perform the exercise correctly. These instructions were identical for each subject.

In this study, condition and dominance were independent variables and the subjects were dependent variables, which made it possible to determine the difference in muscle activity between the stick and AB condition across subjects.
Subjects

A total of twenty healthy candidates (ten males, ten females) volunteered to participate in this study. Only subjects with an age ranging between 18-30 years (y) were included. The participants’ mean age, weight and height are shown in Table 1. Experience with destabilizing material during training was not a requirement nor obliged to be included in this study. Exclusion criteria were any musculoskeletal discomfort during sports or lower limb pathology which could influence the outcome results of the experiment. Subjects were instructed not to engage in physical activity twelve hours before testing to avoid residual presence of (muscle) fatigue. Prior to data collection, an informed consent in accordance with the Declaration of Helsinki was signed by every subject. Ethical approval was obtained from the research ethics committee of Ghent University Hospital (number of approval: EC/2020/07078-07079-07080).

Table 1: Subject characteristics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>21.1 ± 1.5</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>10 (50)</td>
</tr>
<tr>
<td>Female</td>
<td>10 (50)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>175.8 ± 8.9</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>68.4 ± 9.6</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>22.1 ± 2.1</td>
</tr>
<tr>
<td>Sport (h/week)</td>
<td>2.9 ± 2.9</td>
</tr>
<tr>
<td>Limb dominance</td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>16 (80)</td>
</tr>
<tr>
<td>Left</td>
<td>4 (20)</td>
</tr>
</tbody>
</table>

Values are presented as mean ± SD or n (%).
Testing Procedure

Prior to EMG data collection, the maximal EMG amplitudes of each muscle were collected during three MVC’s. They were collected in order to normalize the AB-associated EMG data in each subject, to allow valid and reliable in-between-condition and in-between-subject analysis. Between repetitions, a 10 s resting period was given. This MVC data collection consisted of resisted isometric contractions of each muscle in positions according to manual muscle testing principles (16) and was performed to map the maximal electrical potential of the LES, EO, GME, GMA, BF and RF. In order to gather the participant’s maximal electrical muscle activity signal, subjects were instructed to gradually increase force over 2 s, after which they were instructed to generate a maximal isometric contraction against the manual resistance of the tester during 5 s. Verbal feedback was given by another researcher. For the ES and EO muscles, a belt was used to fixate the lower limbs of the individuals to reduce compensation strategies while performing the isometric hold. For each muscle, the average EMG amplitude of the three repetitions was used as the reference MVC for post hoc data normalization.

A parallel squat, a forward lunge and a step-up were performed three times using a wooden stick (control condition) and an AB (Ultimateinstability, 2013) (experimental condition) (Figure 1). The forward lunge and step-up were performed with the dominant leg. Based on the subject’s weight, a small (4 kg) or medium size (8 kg) AB was assigned (cut-off: 70 kg). The resting time between each repetition and condition was 10 s. Between two types of exercises, 60 s of rest were allowed to ensure complete recovery. Each subject was instructed on how to perform every task in a standardized manner. Participants started by practicing each exercise using the wooden stick. If the participant was able to perform the exercise correctly, the actual EMG-data collection during both conditions commenced. During the tryout, all subjects were given verbal and visual feedback.

Pieces of colored adhesive tape were placed on the floor to standardize foot position for all repetitions of every exercise. Participants were not allowed to practice the exercises with the AB. If an individual totally lost balance, the test was excluded from further analyses and a new attempt was allowed.
**Exercise 1: Parallel squat (Figure 2)**

For the starting position, feet were placed slightly wider than shoulder width and were instructed to point straight forward. The wooden stick or AB was placed behind the neck, resting on the upper trapezius muscle. The pronated grip was wider than the shoulders and hands were placed on the ends of the stick. In the AB condition, the outer handles were used. The trunk had to be maintained in a vertical position. Subjects descended by flexing the hips and knees after initiating the exercise by performing an anterior pelvic tilt. Guidelines were given to squat down reaching 60 degrees of knee flexion. Subjects were instructed to perform this exercise at a pace corresponding with a 2 s down (eccentric) phase and a 2 s up (concentric) phase.

