This is a post-peer-review, pre-copyedit version of an article published in European Journal of Applied Physiology. The final authenticated version is available online at: 10.1007/s00421-019-04262-y

Short term effect of delayed-onset muscle soreness on trunk proprioception during force reproduction tasks in a healthy adult population: a crossover study

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Conflict of Interest Statement: There is no conflict of interest.

Funding: This research received funding from Natural Sciences and Engineering Research Council of Canada (NSERC).

Abstract:

Purpose: The aim of this study was to evaluate the effects of lumbar muscle delayed-onset muscle soreness (DOMS) on the ability of the trunk muscles to reproduce different levels of force.

Methods: Twenty healthy adults (10 males and 10 females) were recruited for this study. Force reproduction in trunk extension and flexion was assessed at 50 and 75% of participants' maximal isometric voluntary contraction in flexion and extension before and after a lumbar muscle DOMS protocol. Trunk proprioception was evaluated and compared between these conditions using different variables such as constant errors (CE), absolute errors (AE), variable errors (VE) and time to peak force (TPF). For each variable, repeated measure ANOVAs were conducted.

Results: AE were higher when participants had to reach the target post-DOMS protocol in extension compared to flexion and in presence of higher demand of force (p=0.02). For VE, results showed that participants were more variable in extension than in flexion when the required force was higher (p=0.04). CE variable was higher when participants had to reach the force target in extension compared to flexion under the effect of DOMS (p=0.02). Results also showed that participants took less time to reach the force target post-DOMS protocol in extension (0.62 ± 0.20 sec) and in flexion (0.53 ± 0.19 sec) than pre-DOMS protocol in extension (0.55 ± 0.15) and in flexion (0.50 ± 0.20) (p<0.001).

Conclusion: Lumbar muscle DOMS affect trunk proprioception during force reproduction tasks especially in trunk extension and at higher force.

Keys words: Delayed-onset muscle soreness, lumbar, sensorimotor control, pain, proprioception

List of abbreviations

DOMS: Delayed-onset muscle soreness

MVC: Maximum voluntary contraction

IPAQ: International physical activity questionnaire

CE: Constant error

AE: Absolute error

VE: Variable error

TPF: Time to peak force

Introduction

Delayed-onset muscle soreness (DOMS) can be defined as musculoskeletal pain and soreness and as a sensation of discomfort (Cleak and Eston 1992) that lasts for several days (Weerakkody et al. 2001) and that is induced by unusual intense exercises and/or eccentric contractions (Coudreuse et al. 2004; MacIntyre et al. 1995; Proske et al. 2003). The DOMS effects peak between 24 to 72 hours following those exercises and disappear progressively in three to five days (Cheung et al. 2003; Coudreuse et al. 2004). DOMS is usually associated with inflammation and muscle damage and individuals presenting DOMS can experience muscle stiffness, pain and/or movement restrictions (Farias-Junior et al. 2019) and a decrease of maximal muscle strength (Abboud et al. 2019). Effects of DOMS on proprioception are characterized by a significant increase in errors in upper limb positioning and force reproduction tasks (Proske et al. 2003), suggesting that, when muscles become sore in the presence of DOMS or following paralysis, the motor command sent to muscles is not relevant to the desired outcome. Proprioception includes the sense of limb position and movement, and the sense of force and effort (Jerosch and Prymka 1996). Proprioception can be evaluated by repositioning tasks and force reproduction tasks, which mainly assess conscious proprioception (Hagert 2010).

Trunk proprioception in lumbar muscles as well as abdominal muscles can be altered in patients with chronic or recurrent low back pain (Hodges and Richardson 1999; Rausch Osthoff et al. 2015; Tong et al. 2017). However, because of within- and between- patient variability in motor behaviour (van Dieen et al. 2017), drawing conclusion about the mechanism underlying proprioception alterations in this population is still challenging. Lumbar muscle DOMS is therefore a relevant experimental pain model because of its ability to recreate altered motor functions, such as a decrease in lumbar muscles strength and an increase of fear of pain (Abboud et al. 2019; Bishop et al. 2011), which are also observed in lumbar muscles of patients with chronic or recurrent non-specific low back pain (Hodges and Danneels 2019).

Furthermore, using DOMS as a pain model may help clarify the mechanism underlying proprioception alterations in patients with low back pain. Therefore, the aim of this study was to evaluate, in a healthy adult population, the effects of lumbar muscle DOMS during different force reproduction conditions. We hypothesized that trunk proprioception in the direction of extension will be more altered than in flexion and that this alteration will increase with higher force demand (della Volpe et al. 2006; Proske et al. 2003).

Materials and Methods

Study design

We conducted a crossover study at the University [XXX] Laboratory. Recruitment and data collection were completed from May to July 2018.

Participants

Twenty healthy adults, 10 females and 10 males, were recruited among the university community and employees and by social medias. To be included in the study, participants had to be back pain free. If they have experienced recurrent back pain or occasional pain in the last six months, they were not allowed to participate in this study. Other exclusion criteria were health conditions such as neuromuscular diseases, uncontrolled hypertension and heart disease, or cancer. Pregnant women were also excluded. The study was approved by the University humans research ethics board (CER-18-245-07.10) and written informed consent was obtained from each participant before the beginning of the experiment. Participants were advised that they had the possibility to withdraw from the study at any moment.

Experimental protocol

The experimental protocol was divided into two sessions separated by 24 to 36 hours. The period between the first and the second session was based on a previous study showing that pain and soreness following a lumbar muscle DOMS protocol peaks between 24- and 36 hours (Abboud et al. 2019). In the first session, participants were asked to fill in one questionnaire. Then, isometric muscles trunk extension and flexion maximum voluntary contraction (MVC) and different force reproduction tasks were evaluated for each participant. Finally, participants were asked to perform the lumbar muscle DOMS protocol. In the second session, trunk extension and flexion MVC and force reproduction tasks were assessed again. A timeline for clinical and physical outcome assessment is presented in Figure 1.

[Insert figure 1. about here]

Questionnaire

To assess level of physical activity, participants were invited to complete the short version of the International Physical Activity Questionnaire (IPAQ). Reliability and validity of the IPAQ short form have been tested in over twelve countries (Craig et al. 2003). This questionnaire is composed of 9 items assessing the intensity of physical activity habits in the past week (Lee et al. 2011).

