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Effectiveness of the Copenhagen adduction modified position stage 1: EMG measurements and hand-held dynamometer analysis in young and healthy men

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ABSTRACT

Objectives: To verify the effectiveness of the use of a modified position of the Copenhagen Adduction (CA) stage 1 compared to the original position.
Design: Cross-sectional study.
Setting: Laboratory.
Participants: 31 healthy men aged 23.7 ± 1.9 years with no recent or chronic general pathology.
Main outcome measures: Differences between EMG amplitudes for the adductor longus (AL), rectus femoris (RF) and semi tendinous (ST) during dynamic contractions and adductor maximal isometric voluntary contraction (MIVC) force values between CA stage 1 standard and modified positions were assessed with either Wilcoxon or paired *t*-test.
Results: No significant differences were observed for EMG amplitudes of the AL (p-value = 0.724) and for the RF muscle (p-value = 0.337) and for the adductor force (p-value = 0.361) between the two positions. A significant difference was obtained for the ST (p-value<0.001) mainly explained by the adapted position of the non-dominant leg which unlocked the hip joint and generated less muscle activity in the hamstrings.
Conclusions: Muscle activity of the AL muscle and adductor force being similar in both positions, the CA stage 1 modified position could be of interest for rehabilitation after adductor injury or strengthening of the adductors in elite athletes.

1. Introduction

Groin pain and hip disorders are highly present in soccer at every level of practice (Waldén et al., 2015). Their prevalence is estimated at about 4–19% of playing time lost among senior soccer players (Waldén et al., 2015). In the case of groin pain, 2/3 of them are related to hip adductor muscles underlying the importance of prevention and rehabilitation (Mosler et al., 2018).

The imbalance of the musculature in agonist and antagonist muscle groups in the lower limb are often observed in soccer players during the season (Moreno-Pérez et al., 2021). There is an increase in the peak strength of hip abductors while the peak strength of adductor muscles remains stable in the middle and at the end of the season (Moreno-Pérez et al., 2021). A history of acute groin injury and adductor muscle weakness are strong risk factors for recurrent adductor injury (Engebretsen et al., 2010; Ryan et al., 2014). To avoid this imbalance, a hip adductor strengthening program that incorporates the Copenhagen adduction (CA) protocol demonstrated promising results in reducing the prevalence of hip problems in 41% of semi-professional soccer players during a single season (Harøy et al., 2019). After 8 weeks of progressive training including CA protocol, a gain in eccentric strength of 35.7% and concentric strength of 20.3% has been observed in a population of young soccer players (Ishøi et al., 2015). The CA program can be divided in three stages from the easiest to the more stressful position (Fig. 1) (Harøy et al., 2019).

Surface electromyography (EMG) can be used to measure the electrical activity of a muscle and to provide quantification of muscle activity with EMG amplitude (Besomi et al., 2019). Serner et al. showed

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that EMG signal was observable for the adductor longus (AL) muscle in 40 healthy participants during different exercises of the CA protocol (Serner et al., 2014). Based on their results, there was significantly more muscle activity in the AL muscle for the later stage of the CA protocol. There was also significantly more activity in the dominant leg compared to the non-dominant leg for healthy participants in both first and third stages of the CA protocol, reporting a potential asymmetry. Thorborg et al. showed a significant difference in strength between the adductors of the dominant and non-dominant leg and an isometric hip adduction/abduction ratio significantly lower in players with groin pain during the hip adduction test compared to players with a pain-free test (Thorborg et al., 2011). Finally, AL muscle activity was showed to be the greatest in the first stage of the CA protocol in comparison with other dynamic adduction exercises protocol (Delmore et al., 2014), suggesting that the first stage of the CA protocol had not only interest for therapeutic strengthening purposes, but should also be used for strength measurements of the AL muscle and for maximal isometric voluntary contraction (MIVC) tests used for EMG normalisation (Besomi et al., 2020).

In addition to EMG measurements, muscle strength can be objectively and clinically assessed with a hand-held dynamometer (HHD) (Stark et al., 2011). The HDD demonstrated valid and reliable measurements, is easy to use and allows the clinician to directly measure a patient's force (Stark et al., 2011). Mentiplay et al. also showed that in a healthy population, the HHD had inter-examiner and intra-examiner reliability considered good to excellent for assessing the isometric strength and power of the lower limb muscles (Mentiplay et al., 2015).

