European Journal of Applied Physiology

Paraspinal muscle function and pain sensitivity following exercise-induced delayed-onset muscle soreness

--Manuscript Draft--

Manuscript Number:	EJAP-D-18-00863R2
Full Title:	Paraspinal muscle function and pain sensitivity following exercise-induced delayed-onset muscle soreness
Article Type:	Original Article
Keywords:	Experimental pain; lumbar; muscle strength; exercise induced-damage
Corresponding Author:	Jacques Abboud Universite du Quebec a Trois-Rivieres CANADA
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Universite du Quebec a Trois-Rivieres
Corresponding Author's Secondary Institution:	
First Author:	Jacques Abboud
First Author Secondary Information:	
Order of Authors:	Jacques Abboud
	Arianne Lessard
	Mathieu Piché
	Martin Descarreaux
Order of Authors Secondary Information:	
Funding Information:	
Abstract:	Purpose The aim of this study was to evaluate the effectiveness of an exercise protocol designed to induce delayed-onset muscle soreness (DOMS) in paraspinal muscles and its effects on low back functional capacities. Methods Twenty-four healthy participants were asked to perform four series of 25 trunk flexion-extension in a prone position (45-degrees inclined Roman chair). The protocol was performed using loads corresponding to participant's trunk weight plus 10% of their trunk extension maximal voluntary contraction. Perceived soreness and pain were assessed using an 11-points numerical analogue scale 3 times a day during 5 days post-DOMS protocol. Pressure pain thresholds (PPT) in paraspinal muscles (L2 and L4 bilaterally) and the vastus medialis (control site), and trunk extension maximal voluntary contraction were assessed 24 to 36 hours post-protocol and compared to baseline (t-tests). Results Muscle soreness (3.8/10) and pain (2.1/10) peak scores were observed 24 to 36 hours post-protocol (mean of 28 hours). A significant reduction in trunk extension maximal voluntary contraction was observed post-protocol (p=0.005). Significant reductions in PPT were observed post-protocol for all trunk extensor sites (ps<0.01), but not for the control site (p=0.40). Conclusions

	The exercise protocol efficiently led to low back muscle DOMS, reduced functional capacities and increased pain sensitivity locally. Such protocol could be used as an efficient and safe experimental low back pain model.
Response to Reviewers:	

Paraspinal muscle function and pain sensitivity following exercise-induced delayed-onset muscle soreness

Jacques Abboud[1], Arianne Lessard[2], Mathieu Piché[3], Martin Descarreaux[2]

[1] Département d'Anatomie, Université du Québec à Trois-Rivières, Canada

[2] Département des Sciences de l'Activité Physique, Université du Québec à Trois-Rivières, Canada

[3] Département de Chiropratique, Université du Québec à Trois-Rivières, Canada

Corresponding author: Jacques Abboud, 3351, boul. des Forges, C.P. 500, Trois-Rivières, Québec, Canada, G9A 5H7. Telephone number: +1 (819) 376-5011. E-mail: jacques.abboud@uqtr.ca

Abstract

Purpose: The aim of this study was to evaluate the effectiveness of an exercise protocol designed to induce delayed-onset muscle soreness (DOMS) in paraspinal muscles and its effects on low back functional capacities.

Methods: Twenty-four healthy participants were asked to perform four series of 25 trunk flexion-extension in a prone position (45-degrees inclined Roman chair). The protocol was performed using loads corresponding to participant's trunk weight plus 10% of their trunk extension maximal voluntary contraction. Perceived soreness and pain were assessed using an 11-points numerical analogue scale 3 times a day during 5 days post-DOMS protocol. Pressure pain thresholds (PPT) in paraspinal muscles (L2 and L4 bilaterally) and the vastus medialis (control site), and trunk extension maximal voluntary contraction were assessed 24 to 36 hours post-protocol and compared to baseline (*t*-tests).

Results: Muscle soreness (3.8/10) and pain (2.1/10) peak scores were observed 24 to 36 hours post-protocol (mean of 28 hours). A significant reduction in trunk extension maximal voluntary contraction was observed post-protocol (p=0.005). Significant reductions in PPT were observed post-protocol for all trunk extensor sites (ps<0.01), but not for the control site (p=0.40).

Conclusions: The exercise protocol efficiently led to low back muscle DOMS, reduced functional capacities and increased pain sensitivity locally. Such protocol could be used as an efficient and safe experimental low back pain model.

Keywords: Experimental pain; lumbar; muscle strength; exercise induced-damage

Abbreviations:

DOMS	Delayed-onset muscle soreness
MVC	Maximal voluntary contraction
PPT	Pressure pain threshold

Introduction

Delayed-onset muscle soreness (DOMS) usually occurs following unaccustomed or strenuous physical activity, such as the first training of the season after a long break, or when the intensity and/or the volume of the activity is suddenly increased (Lewis et al. 2012; Newham et al. 1983). Moreover, it is well documented that DOMS is more likely to happen following eccentric exercise (Clarkson and Hubal 2002) leading to contraction during muscle lengthening. Such lengthening during repetitive eccentric contractions may lead to overstretching of sarcomeres, resulting in muscle damage (Proske and Allen 2005). DOMS typically peaks around 24 to 48 hours following exercise, with pain and soreness arising from the damaged muscle (Cheung et al. 2003; Cleak and Eston 1992). Pain and soreness are usually accompanied by a loss of muscle force (Clarkson and Hubal 2002) reaching up to 40% (Prasartwuth et al. 2005) and lasting several days (Crameri et al. 2007; Lewis et al. 2012), resulting in alteration of motor task performance (Vila-Cha et al. 2012).