Force reproduction tasks

All force reproduction conditions were performed on an isokinetic device (The LIDO Active Loredan Biomedical, West Sacramento, CA). Participants were semi-seated in a neutral position and they were attached to the device with four belts (Figure 2). Neutral position was defined as natural spine curve, hip angle was ~135° and knees were in full extension to minimize the contribution of lower limbs muscles and to better isolate trunk muscles during the force reproduction tasks. In fact, it has been shown that the pelvic stabilization increases the recruitment of low back muscles and decreases the contribution of hip extensors during dynamic lumbar extensions (da Silva et al. 2009). One belt was placed over the chest, another one was over the upper abdomen and the last two were over the hips and on the thighs. At first, three MVC were realized for both flexion and extension. The highest value of MVC for flexion and extension was used for the force reproduction tasks. Participants were free to experiment flexion and extension on the isokinetic device to familiarize with the equipment before performing MVC. For the flexion MVC, participants were told to push as hard as they can for 5 seconds against a resistance located at the sternum. For the extension MVC, the middle of the resistance was placed on the eighth thoracic vertebra. Then, trunk force reproduction was assessed in four conditions: trunk flexion and extension at

50% and 75% of MVC. Each condition of the force reproduction task was conducted both with and without visual feedback. The condition's order was randomized using computer random number generator (randomization.com) to minimize possible learning effects and residual muscle fatigue. Prior to recording the force reproduction task without visual feedback, practice trials within a 10% margin error of the target goal were allowed to each participant to get familiar with the task. Practice trials were stopped when 10 consecutive trials were performed within the margin of error. Participants were then asked to reproduce 10 trials of the same force level without visual feedback (Figure 3) and analyses were conducted considering these 10 repetitions without feedback. Participants were given a one-minute rest period between conditions to limit the occurrence of muscular fatigue. For all trials, participants were asked to provide a single impulse without correcting the force once the contraction was initiated. Participants were instructed to perform the task as quickly as possible.

[Insert figures 2 and 3 about here]

DOMS protocol

First, participants completed three MVC in trunk extension on a 45-degrees Roman chair to evaluate lumbar extensors maximal strength (Figure 4; (Lariviere et al. 2011; Parreira et al. 2013). They had their trunk parallel to the floor in a prone position and were asked to push as hard as possible against a belt installed over the participant's shoulders. A load cell (Model IPM250; Futek Advanced Sensor Technology Inc, Irvine, CA, USA) was connected to the belt and gave indications about peak torque in trunk extension. The highest MVC value was used to determine a 10% external weight which was used for the entire endurance DOMS protocol. Then, participants were invited to complete the DOMS protocol that targeted low back muscles. The lumbar muscle endurance DOMS protocol was performed on the 45-degrees Roman chair in the same position used to establish MVC. In fact, participants initiated the DOMS protocol in a horizontal position with their trunk parallel to the ground. This protocol consisted of 5 sets of 20 repetitions of trunk flexion-extension with the 10% external weight in the hands and with two minutes of rest between each set. A repetition consisted of (1) three seconds 30-degrees trunk flexion from horizontal (2) three seconds of isometric contraction and (3) one-second trunk extension starting from the flexion position to 30-degrees trunk extension from the horizontal (head, trunk and lower limbs needed to be in a neutral alignment). There were two indicators placed to help participants to complete the task adequately: one at 30-degrees trunk extension position and one at 30-degrees of trunk flexion. Participants hips and ankles were stabilized using straps to minimize pelvic tilt movements, which could limit the contribution of muscle groups other than paraspinal muscles during the DOMS protocol. A visual and auditory feedback was provided for participants during the protocol to help them following the tempo (3-3-1). Participants were motivated by verbal encouragements given by the assessors. The validation of the DOMS protocol was performed in a previous study (Abboud et al. 2019).

[Insert figures 4 about here]

Pain and Soreness Assessment

Lumbar muscle pain and soreness were assessed via text messages or emails sent to participants immediately following the first session (DOMS protocol). Text messages or emails were sent by one evaluator and this evaluator was not implicated neither in the lumbar muscle DOMS protocol and in force reproduction tasks. This evaluator was also naïve to expected results of the study. Data collection was completed over five consecutive days, three times a day. Participants received the message at 9 am, 3 pm and 9 pm (Figure 1). Participants were asked to rate the intensity of both lumbar muscle pain and lumbar muscle soreness using a 0-10-point scale. They were also asked to report any other side effects while answering daily text messages. During these five days, participants were asked to avoid any high intensity or unusual exercise or medication aiming to reduce pain or soreness. Based on the pain and soreness scores of each participant, the time it takes to higher level of pain and soreness were computed using the average time until the occurrence of the highest pain and soreness scores.

Dependent Variables

Constant error (CE), absolute error (AE), variable error (VE) and time to peak force (TPF) were calculated and compared between each condition (50% and 75% in extension and flexion) and each session (pre-DOMS and post-DOMS). These four variables are commonly used to assess trunk proprioception (Abboud et al. 2018; Boucher et al. 2015; Lee et al. 2010; McNair and Heine 1999). CE was the positive or the negative difference between the force value deployed by participants and the targeted force identified based on 50 or 75% of participants' MVC in extension or in flexion. AE was the absolute difference between the force value deployed by participants to reach the target and the force identified as the target. VE was defined by the peak force reach consistency compared with the average score of participants. TPF represented the time needed by participants to reach the force target.

Statistical Analysis

Analyses were performed using STATISTICA statistical package version 10 (Statsoft, Tulsa, OK), and the level of significance was set at $p \leq 0.05$. Normality of distribution was assessed with the Kolmogorov–Smirnov test and by visual inspection. A mixed model three-way repeated measure ANOVAs were conducted to assess for each dependent variable: (1) the direction effect (flexion versus extension); (2) the force intensity effect (50 versus 75% MVC); (3) the DOMS effect (pre- versus post-DOMS); and (4) all the interaction effects. When necessary, the Tukey post-hoc test was performed as the post-hoc analysis for pairwise comparisons. Effects size of significant difference were calculated using partial eta-squared (0.01 = small effect; 0.06 = medium effect; 0.14 = large effect).