While many studies have shown the importance of strengthening the hip adductors for prevention or rehabilitation using CA program, patients with hip pathologies or groin pain, e.g. femoroacetabular impingement (FAI) may not tolerate the CA stage 1 position as it could create discomfort or pain provoked by an impingement sensation. This could impede the CA protocol and consequently the rehabilitation. Therefore, a modified CA stage 1 position has been introduced into the revalidation process. Compared to the CA stage 1 position, the modified position proposes to place the non-dominant leg, used for support, behind the knee of the dominant leg (Fig. 2). In this position the patient is able to do an adduction of the lower limb even if he was not able to do it in the original position of the Copenhagen protocol. The observation was a purely clinical practical adaptation of the protocol. The first step

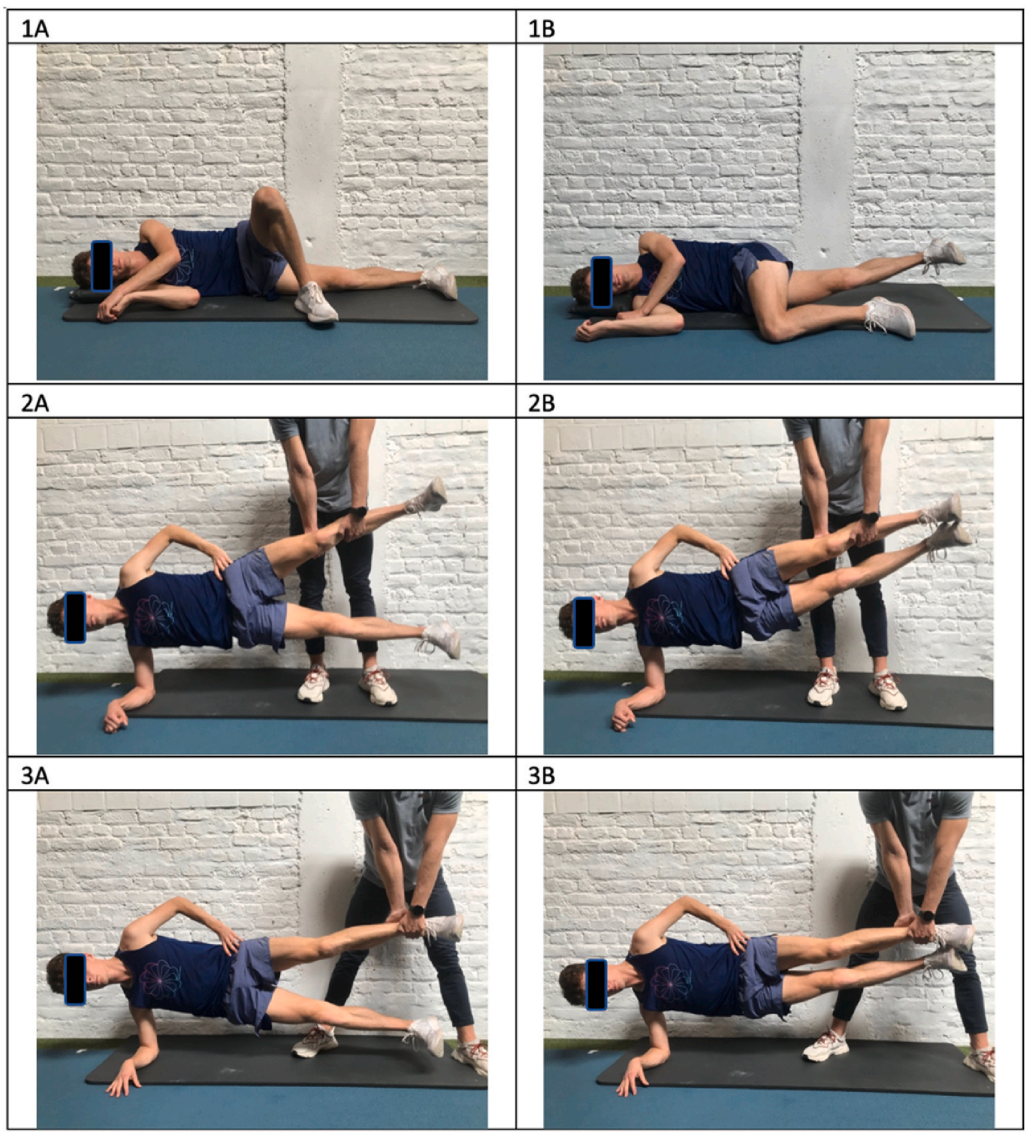

Fig. 1. The different stages in the Copenhagen adductor strengthening program: stage 1 in 1A and 1B, stage 2 in 2A and 2B and stage 3 in 3A and 3B. "A" is the beginning/end of the movement and "B" is the middle of the movement. To complete the movement, the participant must return slowly from "B" to "A" to add the eccentric phase.