It has been shown that back pain and disability occur following a low back DOMS protocol, which makes DOMS an interesting experimental model to investigate the effect of low back pain on functional capacities (Bishop et al. 2011b; Hjortskov et al. 2005; Horn and Bishop 2013; Larsen et al. 2017; Mayer et al. 2006; Soer et al. 2008; Trost et al. 2011; Udermann et al. 2002). However, the experimental protocol used to induce low back DOMS varies across studies, which limits result comparisons. In 2002, a standardized exercise protocol was proposed to induce DOMS in the lumbar region (Udermann et al. 2002). In the study, three groups of participants were submitted to three different DOMS protocols. These protocols consisted in a variable number of flexion-extension trunk movements with a weight load requiring 40 to 100% of maximal peak torque in back extension. The authors concluded that participants should perform 2 sets of 25 repetitions of lumbar extension with an external load corresponding to 100% of their maximal peak torque, in order to elicit significant DOMS in low back muscles (Udermann et al. 2002). However, participants reported strong lumbar pain (approximately 9/10) and soreness (approximately 5/5 on a 0-5 scale, with 5 corresponding to severe soreness) after this protocol. This limits the application of the protocol since inducing strong low back pain is contraindicated in some individuals and poses some challenges when studying motor behaviors.

Subsequent studies induced low back DOMS using physical activity lasting up to two hours (Hjortskov et al. 2005; Soer et al. 2008). The two studies showed an increase in pain and/or soreness in the lumbar region, as well as a reduction of functional capacity following exercise. However, the lack of information and specificity regarding the protocol used to induce DOMS (e.g. two hours of floorball training) (Hjortskov et al. 2005; Soer et al. 2008) limits the reproducibility of these protocols. Moreover, these protocols do not specifically target lumbar muscle DOMS and cannot be implemented in laboratory settings. Another group of researchers induced low back DOMS by asking participants to perform as many trunk extension repetitions as possible at 80% of their maximal torque (Bishop et al. 2011a; Bishop et al. 2011b; Bishop et al. 2011c; Horn and Bishop 2013), while in other studies, participants were instructed to perform as many trunk flexion as possible without extra load, while trunk extension was manually supported by the experimenter (Larsen et al. 2017; Lo Vecchio et al. 2015). Although in these studies participants reported increased pain intensity and tenderness in the lumbar region, the absence of standardized number of trunk flexion repetitions leave room to uncertainty. Moreover, performing a DOMS protocol at 80% of the maximal lumbar muscles strength may not be as representative as it could be regarding daily functional task involving these muscles. Therefore, the aim of the current study was to evaluate the effectiveness of a standardized and safe exercise protocol designed to induce DOMS in the lumbar muscles.

Methods

Participants

Twenty-four healthy adult participants (12 males and 12 females) without any episode of low back pain in the past six months were recruited from the university community. All experimental procedures conformed to the standards set by the latest revision of the Declaration of Helsinki and were approved by the Research Ethics Board of “Université du Québec à Trois-Rivières”. All participants gave written informed consent, acknowledging their right to withdraw from the experiment without prejudice and received compensation of $ 30 for their travel expenses, time and commitment.

Experimental design

The study was conducted over two sessions. In the first session (baseline), lumbar mechanical pain sensitivity and back muscle strength were assessed. Participants were then requested to perform the DOMS protocol. Based on the analysis of pilot data, the second session took place 24 to 36 hours later (mean of 28 hours). In this second session, pain sensitivity and muscle strength were assessed a second time. The day following the DOMS protocol (first session), lumbar pain and soreness ratings were collected by email or text message for five consecutive days, three times a day (9 am, 3 pm and 9 pm). During these days, participants were instructed to avoid any unusual physical activity and/or any medication to decrease muscle soreness or pain.

Trunk muscle strength assessment

Initially, participants started with a familiarization protocol in order to be comfortable with the apparatus used during this experiment. Then, three maximal voluntary isometric trunk extension contractions (MVCs) were performed. In a prone position, using a 45-degrees inclined Roman chair with their trunks parallel to the ground, participants were asked to push as hard as possible against a belt installed over their shoulders for approximately 5 seconds. The belt was connected to a load cell (Model LSB350; Futek Advanced Sensor Technology Inc, Irvine, CA, USA). A one-minute rest period was provided between each MVC to limit the occurrence of muscle fatigue. The highest MVC values was considered for the DOMS protocol. Trunk extension MVCs were assessed at baseline (before the DOMS protocol) and in the second session. The highest of the three MVC trials was used for the analysis.

Delayed-onset muscle soreness protocol

The DOMS protocol consisted of 4 series of 25 trunk flexion-extension separated by one-minute of rest. Trunk flexion-extension repetitions were performed using the same position as the one used for the MVC protocol (Fig. 1). While performing the DOMS protocol, an external load corresponding to 10% of the participant's trunk extension MVC was added. The total resistance during the DOMS protocol corresponded to the addition of this external load (10%) and the weight of participant's upper body (trunk and head). This weight was calculated based on anthropometric tables (de Leva 1996). In total, participants' resistance represented approximately 45% of their MVC (ranged from 38 to 58%). Straps were placed at hip level to minimize pelvic tilt movements, which could limit the contribution of muscle groups other than parapsinal muscles during the DOMS protocol. The starting position of participants corresponded to the neutral alignment of the trunk (no flexion or extension). Participants were asked to perform a trunk flexion (lumbar paraspinal eccentric contraction) that lasted 3 seconds and corresponded to 30 degrees of trunk flexion relative to a horizontal position (Fig. 1). Then, participants were asked to remain still in this position for 3 more seconds (lumbar paraspinal isometric contraction), and finally to go back to the initial neutral position in 1 second (lumbar paraspinal concentric contraction). To ensure that the movement was executed in the required trunk range of motions of the DOMS protocol, two foam bars guided the participants, one positioned over the participant's trunk and corresponding to the initial position, and one under the participant's trunk and corresponding to the flexed position. During the DOMS protocol, auditory and visual feedbacks were provided using a laptop positioned in front of the participants to help him follow the tempo (3-3-1). Moreover, the assessors provided intense verbal encouragements for each participant during the entire protocol. The DOMS protocol, including the time to perform the MVC, took less than 20 minutes.