Results

Baseline demographics

Twenty participants (10 females and 10 males) were included in the study and completed the protocol. Mean scores and standard deviation were calculated for all clinical and physical outcomes and are presented in Table 1. All participants experienced pain and/or soreness in the lumbar muscles. The highest pain values were observed approximately 20 hours following the DOMS protocol, while the highest soreness values occurred after 30 hours. Immediately after DOMS protocol, 2 participants reported a light hyperalgesia in the thigh lasting 2 days due to the contact pressure point on the inclined Roman bench.

[Insert table 1. about here]

Force reproduction task

Dependent variable means and standard deviations for each condition during pre-DOMS and post-DOMS protocol are presented in Table 2. ANOVAs results showed significantly higher values for all dependent variables (CE, AE, VE and TPF) in extension when compared to flexion (all ps≤0.01; Table 3 and Figure 5). Moreover, a significant DOMS X Direction X Force interaction was found for AE (p=0.02) as illustrated in Figure 6. Results from the post-hoc test showed significantly higher AE value in extension post-DOMS in comparison to flexion post-DOMS protocol at 50% (p=0.046) and 75% (p=0.01). Results also showed a significant influence of force intensities (50% versus 75%), with higher value at 75% MVC for AE (p=0.03) and VE (p=0.04). A significant decrease was shown in TPF (p<0.001) between pre- and post-DOMS protocol. There was also a significant main effect of direction (extension versus flexion; p=0.01) showing that participants were poorer in extension than in flexion to reproduce the task. A significant Direction X Force intensity interaction effect for VE variable was also found (p=0.04) and Tukey post-hoc revealed that participants were more variable at 75% than at 50% in extension for VE (p≤0.003) but not in flexion (p=0.74). Tukey post-hoc also showed that they were more variable in extension than in flexion for both forces (p=0.02 at 50% and p≤0.001 at 75%). Another significant Direction X DOMS interaction effect for the CE variable was observed (p=0.02). Tukey post-hoc showed that CE was higher in extension compared to flexion post-DOMS protocol (p≤0.001). Post-hoc also showed that CE increased in extension post-DOMS protocol compared to flexion post-DOMS protocol (p=0.03). All other results were not statistically significant (Table 3).

[Insert tables 2 and 3 about here]

[Insert figures 5 and 6 about here]

Discussion

The objective of the present study was to evaluate the effect of lumbar muscle DOMS on trunk proprioception during different force reproduction tasks in a healthy adult population. Our hypothesis was that trunk proprioception in the direction of extension would be more altered than in flexion and that this alteration would increase with higher force demand. Results showed that participants (1) were more variable to reproduce forces (VE) in extension than in flexion regardless of the presence of lumbar muscle DOMS; (2) larger force production errors occurred for the higher level of force and more variability in the produced force was present in extension than in flexion; (3) under the influence of DOMS the performance to reach the force target in trunk extension was altered, while it remained unchanged in trunk flexion; (4) participants were faster in the force reproduction tasks under the influence of lumbar muscle DOMS.

Trunk Proprioception

Across all conditions, force production was observed to be more accurate in flexion compared to extension. Such difference between extension and flexion movement accuracy can be explained by the fact that participants generated higher MVC contractions in trunk extension than in flexion, leading to higher target forces in extension during the force reproduction protocol (more than 2 times higher). In line with this observation, results of the current study also showed differences between force accuracy at 50% and 75% of MVC for both trunk flexion and extension tasks. Participants were more accurate during the execution of force reproduction task at 50% of MVC than to during those performed at 75% of MVC. These results taken together suggest that force variability increases as the target force increases. It has been previously shown that, force variability increases linearly with force at moderate levels of force (Sherwood and A. Schmidt 1980).

DOMS and Trunk Proprioception

Trunk proprioception was altered under the influence of lumbar muscle DOMS, with the observation of higher AE and CE values in trunk extension in comparison to flexion. These findings suggest that DOMS had a direct impact on the proprioception of muscles that have undergone eccentric contractions, while the proprioception of the unaffected muscles (trunk flexors) remained unchanged. Even if not directly assessed in the current study, these observations support the recent views regarding the important contribution of peripheral sensory information in the production of force (Luu et al. 2011; Scotland et al. 2014) and expand it to axial muscles. A recent study showed that, in healthy individuals under the influence of experimental low back pain triggered by a combination of DOMS and hypertonic saline solution, the increase in trunk extensor muscle activity was not accompanied by an increase in trunk flexor muscle activity during postural perturbations (Larsen et al. 2017). These previous results along with those of the present study suggest that minimal or no change in the control of the trunk flexor muscles are necessary to achieve a desired motor outcome, such as trunk proprioception or postural control (Bartlett et al. 2007).

However, VE variable was not affected by lumbar muscle DOMS. Such lack of DOMS effect on VE could partially be explained by the participants' overall level of physical activity. Participants were considered moderately (at least 600 MET-min/week) to highly (3000 MET-min/week) active with a mean score of 2.7 on the short form of the IPAQ questionnaire. It has been proposed that a higher level of motor variability that is functionally related to the task is present in individuals that are physically active which could favour motor performance while limiting the occurrence of muscle fatigue (Bartlett et al. 2007; Robins et al. 2006). It can be hypothesized that under the influence of lumbar muscle DOMS, participants were able to find a new strategy, such as variation in muscle activity, to perform the desired task. This should be addressed in future research to better understand the effect of DOMS in the lumbar region.

Future studies should also consider exploring the relation between trunk proprioception under DOMS effects and physical activity by including individuals from each active group (sedentary to very active).

Difference and Similarities Between DOMS and Low Back Pain

As expected, the present results showed that the DOMS protocol induced experimental low back pain and soreness, which is consistent with previous studies (Abboud et al. 2019; Cheung et al. 2003). The presence of DOMS was confirmed by lumbar pain and soreness values of 2.8 and 3.8 respectively, which represent mild pain intensity and moderate soreness intensity.