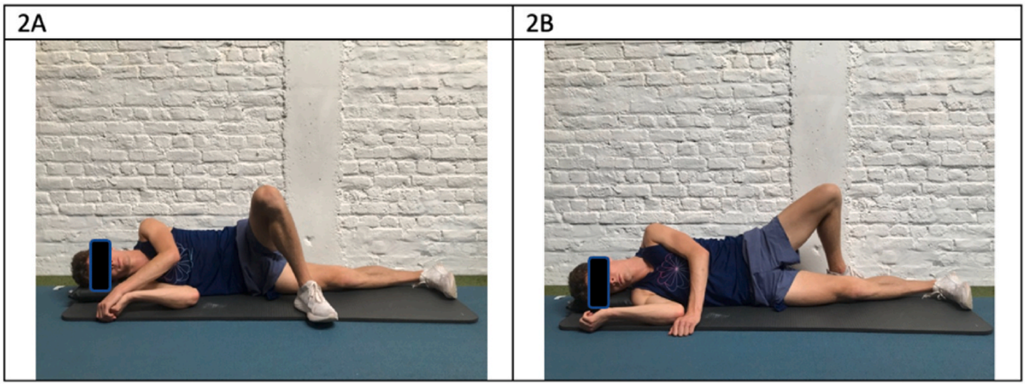

Fig. 2. The CA stage 1 standard (2A) and modified (2B) positions.

was to verify if the modified position had the same muscle activity during the hip adduction movement in a young and healthy population who will not be suffered from pain during the study.

The aim of this study is to verify whether the use of the modified position of the Copenhagen protocol stage 1 is as effective as the CA stage 1 position in terms of functional measurements (EMG and strength). To answer this question, the hypotheses considered are: (i) similar muscle activity of the AL muscle should be measured for both positions during a dynamic exercise and (ii) similar maximum force developed by the lower limb in both positions for a static exercise.

2. Materials and methods

2.1. Population

The participants recruited were all healthy student men, i.e. free of any muscle injury, neurological issue or other health disease for at least 6 months. They were aged between 20 and 31 years old and were randomly recruited. This population was easily accessible at the university campus where the study and experiment took place. The recruited population practised different sports (handball, running, track and field, breaking, triathlon, basketball, waterpolo, combat sports, basketball, climbing, soccer football, fitness, hockey) and were regularly trained, at least 2 times/week.

After having been informed of the objective of the study and of the conduct of the experiment the day before at the latest, each participant signed an informed consent on the day of the experiment. The study was approved by the Hospital-Faculty (Cliniques universitaires Saint-Luc – Université catholique de Louvain) ethics committee (Belgian agreement number: B403201523492).

2.2. Experimental protocol

The experiment took place in a single session on the university campus and included a general warm-up, the placement of the electrodes, and two sets of three MIVC tests in either the modified position or the standard one followed by one set of five dynamic contractions in both positions. The order of the positions was decided randomly (blinded picked by the participant) twice during the experiment, a first time for the MIVC and a second time for the dynamic contractions.

The participants started with a cardio-vascular and respiratory warm-up by cycling on a stationary bicycle during 5 min with a self-selected intensity (Demoulin et al., 2016). It was followed by a specific warm-up including two back-and-forth butt kicks over a 6-m distance, two back-and-forth high stepping exercises over the same distance and 20 jumping jacks.

During the MIVC, the examiner applied a manual resistance with the HDD placed around the knee joint of the dominant leg while asking the participant to provide the greatest contraction possible. More specifically, the HDD was placed at three fingers for the medial knee joint space of each participant's dominant leg to standardise the placement of the HDD during all the MIVC. The contraction lasted 6 s and repeated three times in each position with 1-min break in between and 5-min break between position sets. Auditive feedback was standardised by counting the time with a loud and neutral voice.