![Figure 2: Parallel squat with stick and AB](image)

**Exercise 2: Forward lunge (Figure 3)**

Again, the wooden stick or AB was placed behind the neck, resting on the upper trapezius muscle. A pronated grip wider than shoulder width was used and hands were placed on the ends of the stick. In the AB condition, the outer handles were utilized. To start, subjects placed both feet shoulder width apart, followed by a step forward until a 90 degree angle was reached between each upper and lower leg. During the lunge, subjects had to keep both feet in a parallel position with the toes pointing straight ahead. The rear foot stayed in the same place. Participants were instructed to retain the rear knee parallel to the ground and the position of the front knee behind the toes of the front foot. Individuals were monitored to ensure that they did not take a stutter step with the front foot when returning to the initial position. The pace of this forward lunge was set corresponding to eccentric (descent) and concentric (ascent) phases of four counts each.
Exercise 3: Forward step-up (Figure 4)

Similar to the parallel squat and forward lunge exercise, subjects performed the forward step-up with the wooden stick or AB behind the neck, resting on the upper trapezius muscle. A pronated grip wider than shoulder width was used and hands were placed on the ends of the stick. In the AB condition, the outer handles were utilized. Based on the height (cut-off: 175 cm) of the participants, a low (30.5 cm) or high box (40.2 cm) was chosen. To start the step-up, feet were positioned flat on the floor in a bilateral stance with both feet spread at shoulder width. In 2 s, subjects stepped up with one leg placing the entire foot on top of the box, then forcefully extended the same leg while simultaneously swinging the other leg explosively into the air, so that the thigh of this free leg reached a horizontal position and attained a 90 degree angle between the upper and lower leg. The single-leg position on top of the box was held for 2 s. In the end, participants placed the swinging leg back on top of the box. EMG data collection was performed exclusively during these step-up and hold phases. Returning to the starting position was performed unstandardized as this phase was not included in EMG data acquisition for the step-up exercise.
In order to be able to measure muscle activity during MVC data collection and the performance of the functional exercises, sEMG was utilized. To reduce impedance, the skin was shaved in case of excess body hair, abraded and cleaned with ethyl alcohol in preparation of placing the self-adhesive, disposable, gel-coated electrodes (Ambu® BlueSensor P ECG Electrodes) sized 40.8 mm x 34 mm. Six pairs of electrodes were placed on the dominant side and three pairs of electrodes were placed on the non-dominant side, parallel to the presumed muscle fiber direction on the LES, EO, GME, GMA, BF and RF, confirming to the SENIAM recommendations (Figure 5) (15). To avoid loosening or excessive movements of the electrodes and associated wireless amplifiers, they were fixated on the subject’s skin using Hypafix tape (Figure 6).

![Figure 5: Electrode placement](image1)

![Figure 6: Electrodes and associated wireless amplifiers fixated with Hypafix tape](image2)

Muscle activity (9 channel - sEMG) was measured using the Ultium EMG- and Motion Tracking System (Ultium, Noraxon U.S.A. Inc.) and sent wirelessly via Ultium EMG SmartLeads (i.e. the amplifiers) (Ultium, Noraxon U.S.A. Inc.) to the MyoMuscle MR 3.14.57 software program (Ultium, Noraxon U.S.A. Inc.) on the data acquisition laptop. To minimize potential signal noise from the surrounding devices, lights and cellphones were turned off during testing. For all MVC measurements as well as every exercise and every repetition, raw EMG signals were processed using the software program mentioned above. The signals were ECG reduced, high pass filtered at a frequency of 20 Hz, smoothed (50 ms window) and rectified. After data processing, the mean values (µV) were selected for every trial and normalized by the mean MVC amplitude of the intended muscle, respectively.
Statistical analyses

Statistical analyses were executed using the statistical software package of the social sciences (SPSS V.27) (IBM Corp., New York, NY, USA). The effect of the exercise condition (stick and AB) on muscle activation in core and lower limb on the dominant (LES, EO, GME, GMA, BF and RF) and non-dominant (LES, EO and GME) side during the three separate exercises (squat, lunge and step-up) was investigated with linear mixed models analyses. Analyses were performed with condition and dominance as a fixed predictor (independent variables) and subjects as a random factor (dependent variable). The additional effect of the covariates sex, age, hours of sports activity per week and experience with an AB was investigated. Post hoc analyses were done with Bonferroni corrections. The residuals of the linear mixed models were checked for homoscedasticity and normal distribution. The level of significance was set at \( \alpha = 0.05 \). A two-way random average measures intraclass correlation for absolute agreement as a measure for inter-repetition reliability was > 0.75, which indicates an excellent reliability (7).
Results