DOMS has been used as a relevant pain model, which is able to reproduce alteration usually present in patients with chronic or recurrent low back pain (Abboud et al. 2019; Bishop et al. 2011). As shown in the present study, mild to moderate pain and soreness in addition to the decrease of proprioception are features of DOMS, which are similar to characteristics also found in chronic or recurrent patients with low back pain. DOMS has been associated with a decrease of muscle strength, muscle power and range of motion due to micro muscle damage (Cheung et al. 2003; Mizumura and Taguchi 2016). These muscle damages can create temporary muscles dysfunctions and perceptions (location in the space and/or strength) and, in the same way, affect performance (Larsen et al. 2017; Paschalis et al. 2007; Pearcey et al. 2015) such as precision of movement (decrease of joint range of motion) and proprioception (Vila-Chã et al. 2011), which can affect the recruitment patterns (Larsen et al. 2017; Pearcey et al. 2015; Vila-Chã et al. 2011). Alteration in trunk proprioception, such as increase of errors in reproduction force task, has been also observed in patients with chronic low back pain (Descarreaux et al. 2007).

In the present study, a significant difference in TPF for both flexion and extension tasks were observed between the pre- and post-DOMS protocol. It was recently reported that movements associated with pain are performed faster compared to movements without pain (Karos et al. 2017). Even if participants were statistically faster in pre-DOMS condition, it should be noted that differences between TPF pre- and post-DOMS protocol varied from 30 to 60 milliseconds in flexion and varied from 60 to 70 milliseconds in extension. In a previous study, participants had to reproduce 50% and 75% of their MVC in flexion and in extension in an isometric condition with their eyes closed. The authors showed that patients with chronic low back pain took ~120 milliseconds longer than the healthy group to reach the force target (Descarreaux et al. 2007). Therefore, it remains unknown if changes in TPF should be considered as relevant functional changes for patients with chronic or recurrent low back pain as healthy participants post-DOMS protocol. Theories of short-term pain adaptations propose that changes in the motor system are related to a protection mechanism, while in the long-term this adaptive behaviour may lead to further problems (Hodges and Tucker 2011; van Dieen et al. 2017). Another explanation for the difference between DOMS and clinical low back pain effects on TPF is the fact that participants in the current study were moderately to highly active, while the group of patients with chronic low back pain in Descarreaux et al., (2007) study were considered as moderately disabled.

Limitations and Future Recommendations

Participants were mostly young adults moderately to highly physically active, which could have minimized the effect of DOMS. However, they reported levels of back muscle pain and soreness similar to other studies using similar protocol to induce lumbar muscle DOMS (Abboud et al. 2019; Hjortskov et al. 2005), which suggest the occurrence of DOMS in the lumbar muscles. Having a small group of participants with similar characteristics can limit the generalization which may lead to an overestimation of the current results. However, most of the differences of the current results were highly significant (p=0.02 to p<0.001). Adaptations in the muscle recruitment strategy could have occurred under the influence of DOMS to perform the task, as observed in patients with chronic low back pain (Abboud et al. 2019; Falla et al. 2014). In addition, even if there is a rest time between force reproduction task and that force reproduction tasks were randomized, it was impossible to ensure that participants did not have residual fatigue during the experimentation. Future studies should assess lumbar muscle recruitment strategies under the influence of lumbar muscle DOMS to confirm this theory. Future studies also should assess sex-comparison to evaluate if there is differences in strategies used during force reproduction tasks.

Conclusion

Lumbar muscle DOMS affect lumbar muscles proprioception during force reproduction tasks especially in extension at higher level of force, while this performance was unchanged in trunk flexion. This study suggests that lumbar muscles proprioception in lumbar muscles has been altered in muscles that have been directly affected by the DOMS effects, supporting the important contribution of the peripheral sensory systems in force reproduction. DOMS represent a relevant pain model to better understand function alterations and pain mechanisms present in complex anatomical systems such as the trunk in patients with chronic and recurrent low back pain.

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Table 1: Participant's results on clinical and physical outcomes

	Outcomes	*Experimental Group (n=20) Mean ± SD*
Demographics	Age (years)	25.5 ± 5.2
	F : M	10 : 10
	Weight (kg)	69.6 ± 14.6
	Height (m)	1.7 ± 0.1
	BMI (kg/m^2)	23.3 ± 2.7
	IPAQ-SF	2.7 ± 0.5
Pain	Peak intensity (/10)	2.75 ± 2.27
	Days with pain	1.65 ± 1.27
Soreness	Peak intensity (/10)	3.80 ± 2.35
	Days with soreness	2.10 ± 0.91
MCV	Extension pre-DOMS (Nm)	174.89 ± 78.12
	Extension post-DOM (Nm)	178.53 ± 89.14
	Flexion pre-DOMS (Nm)	79.60 ± 34.03
	Flexion post-DOMS (Nm)	86.18 ± 33.88

F: female, M: Male, BMI: Body Masse Index, IPAQ-SF: International Physical Activity (short-form), MVC: Maximal Voluntary Contraction, DOMS: Delayed onset muscle soreness

Table 2: Means of errors and time to peak for pre- and post-DOMS in flexion and extension

	Flexion		**Extension**	
	Pre-DOMS	***Post-DOMS***	***Pre-DOMS***	***Post-DOMS***
50% force				
	Mean ± SD	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**
CE (Nm)	0.78 ± 11.09	-4.92 ± 5.78	4.80 ± 7.14	9.46 ± 15.28
AE (Nm)	8.07 ± 7.82	6.63 ± 4.13	8.15 ± 5.67	13.95 ± 12.01
VE (Nm)	4.04 ± 2.07	4.07 ± 2.25	6.81 ± 4.49	6.05 ± 2.86
TPF (sec)	0.54 ± 0.16	0.48 ± 0.14	0.62 ± 0.15	0.56 ± 0.10
75% force				
CE (Nm)	2.47 ± 6.50	-2.15 ± 11.15	6.05 ± 24.20	11.97 ± 20.13
AE (Nm)	6.23 ± 4.53	9.71 ± 6.31	18.22 ± 17.07	18.35 ± 14.49
VE (Nm)	4.42 ± 5.53	5.15 ± 2.86	9.80 ± 7.53	9.06 ± 6.83
TPF (sec)	0.53 ± 0.19	0.50 ± 0.20	0.62 ± 0.20	0.55 ± 0.15