Five minutes of rest were given between MIVC and dynamic contractions to avoid fatigue as much as possible (Sesboüé, 2006; Marco et al., 2017). Then, the dominant leg was loaded with a mass attached to the ankle and equal to 2% of the participant's body mass. The participant started the dynamic contractions with the leg raised two cm off the ground to have some tension in the muscle. Each dynamic contraction lasted 4 s in a 2-s concentric (raise the leg as high as possible) and 2-s eccentric (lower the leg back without touching the ground) tempo, guided with an auditive metronome. The total time of dynamic contractions for each position was 20 s, i.e. five repetitions. During the dynamic contractions, the examiner gave verbal feedback to ensure the good rhythm and the correct motion. The participant was given 5-min rest between dynamic contractions on each position.

The surface electrodes were placed by the same examiner throughout the experiment. The same examiner also measured the force developed during MVIC tests, treated the EMG signals and for measurements and carried out the statistical analysis of the results.

To ensure a better record of EMG signals, the participant was asked to shave his thigh the day before (Hermens et al., 2000). On the day of the experiment, the skin was cleaned with alcohol and degreased with ether (Hermens et al., 2000). Three pairs of round surface electrodes (Kendall ECG Electrodes H124SG) were placed on the muscles with an interelectrode distance of 20 mm. Electrodes were placed as follows: at four fingers distal to the pubis for AL (Kaneda et al., 2009), in the middle of the straight line from the anterior superior iliac spine to the upper part of the patella for the rectus femoris (RF) (Hermens et al., 1999) and at the midpoint of the straight line through the ischial tuberosity and the medial condyle of the tibia for the semi tendinous (ST) (Hermens et al., 1999).

The EMG activity of three muscles was recorded during the MIVC tests only for the standard position of the first stage of the CA protocol and during the dynamic contractions for both positions.

2.3. Materials

A 3-channel wireless surface EMG system (BTS FREEEMG 1000, BTS Bioengineering, Italy) was used to record EMG signals of AL, RF and ST. The performance characteristics of the EMG system were: transmission frequency of 2.4 GHz ISM band, input impedance of 100MΩ, resolution of 16bit, common-mode rejection ratio >100 dB at 50–60Hz, a sample rate of 1000Hz, sensitivity of 1 μV and accuracy of ±2%. Raw EMG signals were rectified, filtered using a 5th-order Butterworth lowpass filter with a cut-off frequency of 10 Hz and smoothed with a 150-ms window for visualising (Hinnekens et al., 2019). From filtered EMG signals of MIVC, the EMG amplitude for a given muscle was computed as the root-mean-square (RMS) value of the filtered signal over 5 s. The mean EMG amplitude of the two best MIVC tests (based on the force) was used to normalise filtered EMG signals of dynamic contractions. Normalised EMG signals for dynamic contractions were cut into cycles on a temporal basis and normalised in the temporal basis as well (% cycle). Only cycles 2, 3 and 4 were kept for the analysis to avoid artefacts from the start and the end of the motion. The mean and standard deviation of these three cycles were computed for each subject or for all the subjects together.

An HHD (Microfet 2 Hand-held dynamometer Wireless) was used to measure the force developed during the MIVC. The mean force of the two best MIVC was computed.

2.4. Statistical analysis

Statistical analysis was performed using the SPSS Statistics 27 software. Outcome measures were the normalised force (N/kg), i.e. the mean of the force amplitudes measured with the dynamometer during MIVC divided by the subject body mass, the surface under the curve of the mean of the three normalised cycles and the mean EMG amplitudes over the whole mean normalised cycle. These outcomes measures were computed for both positions.

Normality of the two sets of the three outcomes were checked with the Shapiro-Wilke test. If the same variable had a normal distribution for both positions, a paired *t*-test was performed for this variable between the two positions. If not, a non-parametric Wilcoxon test was performed.

Statistical significance for all tests was considered for alpha = 0.05. When a significant difference was observed, the effect size r was computed and considered as small if $0.1 < r0.3$, medium if $0.3 < r < 0.5$ and large if $r > 0.5$.

3. Results

Over the 31 participants recruited for the experiment, all of them were included in the study. Anthropometric features of the participants are available in Table 1.

When looking at the normality test, none of the EMG sets followed a normal distribution whatever the considered position; only the force sets followed a normal distribution for both positions (Table 2).