Overall, muscle activity during all three functional exercises was significantly higher during the AB condition compared to the control condition (with wooden stick). More specifically, LES significantly displayed more activity during all exercises with the use of an AB compared to the stick condition (p < 0.001 for squat; p = 0.001 for lunge; p = 0.003 for step-up). During the squat and step-up exercises, a significantly higher EO activity was recorded during the AB condition relative to the stick condition (p = 0.034; p = 0.046). Significantly higher BF activity was seen during lunge and step-up in the AB condition compared to the stick condition (p = 0.008; p = 0.008). During the lunge exercise, significantly more GME and GMA muscle activity was observed for the AB condition in comparison with the stick condition (p < 0.001; p = 0.010). Further, no significant correlations were found between the stick and AB condition. Results are presented in Table 2, 3 and 4 and Figure 7, 8 and 9. Regarding the LES, EO and GME muscles on the non-dominant side, no significant differences between the two conditions were detected during all three exercises.

Linear mixed models analyses did not reveal any effect of participant’s gender, age, experience with AB training or weekly amount of physical activity on muscle activity and these variables were therefore not included as covariates in the analyses.
Table 2: EMG activity recorded for the different muscles during squat

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Muscle</th>
<th>Condition</th>
<th>Mean±SD (% MVC)</th>
<th>p-value</th>
<th>Mean difference</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lower bound</td>
<td>Upper bound</td>
</tr>
<tr>
<td>Squat</td>
<td>LES</td>
<td>AB</td>
<td>0.20±0.10</td>
<td>&lt; 0.001</td>
<td>0.034</td>
<td>0.021 to 0.047</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stick</td>
<td>0.16±0.09</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>EO</td>
<td>AB</td>
<td>0.13±0.09</td>
<td>0.034</td>
<td>0.019</td>
<td>0.002 to 0.036</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stick</td>
<td>0.11±0.08</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>GME</td>
<td>AB</td>
<td>0.10±0.06</td>
<td>0.257</td>
<td>-0.019</td>
<td>-0.052 to 0.015</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stick</td>
<td>0.12±0.11</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>GMA</td>
<td>AB</td>
<td>0.11±0.08</td>
<td>0.644</td>
<td>0.005</td>
<td>-0.018 to 0.029</td>
</tr>
<tr>
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<td>0.10±0.07</td>
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<tr>
<td></td>
<td>BF</td>
<td>AB</td>
<td>0.12±0.12</td>
<td>0.274</td>
<td>0.009</td>
<td>-0.008 to 0.025</td>
</tr>
<tr>
<td></td>
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<td>Stick</td>
<td>0.12±0.13</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>RF</td>
<td>AB</td>
<td>0.31±0.22</td>
<td>0.493</td>
<td>0.011</td>
<td>-0.022 to 0.045</td>
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<td>Stick</td>
<td>0.30±0.25</td>
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</table>

P-value in bold indicates statistical significance, p < 0.05. AB, aquabag; BF, biceps femoris; CI, confidence interval; EO, external oblique; GMA, gluteus maximus; GME, gluteus medius; LES, lumbar erector spinae; MVC, maximum voluntary isometric contraction; RF, rectus femoris; SD, standard deviation.

Figure 7: Normalized EMG activation of the LES, EO, GME, GMA, BF and RF in the squat performed with AB and stick. Values are given as mean ± SD. * Significant difference (p < 0.05).
Table 3: EMG activity recorded for the different muscles during lunge