CE: constant error, AE: absolute error, VE: variable error, TPF: time to peak force, SD: standard deviation, DOMS: Delayed onset muscle soreness

Table 3: Statistical analysis for each dependent variable

	Direction (Di)	**Force (F)**	**DOMS (Do)**	**Di x F**	**Di x Do**	**F x Do**	**Di x F x Do**
CE	F=10.75 *$p \leq 0.001$ ηp^2=0.36	F=1.32 p=0.26	F=0.001 p=0.97	F=0.003 p=0.95	F=6.32 *p=0.02 ηp^2=0.25	F=0.22 p=0.64	F=0.0005 p=0.98
AE	F=26.96 *$p \leq 0.001$ ηp^2=0.59	F=5.61 *p=0.03 ηp^2=0.23	F=3.17 p=0.09	F=2.76 p=0.11	F=0.57 p=0.46	F=0.02 p=0.88	F=6.18 *p=0.02 ηp^2=0.25
VE	F=23.82 *$p \leq 0.001$ ηp^2=0.56	F=4.92 *p=0.04 ηp^2=0.21	F=0.29 p=0.59	F=5.00 *p=0.04 ηp^2=0.21	F=1.84 p=0.19	F=0.18 p=0.67	F=0.48 p=0.50
TPF	F=8.00 *p=0.01 ηp^2 =0.30	F=0.004 p=0.95	F=11.38 *$p \leq 0.001$ ηp^2 =0.37	F=0.22 p=0.64	F=0.14 p=0.71	F=0.52 p=0.48	F=0.97 p=0.34

CE: constant error, AE: absolute error, VE: variable error, TPF: time to peak force, SD: standard deviation, *significant *p* values based on ANOVA

Figure captions

Fig. 1. Timeline for clinical and physical outcomes.

DOMS: delayed-onset muscle soreness, MVC: maximum voluntary contraction.

Fig. 2. Position of participants on lido for trunk strength reproduction task.

Fig. 3. Example of steps of the force reproduction task.

Fig. 4. Position of participants on the 45 degrees Romain chair during the lumbar muscle DOMS protocol.

Fig. 5. Direction effect (extension vs flexion) for each dependent variable (CE, AE, VE and TPF).

CE: constant error, AE: absolute error, VE: variable error, TP: time to peak, bars indicate standard deviation.

Fig. 6. ANOVA for interaction between direction, force and DOMS for the AE.

Bars indicate standard errors.