[Insert Fig. 1 around here]

Pain sensitivity assessment

Pressure pain thresholds (PPT) in paraspinal muscles and the vastus medialis were assessed using a hand-held algometer with an accuracy of 0.1kg (Model 01163; Lafayette Instrument Company, Lafayette IN USA). The algometer probe corresponded to a circular tip of 12 mm diameter. During the paraspinal PPT assessment, participants were lying in a prone position. The algometer was applied perpendicularly to the desired site. PPT were evaluated in the thickest part of the paraspinal muscles in four different lumbar sites at approximately 2.5 cm from the spinous process: L2 and L4 bilaterally. A fifth site on the right vastus lateralis, in its thickest part, was used as control site. Assessment of PPT for this site was performed in a sitting position where the knees flexed. The same experimenter was in charge of identifying each site by palpation as well as applying the force on each site, in order to avoid inter-experimenter variability. The order of PPT assessment was randomized between participants and sessions. The force was applied at a rate of approximately 1kg/s (Chesterton et al. 2007). Participants were instructed to report the moment at which pain first occurred (pressure sensation changing to pain sensation). PPT was measured three time at each site and values were averaged to obtain one PPT for each site. These averaged PPT were used for subsequent analyses. Following the DOMS protocol, lumbar pain and soreness were assessed using two distinct 11-point numerical analogue scales 3 times a day during 5 days post-DOMS protocol. These rating scales were explained by the experimenter and a numerical guide was provided for each scale: lumbar pain scale ranged from no pain (0/10) to worst possible pain (10/10), while soreness scale ranged from no muscle soreness (0/10) to severe muscle soreness (10/10). Participants received the following question by text message or email: “On a scale from 0 to 10, what is your level of muscle pain and muscle soreness in the lumbar region presently?”.

Statistical analysis

Statistical analyses were performed with Statistica data analysis software system (TIBCO Software version 13.3 Inc, Palo Alto, CA, USA). Normality of distribution was assessed with the Kolmogorov-Smirnov test and by visual inspection. Student *t*-tests for dependant samples were used to compare the following dependant variables before and after the DOMS protocol: PPT at L2 and L4 bilaterally and vastus lateralis and MVC. Means and standard deviations were computed for pain and soreness intensity for all participants. For all statistical analyses, statistical significance was set at $p \leq 0.05$.

Results

Participants' mean (*M*) age, height, weight and BMI were respectively 26.4 (standard deviation [*SD*] = 6.8) years, *M* = 1.73 (*SD* = 0.09) m (1.66 m for female; 1.80 m for male), *M* = 70.4 (*SD* = 12.1) kg (61.2 kg for female; 78.3 kg for male) and *M* = 23.4 (*SD* = 3.1) kg/m^2. Other than DOMS, none of the participants reported adverse events or unusual physical activity during the five days post-DOMS. The mean weight used as an external load during the DOMS protocol was 5.7 kg (*SD* = 2.0). From the 24 participants, 2 participants were unable to finish the entire DOMS protocol due to muscle pain or exhaustion (one participant did a total of 69 repetitions and the other one did 76 out of 100 repetitions). These 2 participants were included in the analyses.

The highest pain and soreness values were observed on the first day, approximately 28.03 hours (± 1.98 hours) following the DOMS protocol. The mean lumbar pain intensity was mild (2.1/10, *SD* = 1.9; see Fig. 2) and the mean lumbar soreness was moderate (3.8/10, *SD* = 2.2; see Fig. 3). The 2 participants that were unable to finish the entire DOMS protocol reported similar pain and soreness values (2-3/10 and 2-4/10 respectively).

Paired *t*-tests revealed a significant decrease of all back muscle PPT following the DOMS protocol compared with baseline (all $p \leq 0.01$; see Table 1). In contrast, the vastus lateralis muscle PPT was comparable following the DOMS protocol compared with baseline ($p = 0.4$ see Table 1). Accordingly, MVC was significantly decreased following the DOMS protocol in comparison to baseline ($p < 0.005$; see Table 1).

[Insert Table 1 around here]

[Insert Figs. 2 and 3 around here]

Discussion

As expected, the protocol used in the current study induced low back DOMS. Twenty-two out of twenty-four participants were able to complete the entire DOMS protocol and all participants experienced lumbar muscle pain and soreness without any adverse outcome other than DOMS. In addition, the protocol reduced functional capacities (maximal strength) and increased mechanical pain sensitivity. Thus, the present protocol provides an efficient and safe experimental low back pain model that involves deep structures of the spine, which is more representative of clinical low back pain than other acute pain models such as phasic electrical or thermal stimulation. This has important implications for mechanistic studies on low back pain.