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Muscle</th>
<th>Condition</th>
<th>Mean±SD (% MVC)</th>
<th>p-value</th>
<th>Mean difference</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lower bound</td>
</tr>
<tr>
<td>Lunge</td>
<td>LES</td>
<td>AB</td>
<td>0.18±0.16</td>
<td><strong>0.001</strong></td>
<td>0.023</td>
<td>0.010</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stick</td>
<td>0.16±0.14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>EO</td>
<td>AB</td>
<td>0.18±0.18</td>
<td>0.071</td>
<td>0.025</td>
<td>-0.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stick</td>
<td>0.16±0.13</td>
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<td></td>
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<tr>
<td></td>
<td>GME</td>
<td>AB</td>
<td>0.18±0.09</td>
<td>&lt; <strong>0.001</strong></td>
<td>0.024</td>
<td>0.013</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stick</td>
<td>0.15±0.08</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>GMA</td>
<td>AB</td>
<td>0.18±0.09</td>
<td><strong>0.010</strong></td>
<td>0.023</td>
<td>0.006</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stick</td>
<td>0.15±0.09</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BF</td>
<td>AB</td>
<td>0.16±0.13</td>
<td><strong>0.008</strong></td>
<td>0.017</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stick</td>
<td>0.15±0.12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>RF</td>
<td>AB</td>
<td>0.34±0.20</td>
<td>0.082</td>
<td>0.018</td>
<td>-0.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stick</td>
<td>0.32±0.18</td>
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</table>

P-value in bold indicates statistical significance, p < 0.05. AB, aquabag; BF, biceps femoris; CI, confidence interval; EO, external oblique; GMA, gluteus maximus; GME, gluteus medius; LES, lumbar erector spinae; MVC, maximum voluntary isometric contraction; RF, rectus femoris; SD, standard deviation.

Figure 8: Normalized EMG activation of the LES, EO, GME, GMA, BF and RF in the lunge performed with AB and stick. Values are given as mean ± SD. * Significant difference (p < 0.05).
Table 4: EMG activity recorded for the different muscles during step-up

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Muscle</th>
<th>Condition</th>
<th>Mean±SD (% MVC)</th>
<th>p-value</th>
<th>Mean difference</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lower bound</td>
</tr>
<tr>
<td>Step-up</td>
<td>LES</td>
<td>AB</td>
<td>0.15±0.10</td>
<td><strong>0.003</strong></td>
<td>0.025</td>
<td>0.010</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stick</td>
<td>0.13±0.10</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>EO</td>
<td>AB</td>
<td>0.20±0.17</td>
<td><strong>0.046</strong></td>
<td>0.024</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stick</td>
<td>0.17±0.14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>GME</td>
<td>AB</td>
<td>0.30±0.17</td>
<td>0.205</td>
<td>0.027</td>
<td>-0.016</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stick</td>
<td>0.28±0.13</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>GMA</td>
<td>AB</td>
<td>0.19±0.10</td>
<td>0.051</td>
<td>0.023</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stick</td>
<td>0.16±0.08</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BF</td>
<td>AB</td>
<td>0.20±0.15</td>
<td><strong>0.008</strong></td>
<td>0.030</td>
<td>0.009</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stick</td>
<td>0.17±0.13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>RF</td>
<td>AB</td>
<td>0.22±0.19</td>
<td>0.069</td>
<td>0.38</td>
<td>-0.003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stick</td>
<td>0.18±0.12</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*P-value in bold indicates statistical significance, p < 0.05. AB, aquabag; BF, biceps femoris; CI, confidence interval; EO, external oblique; GMA, gluteus maximus; GME, gluteus medius; LES, lumbar erector spinae; MVC, maximum voluntary isometric contraction; RF, rectus femoris; SD, standard deviation.

Figure 9: Normalized EMG activation of the LES, EO, GME, GMA, BF and RF in the step-up performed with AB and stick. Values are given as mean ± SD. * Significant difference (p < 0.05).
Discussion

This study sought to evaluate the effect of AB’s on stabilizing and mobilizing core and lower limb muscle activity during squat, lunge and step-up exercises in a sample of healthy individuals. The main finding of this study is that muscle activity during all three functional exercises was significantly higher during the AB condition compared to the control condition (with wooden stick). These significant differences in muscle activity were found for both the stabilizing core and pelvis muscles (LES (all exercises), EO (squat and step-up) and GME (lunge)), and the mobilizing lower limb muscles (BF (lunge and step-up) and GMA (lunge)).