The peak EMG activity of AL over the whole cycle was 95.29 ± 54.00 (%MIVC) for the CA stage 1 position and 92.19 ± 63.27 (%MIVC) for the modified position. No difference (p-value = 0.724) was noticed between the two positions over the cycle (Table 2 and Fig. 3). Similarly, no difference (p-value = 0.337) was obtained for RF (Table 2 and Fig. 3). However, for ST, there was a significant difference (p-value<0.001) between both positions, illustrated by smaller EMG amplitudes for the CA stage 1 modified position over the whole cycle (Fig. 3). While for the CA stage 1 position, the ST EMG amplitude reached a peak around 50% MIVC at 40% of the cycle, the ST EMG amplitude for the CA stage 1 modified position was constant around 30%MIVC over the whole cycle. The effect size of this difference gave a r equal to 0.547 standing for a large effect of this difference.

The force measured with the HHD during the MIVC tests was 3.75 ± 0.57 N/kg for the CA stage 1 position and 3.81 ± 0.65 N/kg for the modified position. According to the paired *t*-test, no statistically significant difference (p-value = 0.361) could be certified (Table 2). This result was also highlighted by looking at differences and agreements between the normalised forces measured in the original and modified positions with a Bland-Atlman plot (Fig. 4). The mean of differences between the two measurements was −0.06 N/kg with the differences evenly (in number) but randomly (no specific trend) distributed on both sides of the bias.

Table 1
Participants' features (Mean ± sd). BMI is for body mass index.

Features	Participants, n = 31
Age (years)	23.7 ± 1.9
Height (m)	1.80 ± 0.06
Mass (kg)	72.50 ± 8.58
BMI (kg/m^2)	22.03 ± 1.96
Dominant side	25 = right-handed 6 = left-handed

Table 2
P-values for the normality and statistical (Wilcoxon or t-paired) tests. AL – adductor longus; RF – rectus femoris; ST – semi tendinous. Significant p-values are in **bold**.

	Normality test		Statistical test	
	CA stage 1	CA stage 1 modified	Wilcoxon	Paired *t*-test
AL	**<0.001**	**<0.001**	0.724	–
RF	**0.002**	**<0.001**	0.337	–
ST	**0.008**	**0.002**	**<0.001**	–
Force	0.738	0.575	–	0.361

4. Discussion

The main objective of this study was to verify if the modified CA stage 1 position was as effective as the original position of the Copenhagen protocol. Based on the results, there was no significant difference in EMG amplitude nor strength of the AL with the CA stage 1 position.

In the literature, the CA protocol is well documented and has been shown to be effective in prevention and rehabilitation of hip adductor muscles (Delmore et al., 2014; Harøy et al., 2019; Ishøi et al., 2015; Serner et al., 2014; Thorborg et al., 2011). The modified position is often proposed in clinical setting in patients who could not tolerate hip adduction. While this modified position allows patients to start their rehabilitation, the muscle work remained unclear.

With regard to the comparison of EMG amplitudes of the AL muscle in both positions, no significant difference could be observed. This result would suggest that both positions recruited similarly the AL muscle. The peak EMG amplitude of the AL muscle during the CA stage 1 position was higher than values previously reported in the literature. Serner et al. obtained a peak EMG amplitude of 64%MIVC (Serner et al., 2014) while Delmore et al. obtained a peak value of 60.1%MIVC (Delmore et al., 2014). This difference can be explained by the normalisation method. In the present study, EMG signals were normalised by the RMS value of the EMG signals from the MIVC over 5 s while in both Serner's and Delmore's studies, EMG signals were normalised by the peak value of EMG signals from the MIVC tests. This could explain the smaller peak values reported in these studies as well as the large standard deviation observed in the present study.