Characteristics of pain and soreness

Lumbar muscle pain and soreness intensity ranged from very mild (1/10 and 0.5/10, respectively) to very high (8/10 and 10/10, respectively) with an average pain of mild intensity (2/10) and an average soreness of moderate intensity (3.8/10). When participants were asked to perform as many repetitions as possible of paraspinal contraction at 80% of their maximal strength in a sitting position to induce back DOMS (Bishop et al. 2011a; Bishop et al. 2011b; Bishop et al. 2011c), pain intensity as well as tenderness were slightly under the intensity found in the current study. Various psychological factors, such as pain-related fear, could explained the pain perception variability among participants, under the influence of experimental pain (George and Hirsh 2009). Other studies, investigating DOMS found that fear of pain was associated with pain intensity (Bishop et al. 2011b). On the other hand, pain intensity and muscle soreness in the current study were largely lower than the scores reported in Udermann et al. study, during which extreme pain intensity and soreness following 50 repetitions of trunk flexion-extension at 100% of their maximal strength were observed (Udermann et al. 2002). Results of the current study also showed that lumbar muscle soreness and pain with this type of exercise peaked approximately 30 hours following the DOMS protocol, which is similar to pain pattern described in previous studies (e.g. (Bishop et al. 2011b)), but can remain up to 4 days.

The current study also showed that under the influence of low back DOMS, a decrease in lumbar muscle maximal strength occurred. Even if this decrease could be considered small (less than 10%), a large effect size was observed ($\eta p^2 = 0.29$). Moreover, a decline of trunk extension maximal strength following a DOMS protocol is consistent with previous studies (Bishop et al. 2011b; Bishop et al. 2011c). Interestingly, Udermann et al. reported a decrease of lumbar maximal strength following trunk flexion-extension at 100% of the participant's maximal strength, while performing trunk flexion-extension at 40% did not seem to affect lumbar maximal strength (Udermann et al. 2002). This could be explained by the fact that in their study testing at 40% of the participant's MVC induced lower pain and soreness reported by the participants than in our study. Moreover, small sample sizes (N=5-8/group) and the lack of standard deviation values could limit the generalisability of their findings. Alteration in lumbar extension strength is also commonly observed in people with chronic low back pain (Steele et al. 2014). Even if it was not directly assessed in the current study, several participants, following the DOMS protocol, felt they moved differently because of the muscle soreness, during their daily activities, such as putting a pair of shoes. It was recently proposed that the alteration of movement pattern can be a good indicator of neuromuscular dysfunction in patients with chronic neck pain (Falla et al. 2017) or low back pain (Falla et al. 2014). Altogether, DOMS-induced low back pain may alter trunk functional capacities in ways that are similar to clinical chronic pain.

Moreover a decrease in pain sensitivity was found with the observation of lower PPT values under the influence low back DOMS. This decrease was present across the lumbar region (L2 to L4), but not in the anterior lower limbs indicating that the low back region was affected specifically following the DOMS protocol. The finding of local reduction in pressure-pain sensitivity following DOMS is consistent with previous studies (Bishop et al. 2011b). These observations could reflect peripheral sensitization with limited central sensitization that does not spread widely to other regions. It has been suggested that peripheral sensitization is related to inflammatory processes or tissue damage (Latremoliere and Woolf 2009), which are also observed following DOMS (Lewis et al. 2012). These findings are of interest because of the potential implication for future studies which will aim to study the effects of DOMS only on the lumbar region without altering the other limbs.

Although results from Bishop et al. studies show promising results, such as an increase in pain and/tenderness following a low back DOMS protocol, the proposed DOMS protocol requires a high level of exercise intensity without a specific number of repetition

(Bishop et al. 2011a; Bishop et al. 2011b; Horn and Bishop 2013). Based on the findings of the current study, one could argue that a standardised number of back contraction repetitions (100) at a low physical intensity is easier to implement. It is also less expensive since it only requires a Roman chair and an external load to induce low back DOMS using the current protocol. Moreover, inducing low back DOMS using contraction intensity as low as 45% of the maximal strength of the lumbar muscle may be safer for the general population. Therefore, we believe that such protocol may be used in clinical studies as well as in patients with low back pain to better understand the motor behavior changes in this population.

Relevance of delayed-onset-muscle-soreness as a back pain model

As a model to induce experimental back pain, DOMS presents several assets over other pain models. Experimental back pain is commonly induced using external stimuli such as intramuscular injections of hypertonic saline (Tsao et al. 2010) or thermal cutaneous pain (Dubois et al. 2011). However, these models have some limitations. There is evidence suggesting that hypertonic saline can excite motor axons (Kumazawa and Mizumura 1977; Weerakkody et al. 2003), which may alter lumbar sensorimotor control independently, regardless of pain-related processes. As for thermal cutaneous heat pain, the model does not allow performing pre-post comparisons of experimental pain effects, which limits results interpretation. In addition, DOMS provides an important advantage over other models by involving, to a certain point, psychological factors commonly observed in patients with chronic low back pain, such as fear of movement (Vlaeyen and Linton 2000). This allows a more ecological investigation of pain adaptation mechanisms.