Core stability: LES & EO

LES

There has been a lot of research concerning the effect of incorporating destabilizing training material on core muscle activity, when integrated in functional exercises. However, only one study used an AB as an unstable condition; Calatayud et al. (4) found higher core muscle activation (LES and EO) when young fit male university students performed a clean and jerk exercise with an AB compared to a barbell and sandbag. This is in line with the results of this study, since LES activity was significantly higher when performing all exercises with an AB and the same results were found for EO muscle activity during squat and step-up. This finding was no surprise, since this muscle group is, among others, responsible for stabilizing the spine. Therefore, when higher postural control is required, LES activation will increase. However, it should be taken into consideration that, in this study, the AB of 4 and 8 kg respectively weighed 16 and 32 times more than the stick with an absolute load of 250 g. This means that the mass of the stick only is 6.25% of the mass of the 4 kg AB and 3.13% of the mass of the 8 kg AB. Due to this big difference in load, a higher amount of overall muscle activation is expected during the AB condition, independently of its destabilizing characteristics. Calatayud et al. (4) compared the AB to a barbell and sandbag. Although the same absolute load of 20 kg was used across the three conditions, the use of an AB still caused a significant increase of core muscle activity. This could indicate that more LES activity occurs when greater challenge to the postural control systems is generated and a higher amount of instability is provoked (4).

Concerning the paraspinal muscles, Glass & Albert (14) found more activation during the eccentric phase of an overhead squat when comparing exercise modalities using a water tube with an open valve condition, with a similar stable condition where a closed valve condition created no water movement. The participants were instructed to hold the water tube over their head with extended arms, which differed from the starting position in this study. This could possibly affect the amount of compensatory muscle activation.
It is hypothesized that when the load is placed further from the center of mass, more compensatory muscle activation is needed to stabilize the spine.

Contrary to aforementioned studies, Nairn et al. (20) found significantly less LES activity using an Attitube in comparison to an Olympic barbell, both with an absolute load of 22.7 kg, when performing three bipodal squat repetitions. According to Nairn et al. a reduced trunk flexion was observed when performing a bipodal squat with the Attitube, in comparison with the Olympic barbell condition, where more trunk flexion and therefore more LES activity was detected (20). This indicates that the essential differences in trunk kinematics of the bipodal squat movement between both exercise conditions is responsible for this observed decrease in LES activity during the Attitube condition, making it difficult to conclude to what extent the Attitube might provide an added value in functional training in terms of effects on muscle activity response.

**EO**

Regarding the EO muscle, performing a squat and a step-up with an AB showed significantly more EMG activity in this study. The amount of studies investigating the influence of top-down instability on muscle activity during squat is relatively extensive. Lawrence & Carlson (19) found a higher activation of the EO muscle while using weights suspended from a barbell by mini elastic resistance bands during a squat. Ditroilo et al. (10) also reported a significant increase in activity of the above-mentioned muscle while performing an isometric squat using a Slashpipe of 12.5 kg, which is a water-filled training tube, when compared to performing a squat with a barbell of the same weight. A third study confirming the significant increase of EO activity when an unstable load is applied during a squat exercise, utilized an Attitube in the unstable condition (20). Calatayud et al. (4), who found a significant increase in EO muscle activity as well while performing a clean and jerk exercise with an AB compared to a barbell and sandbag with the same absolute load of 20 kg, stated that this increase could be due to the trunk rotator and stabilizer function of the EO muscles. The destabilizing AB produced asymmetrical disturbances due to water movement and turbulence, possibly causing a higher amount of EO muscle activity.

The results of this study also demonstrated a significantly higher EO muscle activity when performing a step-up activity with an AB. Although there is a lack of evidence surrounding the effect of top-down instability devices on muscle activity while performing a step-up movement, the present results are promising and support the existing evidence regarding the added value of destabilizing material in rehabilitation, prevention and training settings.
Interestingly, in contrast to the squat and step-up exercises, the AB condition did not result in a significant increase of EO muscle activity when performing a lunge, compared to the stick condition. A possible hypothesis for this finding is that during the performance of this movement with an AB, more trunk flexion occurred than was the case for the execution with a wooden stick. Farrokhi et al. (12) stated that a lunge with a forward movement of the trunk during lunge decreased EO activation and increased LES activation. It should be noted that in the study of Farrokhi et al. (12), subjects were instructed to bring their arms beyond the knee of the front lower limb. This resulted in a relatively large amount of flexion of the trunk relative to the pelvis when comparing this to a neutral alignment of trunk and pelvis. In this study, the lunge exercise was demonstrated with a neutral trunk position, but this aspect was not emphasized in the verbal instructions participants received. Therefore, it seems possible that participants had a tendency to flex their trunk during lunge and because of the higher load applied during the AB condition, no significant difference in EO muscle activation was found while performing a lunge movement.