To enrich the comparison of the two positions, EMG amplitudes of the RF and the ST were recorded with similar activity of the RF and less activity of the ST in the modified position. This difference was a direct consequence of the modified position. By placing the non-dominant leg behind the dominant leg, the participant unlocks the hip joint and gives more place in the joint space and therefore diminishes the conflict situation causing pain. So, ST insertion points come closer what generates a smaller muscle contraction (Rassier et al., 1999). The orientation of the dominant leg during the motion might also explain the smaller ST EMG amplitude for the modified position. The ST deactivation in the modified position may have interest for rehabilitation following an anterior cruciate ligament (ACL) surgery. Indeed, adductor strengthening is important in the protocol for ACL rehabilitation. Furthermore, hamstring tendon autograft is the most used for ACL reconstruction (Frank et al., 2017), resulting in a sensitive area during first hamstrings' contraction exercises with a tear risk of the removal site. If AL could be isolated by diminishing the ST recruitment, it would be safer for the

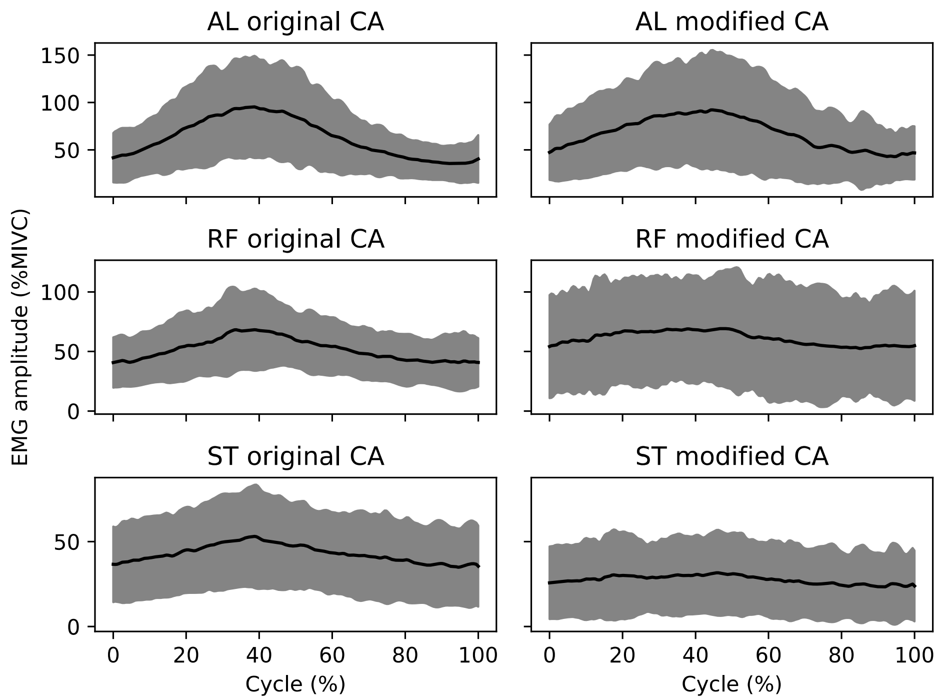

Fig. 3. EMG amplitude (%MIVC) of AL (top), RF (middle) and ST (bottom) over the whole cycle (%) for the CA stage 1 position (left row) and for the CA stage 1 modified position (right row). The black curve stands for the mean of the three cycles and for all subjects and the grey filled surface illustrates the standard deviation.

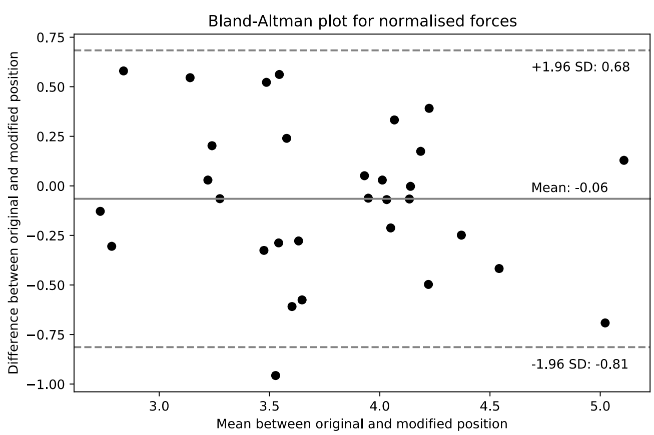

Fig. 4. Bland-Altman plot for the normalised forces measured in the original position vs these measured in the modified position. Each point stands for a subject.

removal site.

The similar maximum force provided in the two conditions confirmed the functional similarity of the CA position and the modified CA position. Force values obtained in this study were a bit greater than equivalent torque-values reported previously (Dawkins et al., 2021; Light & Thorborg, 2016). It was explained by the placement of the HHD on the participant's leg. In previous studies, the HHD was placed at ankle level as it was more reliable and had better test-retest accuracy if the lever arm was larger (at the ankle) (Krause et al., 2007; Light & Thorborg, 2016). In this study, the HDD was placed at knee level to avoid suractivation of the RF and isolate the action of hip adductors. Indeed, if the HHD was placed at ankle level, there was a risk that the participant bent the leg to produce more strength. The examiner should therefore ask to keep the leg straight, what would have recruited the RF and other muscles more.