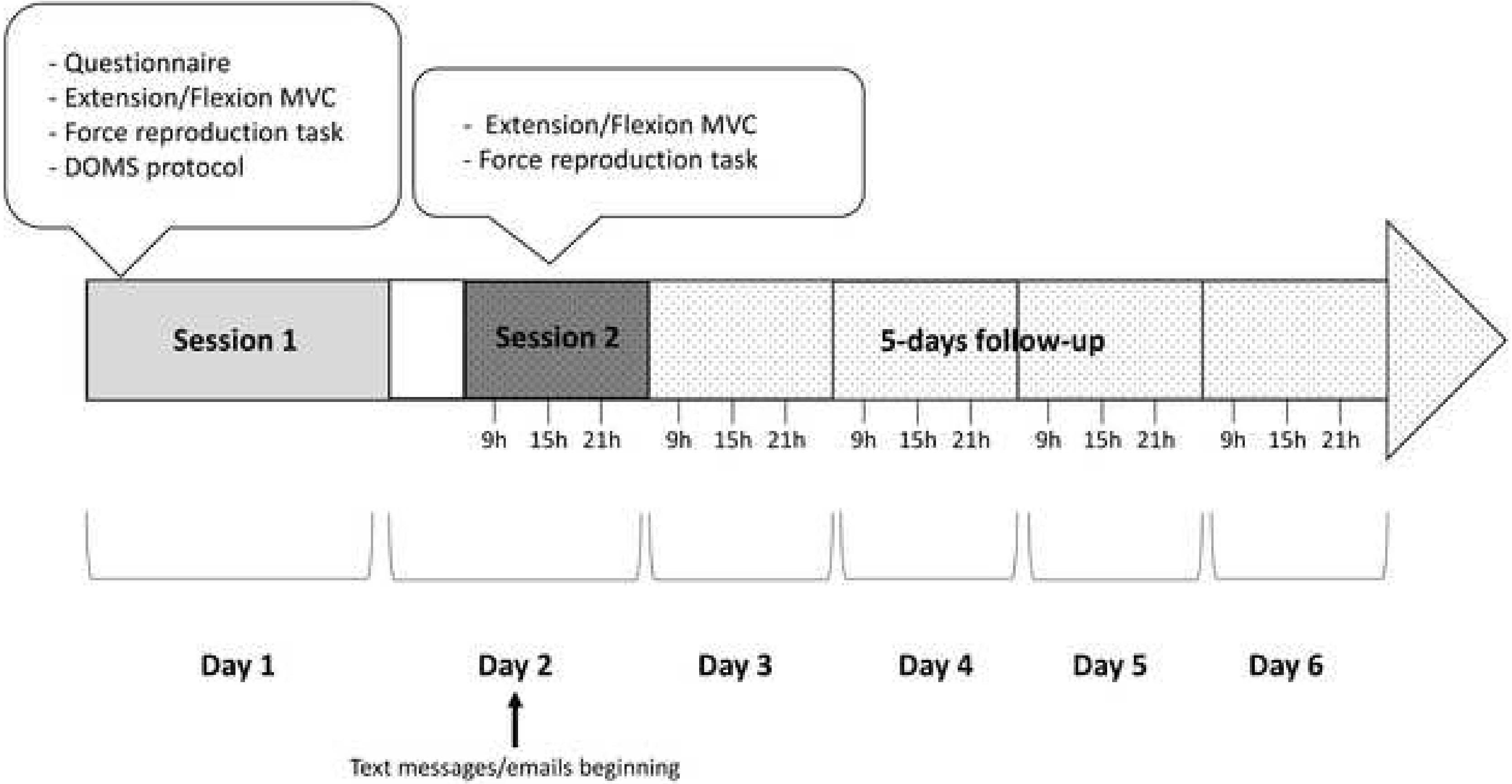
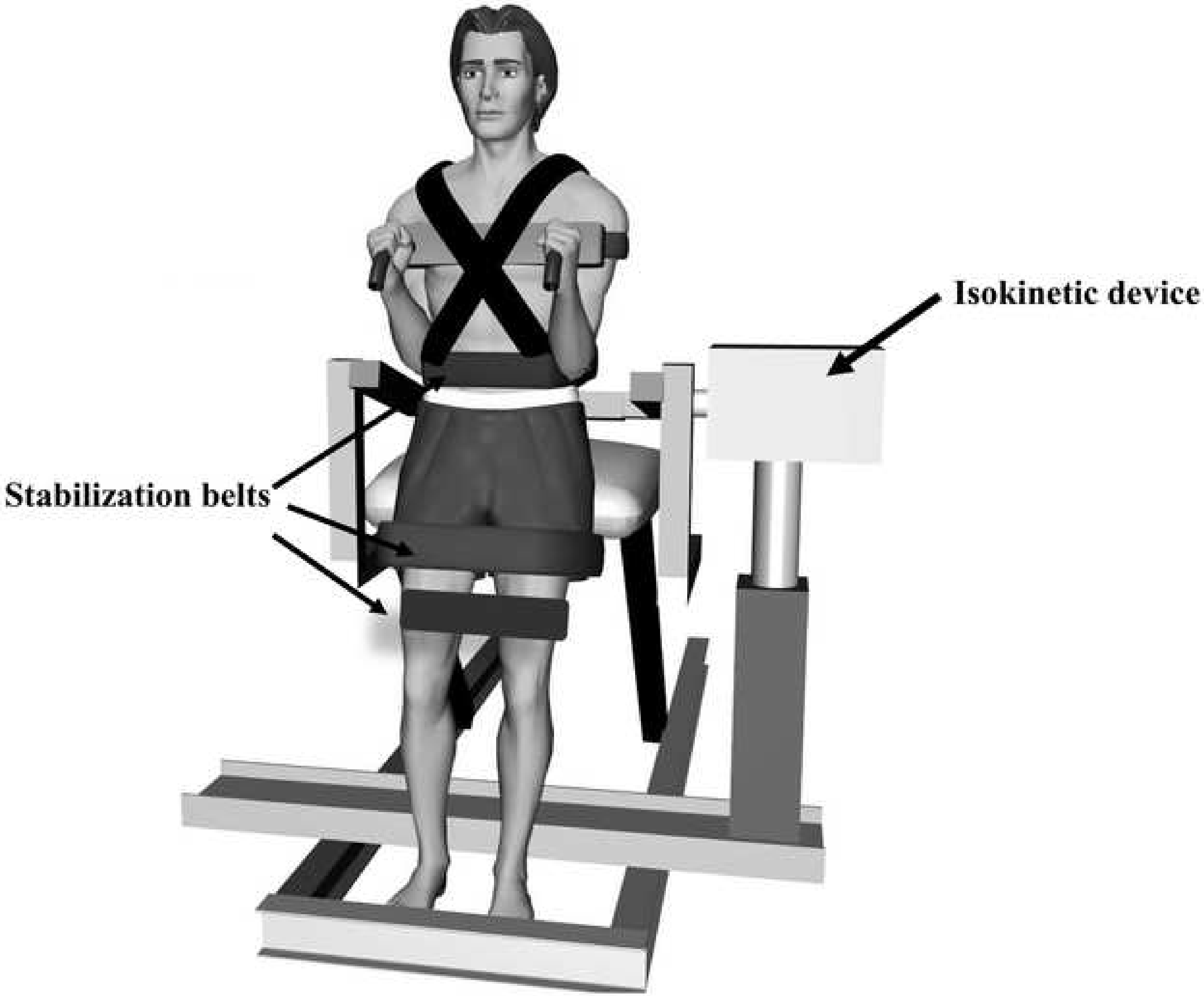
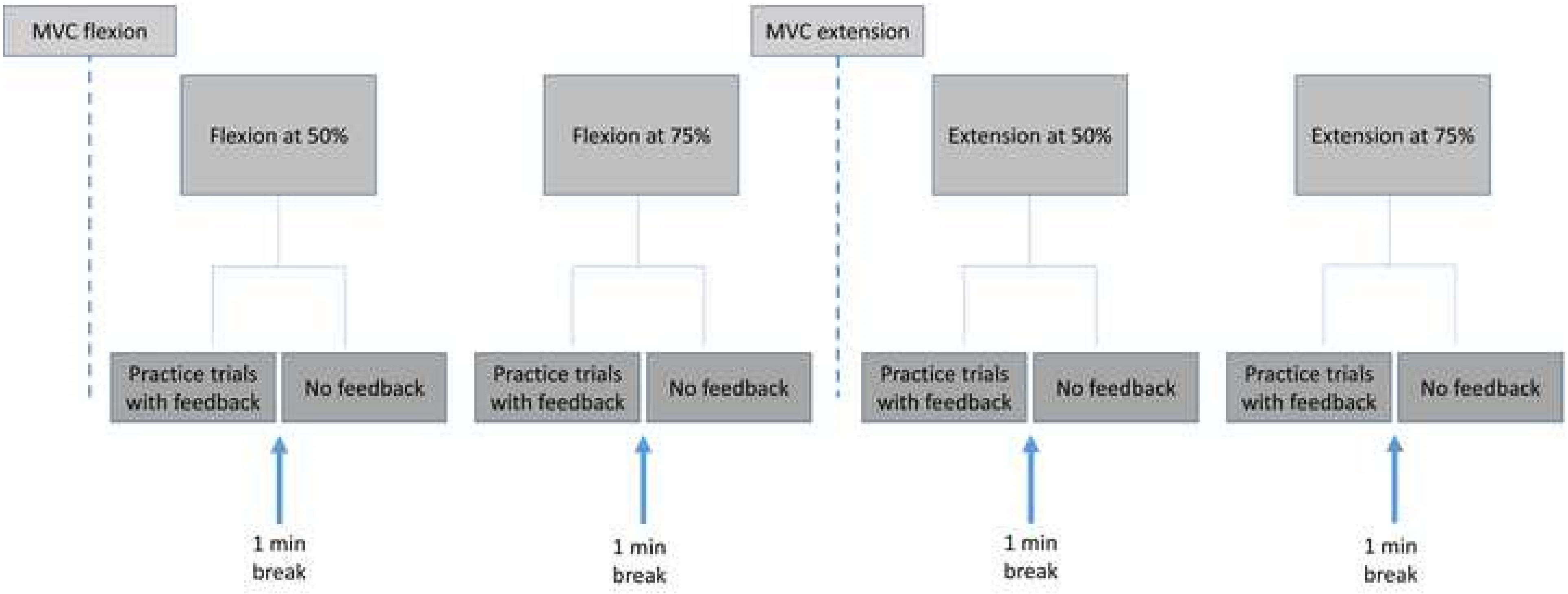