**Stabilizer of lower limb: GME**

The results of this study showed that only the lunge produced more activity of the GME muscle comparing the stick with the AB condition. When analyzing the squat, this is a bilateral, symmetrical movement with a wide base of support, therefore resulting in lower GME activity during both the stable as well as during the unstable condition. As expected when performing a unilateral lower limb exercise, mean GME activity on the dominant side during step-up was high, but no significant increase of muscle activity was found between both conditions. The absence of a significant effect of the AB on GME activation during step-up was particularly remarkable. A possible explanation for these findings could be a difference in degrees of freedom between the functional exercises. The step-up exercise contains a higher amount of degrees of freedom, conceivably resulting in more compensations with the trunk and non-dominant leg. This is in contrast to the lunge, at which less degrees of freedom are available for the trunk to compensate, caused by the bipodal deep flexed closed chain position. To maintain a stable position and movement, more core and pelvis stability thus more activity of GME is demanded during a lunge.

The difference in movement freedom between the lunge and step-up exercises might indeed result in crucial differences in the amount of inter- and intra-individual variability in neuromuscular coordination patterns and subtle differences in kinematic output, contributing to the finding that the GME was only found to be significantly more active during the AB-loaded lunge compared to the stick condition, whereas no differences in GME activity between the two conditions could be retrieved for the step-up exercise.
**Prime movers of lower limb & pelvis: GMA, BF & RF**

**GMA & BF**

This study found significantly higher activation of GMA and BF during the performance of a lunge in the AB condition. GMA and BF are both extensors of the hip (5). As stated in the study of Farrokhi et al. (12) and by analogy to the reasoning concerning core muscle activity mentioned earlier, carrying out a forward lunge with more (tendency towards) flexion of the trunk due to the load of an AB, could enlarge activation of these hip extensors. Since this study did not analyze kinematics during the included exercises, this explanation cannot fully be confirmed although it remains highly plausible that this phenomenon occurred and significantly influenced the results.

Krause et al. (18) reported significantly more GMA and BF activity in the dominant leg performing a suspended lunge compared to a normal lunge. The suspended lunge was performed placing the dorsum of the non-dominant foot (hind leg) in a suspended TRX loop, while the dominant leg was positioned forward. While the participants of Krause et al. (18) performed a more stationary lunge with the focus on moving up and down, the subjects in this study also stepped forwards and backwards while performing the lunge. Consequently, when taking into account the results mentioned above, it is plausible that instability could challenge these prime mover muscles during a lunge, thus causing a significantly higher GMA and BF activity.

In the present study, performing a step-up with an AB also significantly increased BF activity, compared to the same exercise performed with a stick. In currently available literature, studies investigating muscle activity during forward step-up exercises with a top-down instability device are not present so current results cannot yet be supported by existing evidence.

Concerning the squat, this study found no significant increase in activation of the GMA and BF muscles when performing this exercise with the AB. The findings as regards GMA activity are in accordance with the results of Nairn et al. (20), who even found a decrease in GMA activity when performing a squat with an Attitude tube compared to a barbell of the same absolute weight. It was hypothesized that this occurred due to a reduced velocity of the tube, resulting in less of a muscle burst during the concentric phase of the squat (20). Another possible explanation for the results of this study could be that the instability caused by the AB was mainly compensated by the core stabilizing muscles and had less influence on the activation of the lower limb prime movers. Further, the squat movement itself is a relatively stable and symmetrical motion in comparison with the lunge and step-up. No further research was found concerning BF.
Concerning RF activity, no significant differences between the AB and stick condition were found for none of the exercises. The RF muscle is considered to be a prime mover when performing a squat exercise, due to its function as a knee extensor (8). It is plausible that based on its function as a knee extensor and hip flexor, this muscle is also a prime mover during lunge and step-up movements.

Similarly to our results, several studies found that the unstable condition produced no significantly higher muscle activity of the RF during a squat or lunge (18, 19). It was hypothesized by Krause et al. (18) that RF was similarly activated during the unstable and stable condition, since its main role is performing knee and hip movement (as a prime mover). When an unstable load is applied, other muscles are responsible for maintaining stability of the pelvis and hip in the transversal and frontal plane (25). This can be related to the prime mover characteristics of the RF mentioned above. Since the step-up movement is also a unilateral stepping motion similar to a lunge, this could explain why no significantly higher RF activation during the AB condition was detected (25).