Limitations and future directions

Although the present findings show several advantages of the DOMS protocol over other pain models, some limitations should be considered. Firstly, two participants could not complete the DOMS protocol. This could result from a lack of motivation despite the verbal encouragement provided by the experimenter to minimize this limitation. Another explanation could be that these participants may have used alternative recruitment strategies during the MVC protocol (involving other muscle groups) to reach MVC values. Consequently, the load used during the DOMS protocol was too high. Future studies will need to investigate the muscle activation of the trunk extensor muscles during this test in order to confirm this hypothesis. Another consideration is the inter-individual variability of pain and soreness ratings. Some participants reported very mild pain and soreness following the DOMS protocol. This observation should be taken into consideration for future studies as this low level of pain may not alter trunk motor control in other task than maximal strength in trunk extension. Moreover, some participants reached their pain and soreness peak on the second day after the DOMS protocol. Therefore, it remains to be determined whether the model is effective to investigate low back pain even for participants with low ratings and it may be useful to adapt the experimentation to the time window in which participants are most likely at their peak pain and soreness. Accordingly, we propose that 30 hours following the present DOMS protocol is the most appropriate time for most participants. Future studies should consider using a standardized delay between the provoking exercise and the test. Moreover, different factors not considered in this study, such as diurnal variation in cortisol and other hormones, which vary during the day, might have impacted the effect of DOMS in the lumbar region and should be considered in future studies. Finally, young adult participants were recruited for this study. Future research should validate this DOMS protocol in an older population since age is known to affect the time course of DOMS (Clarkson and Dedrick 1988). For this population, it should be emphasized that the current protocol is advantageous considering the requested effort, relying on back contractions at 45% of the maximal strength compared with previous DOMS protocols using 80 to 100% of the maximal back muscle strength.

Conclusion

The exercise protocol efficiently led to back muscle DOMS, reduced functional capacities and increased pain sensitivity. Such protocol could be used as an alternative to experimental low back pain in mechanistic studies.

Acknowledgment

The authors wish to acknowledge the contribution of Catherine Pauzé-Brodeur (undergraduate student) who assisted the authors during the experiment.

Conflict of interest

The authors declare that they have no conflicts of interest.

References

Bishop MD, Horn ME, George SZ (2011a) Exercise-induced pain intensity predicted by pre-exercise fear of pain and pain sensitivity The Clinical journal of pain 27:398-404 doi:10.1097/AJP.0b013e31820d9bbf

Bishop MD, Horn ME, George SZ, Robinson ME (2011b) Self-reported pain and disability outcomes from an endogenous model of muscular back pain BMC musculoskeletal disorders 12:35 doi:10.1186/1471-2474-12-35

Bishop MD, Horn ME, Lott DJ, Arpan I, George SZ (2011c) Magnitude of spinal muscle damage is not statistically associated with exercise-induced low back pain intensity The spine journal : official journal of the North American Spine Society 11:1135-1142 doi:10.1016/j.spinee.2011.11.005

Chesterton LS, Sim J, Wright CC, Foster NE (2007) Interrater reliability of algometry in measuring pressure pain thresholds in healthy humans, using multiple raters The Clinical journal of pain 23:760-766 doi:10.1097/AJP.0b013e318154b6ae

Cheung K, Hume P, Maxwell L (2003) Delayed onset muscle soreness : treatment strategies and performance factors Sports Med 33:145-164

Clarkson PM, Dedrick ME (1988) Exercise-induced muscle damage, repair, and adaptation in old and young subjects J Gerontol 43:M91-96

Clarkson PM, Hubal MJ (2002) Exercise-induced muscle damage in humans American journal of physical medicine & rehabilitation / Association of Academic Physiatrists 81:S52-69 doi:10.1097/01.PHM.0000029772.45258.43

Cleak MJ, Eston RG (1992) Delayed onset muscle soreness: mechanisms and management J Sports Sci 10:325-341 doi:10.1080/02640419208729932

Crameri RM, Aagaard P, Qvortrup K, Langberg H, Olesen J, Kjaer M (2007) Myofibre damage in human skeletal muscle: effects of electrical stimulation versus voluntary contraction The Journal of physiology 583:365-380 doi:10.1113/jphysiol.2007.128827

de Leva P (1996) Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters Journal of biomechanics 29:1223-1230

Dubois JD, Piche M, Cantin V, Descarreaux M (2011) Effect of experimental low back pain on neuromuscular control of the trunk in healthy volunteers and patients with chronic low back pain Journal of electromyography and kinesiology : official journal of the International Society of Electrophysiological Kinesiology 21:774-781 doi:10.1016/j.jelekin.2011.05.004

Falla D, Gizzi L, Parsa H, Dieterich A, Petzke F (2017) People With Chronic Neck Pain Walk With a Stiffer Spine The Journal of orthopaedic and sports physical therapy 47:268-277 doi:10.2519/jospt.2017.6768

Falla D, Gizzi L, Tschapek M, Erlenwein J, Petzke F (2014) Reduced task-induced variations in the distribution of activity across back muscle regions in individuals with low back pain Pain 155:944-953 doi:10.1016/j.pain.2014.01.027

George SZ, Hirsh AT (2009) Psychologic influence on experimental pain sensitivity and clinical pain intensity for patients with shoulder pain The journal of pain : official journal of the American Pain Society 10:293-299 doi:10.1016/j.jpain.2008.09.004

Hjortskov N, Essendrop M, Skotte J, Fallentin N (2005) The effect of delayed-onset muscle soreness on stretch reflexes in human low back muscles Scandinavian journal of medicine & science in sports 15:409-415

Horn ME, Bishop MD (2013) Flexion Relaxation Ratio Not Responsive to Acutely Induced Low Back Pain from a Delayed Onset Muscle Soreness Protocol ISRN Pain 2013:617698 doi:10.1155/2013/617698

Kumazawa T, Mizumura K (1977) Thin-fibre receptors responding to mechanical, chemical, and thermal stimulation in the skeletal muscle of the dog The Journal of physiology 273:179-194

Larsen LH, Hirata RP, Graven-Nielsen T (2017) Pain-evoked trunk muscle activity changes during fatigue and DOMS Eur J Pain 21:907-917 doi:10.1002/ejp.993

Latremoliere A, Woolf CJ (2009) Central sensitization: a generator of pain hypersensitivity by central neural plasticity The journal of pain : official journal of the American Pain Society 10:895-926 doi:10.1016/j.jpain.2009.06.012