Differences and agreements between the normalised forces from the original position and these from the modified position tended to confirm that there was no difference in terms of forces. The bias was almost equal to 0 with an evenly distribution of the differences on both sides of the bias, without any specific trend. The distribution of the differences was also random at the same time, which indicated consistency of the difference across the magnitudes of normalised forces. Finally, all subjects but one were in the limits of agreement defined by the 95% confidence interval, which suggested that both positions were similar.

Considering the absence of significant differences for the AL, the RF and the strength developed during the MIVC tests between the two positions, it seems reasonable to consider the proposed modified CA stage 1 position as an appropriate alternative for people who could not start the CA program due to hip pain or discomfort.

4.1. *Limitations of the study and future work*

In this study, the modified CA stage 1 position was validated only on healthy individuals while the CA program has been mainly designed to be used in rehabilitation by injured athletes or in prevention by elite athletes (Harøy et al., 2019). Furthermore, the modified CA stage 1 position as it has been proposed here, is intended for patients requiring adductor strengthening and possibly having FAI, whose prevalence in patients with groin pain has been showed (Weir et al., 2011). An additional study involving pathological subjects should be carried out to fully validate the use of the modified CA stage 1 position compared to the standard one.

This study focused on male participants. Given the sex dimorphism for the pelvic anatomy (Lewis et al., 2017) and in the hip joint (Nakahara et al., 2011), sex-related differences could be expected in the CA stage 1 modified position for both muscle activity and adductor strength. Therefore, a study comparing males and females for both CA stage 1 standard and modified position should be considered.

In order to further investigate the clinical potential of the proposed CA stage 1 modified position, it would be interesting to carry out a clinical study by recruiting a sufficient number of pathological subjects suffering from FAI and by making two groups with a random assignation to possibly objectify a clinical difference. The objective would be to evaluate adductor reinforcement by comparing a first control group doing only the CA stage 1 exercise with the second intervention group doing the modified position. Both groups would be assigned to a set of varied exercises for adductor strengthening but not only (Ellsworth et al., 2014; Moran & Rogowski, 2020). Relevant outcomes for this clinical study should be the time needed between the different stages of the CA program, adductor strength, discomfort (visual analogue scale pain (Chandrasekaran et al., 2017; Lindman et al., 2021; Owens et al., 2022)), range-of-motion or patient-reported outcome scores in order to draw conclusions about the effectiveness of each position in a pathological population. A third group could also be considered for this clinical study, in which neither of the two positions of the CA stage 1 would be implemented to study its usefulness and its effectiveness to reach the CA stage 2 compared to other adductor strengthening exercises using elastic bands. The discomfort caused by the CA stage 1 position in practice needs to be confirmed before implementing this clinical study.

Finally, if they are future studies, several settings used in this study during the experiment could be improved. About EMG, a real-time biofeedback of the motion during the dynamic contractions (mirror or floor markings) would ensure its good execution and avoid noise in EMG signals. About both EMG and force during MIVC tests, an external standardised resistance should be implemented instead of a manual resistance.

5. Conclusion

In this study, a modified position of the CA stage 1 exercise was proposed by moving the non-dominant leg behind the dominant leg and therefore limiting the hips internal rotation. The muscle activity of the AL and RF as well as the adductor strength remained constant between both conditions. These results lead to the conclusion that the modified position is similar and as effective as the standard one and can be used in clinical conditions in subjects reporting hip discomfort in the CA stage 1 standard position.

Ethical approval

The study was approved by the Hospital-Faculty (Cliniques universitaires Saint-Luc – Université catholique de Louvain) ethics committee (Belgian agreement number: B403201523492). Each participant signed an informed consent after having been informed of the objective of the study and of the conduct of the experiment.

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CRediT authorship contribution statement

Simon Hinnekens: Writing – review & editing, Validation, Supervision, Software, Resources, Methodology. **Élène Fickers:** Writing – original draft, Methodology, Investigation, Formal analysis. **Grégory Vervloet:** Writing – review & editing, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jbmt.2024.02.017.

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