**Limitations**

Albeit the first study investigating the added value of inducing an AB in squat, forward lunge and step-up exercises as regards muscle activation patterns of the core, pelvis and lower limb, there are some limitations that should be taken into account when interpreting the results. Firstly, the sample size was relatively small which could have led to this study being underpowered to analyze differences in muscle activity between both conditions. Secondly, the order of exercises was not randomized. This may have caused habituation to the instability of the AB when the last exercise (step-up) was performed. Thirdly, the same load was not applied across conditions, since the AB weighed 4 or 8 kg and the stick weighed less than 1 kg. Therefore, it is difficult to conclude to what extent this difference in absolute load between conditions affected the results of this study. However, this does not influence the fact that the use of an AB requires higher activity of core, pelvis and lower limb muscles. Moreover, the comparison between a stick and an AB is clinically relevant, since a stick is also a frequently used tool in clinical practice. By conducting this research, the authors offer clinicians a possibility to implement evidence based practice on a daily basis. Accordingly, the authors highly recommend using an AB in FST and rehabilitation settings.

In future research, the authors recommend to apply equal external loads when investigating the added value of introducing unstable materials in comparison with more static exercise conditions during randomized exercises, in order to explain differences in muscle activity more specifically. Furthermore, including a larger sample size is advised to enlarge generalizability of the results.
**Conclusion and Practical applications**

Destabilizing material is frequently used in FST, a training method which focuses on improving different muscular fitness and functional capacities. It targets multiple joint activities and muscles, concentrates on movement pattern quality and employs various planes of motion to imitate daily activities and sport specific movements. This is of great advantage in the context of both injury prevention and performance improvement, but also in rehabilitation settings. The AB is an addition to this type of training by demanding compensatory activity of stabilizing muscles, specifically in core and pelvis regions. For specific functional exercises such as lunge and step-up, prime movers of the lower limb can be targeted as well by using this device. Since muscle strength, neuromuscular control, coordination and balance are key components of motor behavior, the AB can be used to enhance training and rehabilitation effects among the general public, which consists of healthy individuals, patients and recreational and professional athletes.

**Acknowledgements**

The authors would like to express their gratitude to the subjects who voluntarily participated in this study. This study was conducted without any funding from manufacturers or companies or outside organizations. No conflict of interest was declared by the authors. The results of this study do not constitute endorsement of the product by the authors or the National Strength and Conditioning Association.
References


Abstract in layman’s terms (Dutch)

Achtergrond: Trainen met destabiliserend materiaal zoals een aquabag (AB) wint aan populariteit. De AB is een opblaasbare cilindervormige tube gevuld met water. Deze trainingstool wordt regelmatig gebruikt door kinesitherapeuten en trainers. Hoewel het populair is in de praktijk, ontbreekt wetenschappelijke evidentie over het effect van AB’s op spieractivatie.

Doelstelling: Het effect van AB op spieractiviteit ter hoogte van de romp en bekkenregio evalueren tijdens drie oefeningen.

Methode: Twintig gezonde proefpersonen voerden een squat, lunge en step-up uit met een AB en een houten stok ter referentie. Spieractiviteit van lage rug, buik-, bil- en dijbeenspieren werd gemeten via kleefelektroden en statistisch geanalyseerd.

Resultaten: Vergeleken met de stok, was er bij de uitvoering met een AB significant meer spieractiviteit van lage rugspieren tijdens alle oefeningen, buikspieren tijdens squat en step-up, achterste dijbeenspier tijdens lunge en step-up en bilspieren tijdens lunge.

Ethics committee: proof of approval

Haenebalcke Ann namens Commissie voor Medische Ethiek
Wo: 11/03/2020 15:02
Aan: Evi Wezenbeek; Luna Verhaeghe; Lieze Ravelingien; Katrien Laveynne
CC: HIRUZ CTU <hiruz.ctu@uzgent.be>; Fagq <ct.ec@fagq.be>; Joke Schuermans

Geachte professor
Geachte dokter
Geachte mevrouw, heer

Gelieve in bijlage de goedkeuring(en) te vinden betreffende bovengenoemde dossier(s).

Met vriendelijke groet,

Namens de Commissie voor Medische Ethiek,

ANN HAENEBALCKE
Dossiebeheerder
Commissie voor Medische Ethiek