Lewis PB, Ruby D, Bush-Joseph CA (2012) Muscle soreness and delayed-onset muscle soreness Clin Sports Med 31:255-262 doi:10.1016/j.csm.2011.09.009

Lo Vecchio S, Petersen LJ, Finocchietti S, Gazerani P, Arendt-Nielsen L, Graven-Nielsen T (2015) The Effect of Combined Skin and Deep Tissue Inflammatory Pain Models Pain Med 16:2053-2064 doi:10.1111/pme.12826

Mayer JM, Mooney V, Matheson LN, Erasala GN, Verna JL, Udermann BE, Leggett S (2006) Continuous low-level heat wrap therapy for the prevention and early phase treatment of delayed-onset muscle soreness of the low back: a randomized controlled trial Archives of physical medicine and rehabilitation 87:1310-1317 doi:10.1016/j.apmr.2006.07.259

Newham DJ, Jones DA, Edwards RH (1983) Large delayed plasma creatine kinase changes after stepping exercise Muscle & nerve 6:380-385 doi:10.1002/mus.880060507

Prasartwuth O, Taylor JL, Gandevia SC (2005) Maximal force, voluntary activation and muscle soreness after eccentric damage to human elbow flexor muscles The Journal of physiology 567:337-348 doi:10.1113/jphysiol.2005.087767

Proske U, Allen TJ (2005) Damage to skeletal muscle from eccentric exercise Exercise and sport sciences reviews 33:98-104

Soer R, Groothoff JW, Geertzen JH, van der Schans CP, Reesink DD, Reneman MF (2008) Pain response of healthy workers following a functional capacity evaluation and implications for clinical interpretation J Occup Rehabil 18:290-298 doi:10.1007/s10926-008-9132-5

Steele J, Bruce-Low S, Smith D (2014) A reappraisal of the deconditioning hypothesis in low back pain: review of evidence from a triumvirate of research methods on specific lumbar extensor deconditioning Current medical research and opinion 30:865-911 doi:10.1185/03007995.2013.875465

Trost Z, France CR, Thomas JS (2011) Pain-related fear and avoidance of physical exertion following delayed-onset muscle soreness Pain 152:1540-1547 doi:10.1016/j.pain.2011.02.038

Tsao H, Tucker KJ, Coppieters MW, Hodges PW (2010) Experimentally induced low back pain from hypertonic saline injections into lumbar interspinous ligament and erector spinae muscle Pain 150:167-172 doi:10.1016/j.pain.2010.04.023

Udermann BE, Mayer JM, Graves JE, Ploutz-Snyder LL (2002) Development of an Exercise Protocol to Elicit Delayed-Onset Muscle Soreness in the Lumbar Extensors INTERNATIONAL SPORTS JOURNAL 6:128-135

Vila-Cha C, Hassanlouei H, Farina D, Falla D (2012) Eccentric exercise and delayed onset muscle soreness of the quadriceps induce adjustments in agonist-antagonist activity, which are dependent on the motor task Experimental brain research Experimentelle Hirnforschung Experimentation cerebrale 216:385-395 doi:10.1007/s00221-011-2942-2

Vlaeyen JW, Linton SJ (2000) Fear-avoidance and its consequences in chronic musculoskeletal pain: a state of the art Pain 85:317-332

Weerakkody NS, Percival P, Hickey MW, Morgan DL, Gregory JE, Canny BJ, Proske U (2003) Effects of local pressure and vibration on muscle pain from eccentric exercise and hypertonic saline Pain 105:425-435

Table 1. Pain and muscle strength following the DOMS protocol compared with baseline.

	Baseline	**DOMS**	***t*(df)**	***p****
PPT L2 right (kg)	7.2 (3.3)	5.4 (3.7)	$t(23)=3.17$	0.004
PPT L2 left (kg)	7.7 (4.7)	5.4 (3.2)	$t(23)=3.74$	0.001
PPT L4 right (kg)	7.4 (3.9)	5.4 (3.8)	$t(23)=2.88$	0.008
PPT L4 left (kg)	7.4 (3.4)	5.7 (3.2)	$t(23)=3.32$	0.003
PPT vastus lateralis (kg)	6.2 (2.2)	6.5 (3.0)	$t(23)=0.86$	0.40
MVC (kg)	61.6 (20.8)	57.7 (21.5)	$t(23)=3.08$	0.005

Figure captions

Fig. 1. Illustration of the delayed-onset muscle soreness protocol.

Fig. 2. Time course of pain intensity in the lumbar region following the DOMS the protocol. The black thin line represents the mean (± standard deviation) of participants' pain. Each color line represents the evolution of pain intensity for one participant.

Fig. 3. Time course of soreness intensity in the lumbar region following the DOMS the protocol. The black thin line represents the mean (± standard deviation) of participants' soreness. Each color line represents the evolution of soreness intensity for one participant.