- Questionnaire
- Extension/Flexion MVC
- Force reproduction task
- DOMS protocol
- Extension/Flexion MVC
- Force reproduction task
Session 1
Session 2
5-days follow-up
9h 15h 21h
9h 15h 21h
9h 15h 21h
9h 15h 21h
9h 15h 21h
Day 1
Day 2
Day 3
Day 4
Day 5
Day 6
Text messages/emails beginning

Figure 2




MVC flexion
Flexion at 50%
Practice trials with feedback
No feedback
1 min break
Flexion at 75%
Practice trials with feedback
No feedback
1 min break
MVC extension
Extension at 50%
Practice trials with feedback
No feedback
1 min break
Extension at 75%
Practice trials with feedback
No feedback
1 min break

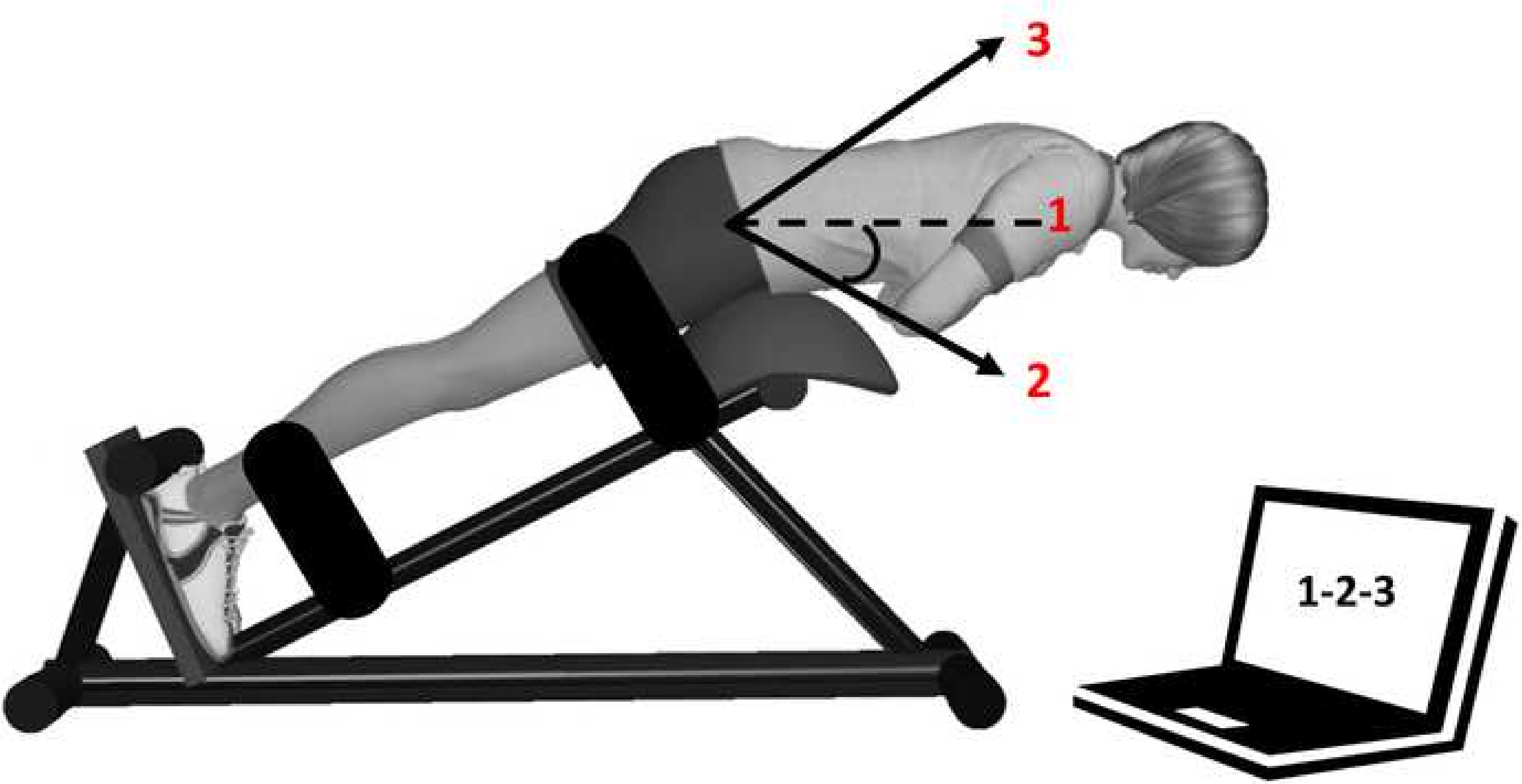
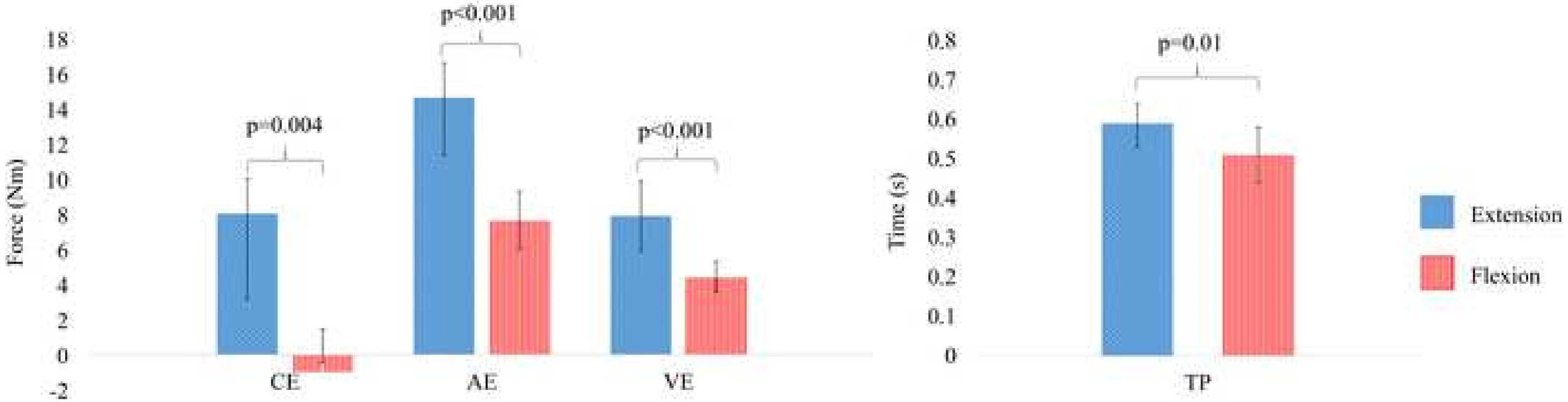
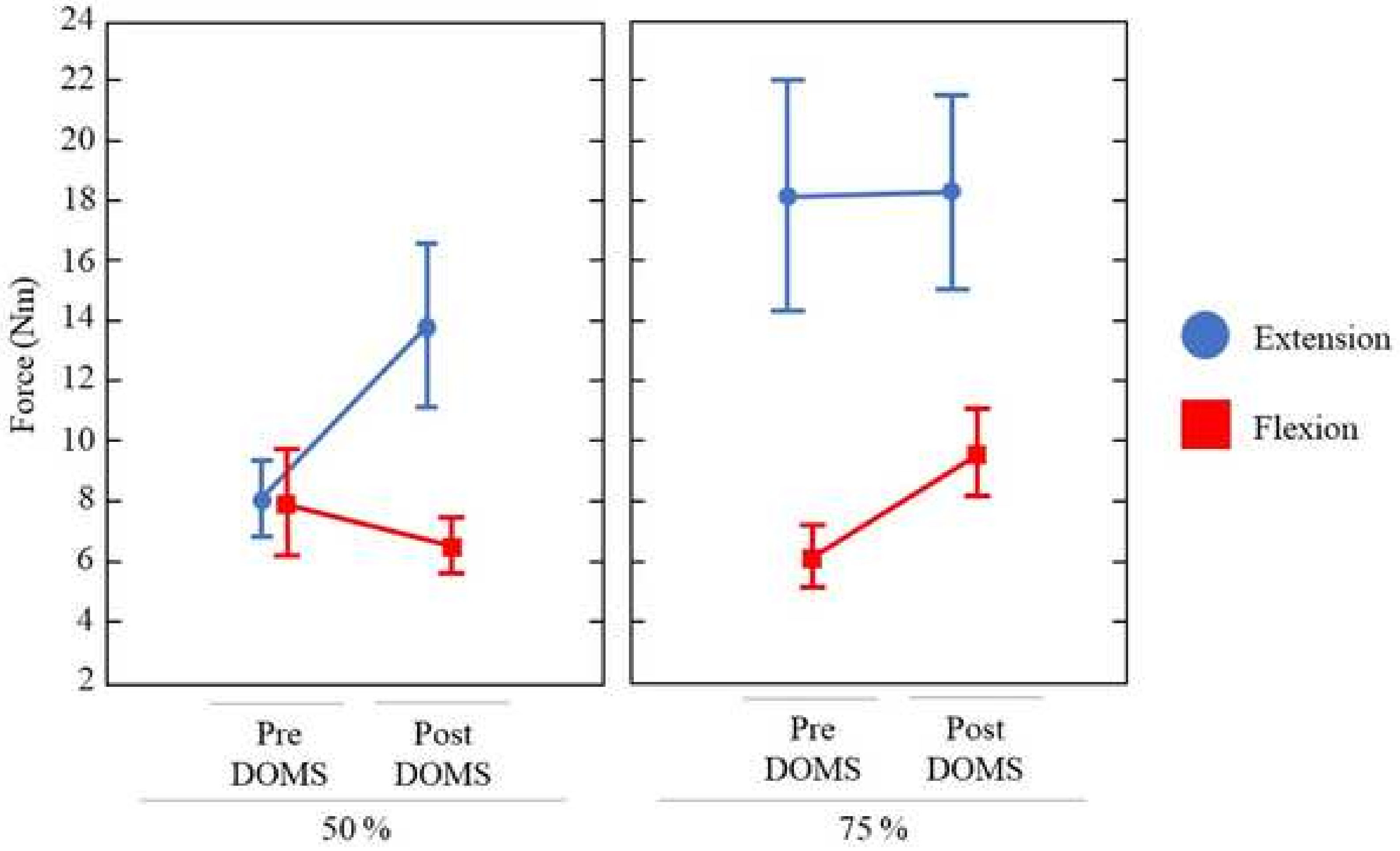

3
1
2
1-2-3

Figure 5


Force (Nm)
18
16
14
12
10
8
6
4
2
0
-2
p=0.004
p<0.001
p<0.001
CE
AE
VE
Time (s)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
p=0.01
TP
Extension
Flexion


24
22
20
18
16
14
12
10
8
6
4
2
Force (Nm)
Pre DOMS
Post DOMS
50 %
Pre DOMS
Post DOMS
75 %
Extension
Flexion

Author contribution statement

All authors have contributed substantially to the manuscript. Study conception and design (MH, JA, MD), acquisition of data (MH, CD, AL, MAM), analysis and interpretation of data (all authors), drafting the manuscript (MH, CD, JA), revising it critically for important intellectual content (all authors), and final approval of the version to be published (all authors).