Figure1

Click here to access/download;Figure;Fig1.jpg

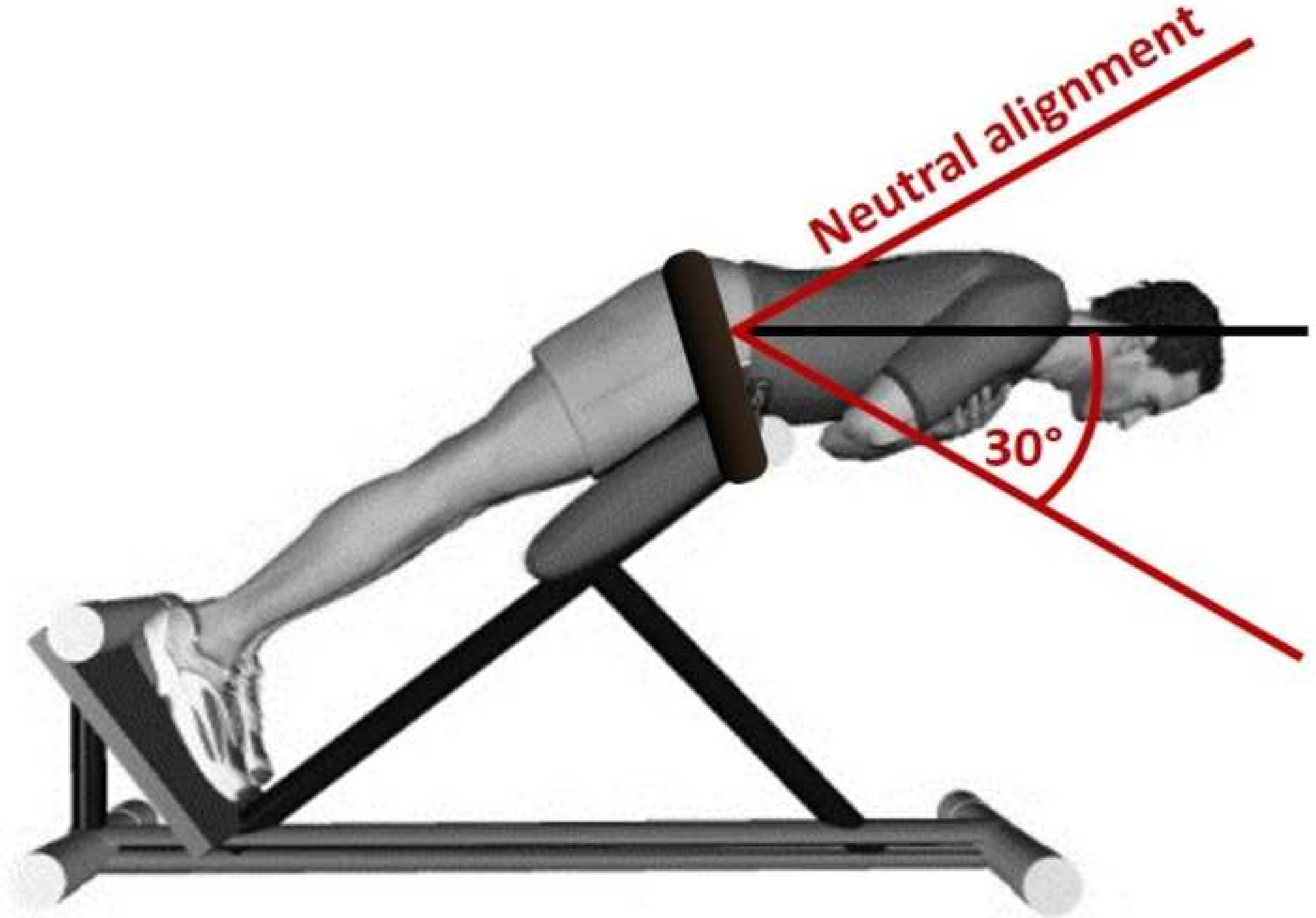


Figure2

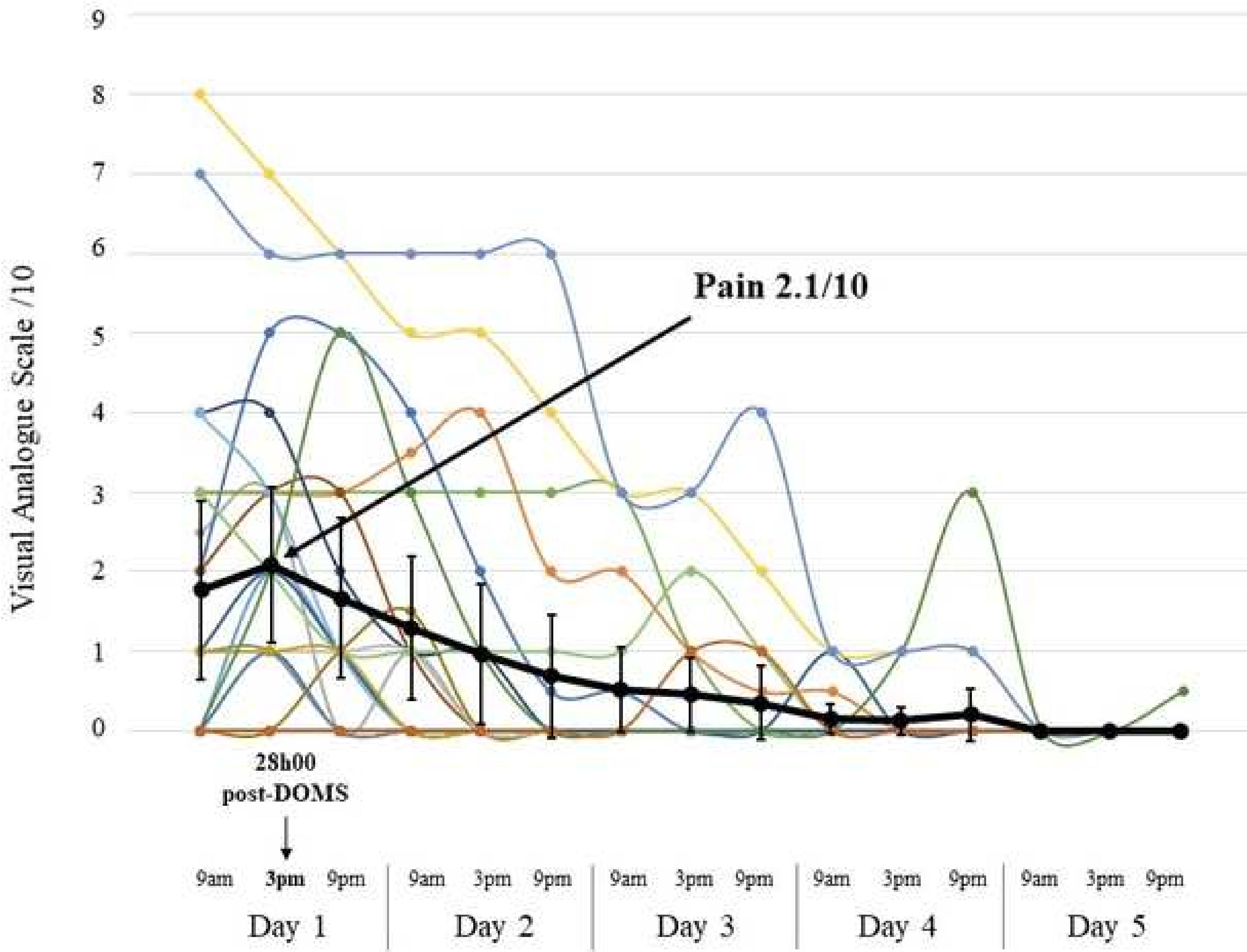
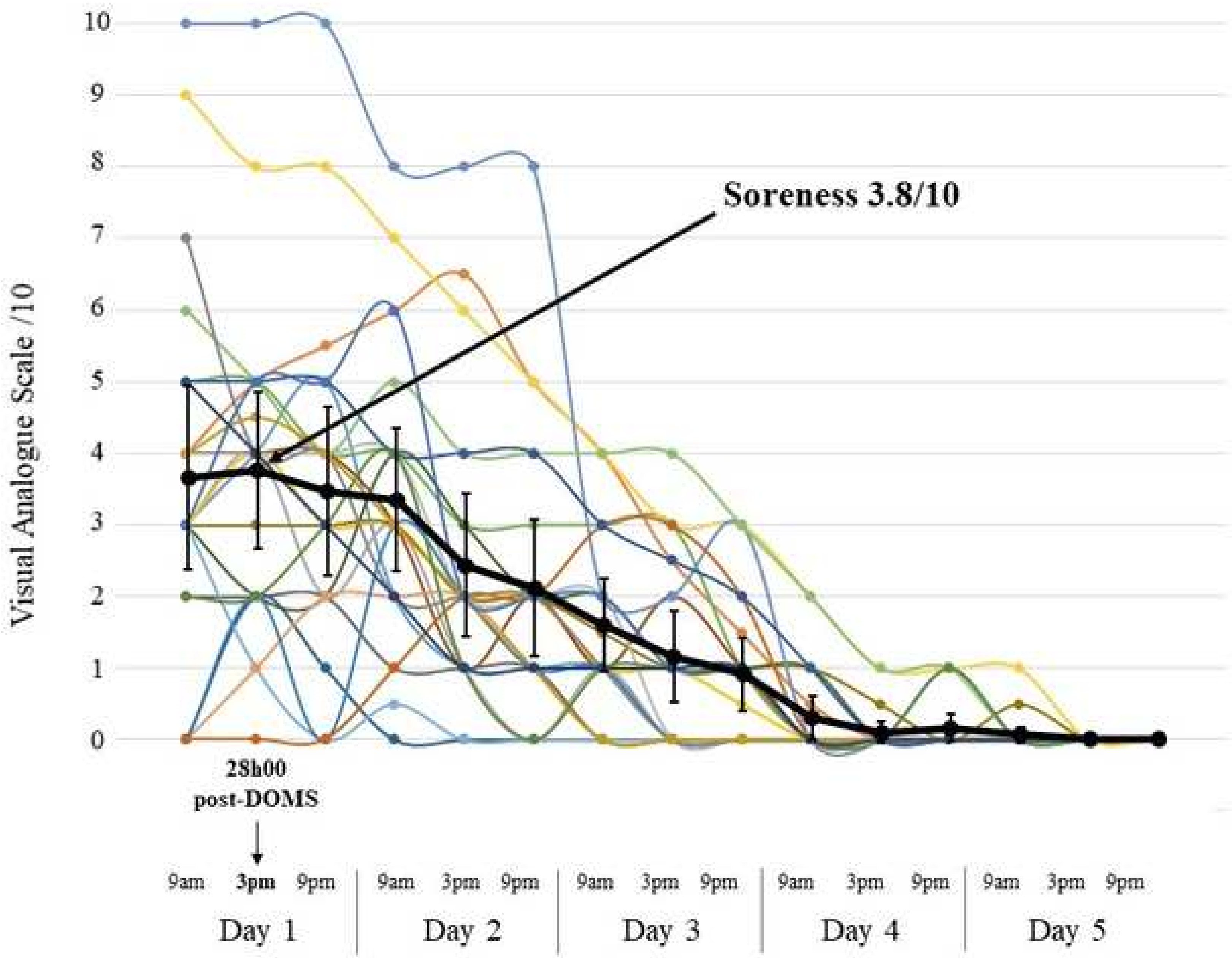

Visual Analogue Scale /10
9
8
7
6
5
4
3
2
1
0
Pain 2.1/10
28h00
post-DOMS
9am 3pm 9pm
Day 1
9am 3pm 9pm
Day 2
9am 3pm 9pm
Day 3
9am 3pm 9pm
Day 4
9am 3pm 9pm
Day 5

Figure3

Click here to access/download;Figure;Fig 3.jpg



Author contribution statement

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