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Trunk proprioception adaptations to creep deformation

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Response to Reviewers:	

Trunk proprioception adaptations to creep deformation

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Abstract

Purpose: To identify the short-term effect of creep deformation on the trunk repositioning sense.

Methods: Twenty healthy participants performed two different trunk-repositioning tasks (20- and 30-degrees trunk extension) before and after a prolonged static full trunk flexion of 20 minutes in order to induce spinal tissue creep. Trunk repositioning error variables, trunk movement time and erector spinae muscle activity were computed and compared between the pre- and post-creep conditions.

Results: During the pre-creep condition, significant increase in trunk repositioning errors, as well as trunk movement time, were observed in 30-degrees trunk extension in comparison to 20 degrees. During the post-creep condition, trunk repositioning errors variables were significantly increased only when performing a 20-degrees trunk extension. Erector spinae muscle activity increased in the post-creep condition, while it remained unchanged between trunk repositioning tasks.

Conclusions: Trunk repositioning sense seems to be altered in presence of creep deformation, especially in a small range of motion. Reduction of proprioception acuity may increase the risk of spinal instability, which is closely related to the risk of low back pain or injury.

Keywords: Repositioning task; sensory motor control; electromyography; erector spinae; spinal stability

Abbreviations:

AE	Absolute Error
ANOVA	Analysis of Variance
CE	Constant Error
EMG	Electromyography
IPAQ	International Physical Activity Questionnaire

MT	Movement Time
MVC	Maximal Voluntary Contraction
RMS	Root Mean Square
ROM	Range of Motion
VE	Variable Error

1. Introduction

The spine is surrounded by various anatomical structures, allowing its movement in different directions and reacting to external forces. These structures are usually categorized as active or passive, and both categories have been shown to play an important role in spinal stability (Panjabi 1992a). Indeed, the active components, which refer to the muscles, enable the spine to withhold spinal loads almost 40 times more than when these muscles are absent or inactive (Callaghan et al. 1998; Crisco and Panjabi 1992). Some spinal muscles have also been shown to pre-activate and/or increase their activity in response to external trunk perturbations in order to stabilize the spine (Hodges 1999; Moseley et al. 2002). As for the passive components, which refer to the ligaments, joint capsules and discs of the spine (Holm et al. 2002), their stabilizing functions reach their maximum efficiency towards the end of range of motions (Panjabi 1992b). Indeed, the passive structures are able to develop reactive forces in order to increase spinal stability (Panjabi 1992a). It has also been shown that the deformation of these structures can contribute to the development or occurrence of low back pain (Chaffin and Park 1973; Guo 2002; Marras et al. 1993). Such deformation, also called creep deformation, can possibly occur when maintaining a prolonged trunk flexion posture, as observed during prolonged seated desk work (Howarth et al. 2013a). One of the most common consequences of creep deformation is an increase in the intervertebral joints laxity (Solomonow et al. 1999), which ultimately leads to an increase in spinal range of motion (Abboud et al. 2016b; Howarth et al. 2013b; Shin and Mirka 2007). Despite a better understanding of the spinal creep mechanisms and its possible association with low back pain, there is still uncertainty about the true effect of creep deformation on spinal stability. A recent review suggested that, in response to unexpected perturbations of the trunk, creep deformation has a negligible effect on spinal stability (Abboud et al. 2016a). Moreover, it has been proposed that by modulating the contribution of active spinal components, healthy individuals can properly stabilize their spine, even when passive structures are absent (Solomonow et al. 1999). Similar observations were reported in patients with low back pain, who increased spinal stiffness in order to compensate for the alteration of passive structures (Freddolini et al. 2014; Hodges et al. 2009).

It is also known that patients with low back pain experience impaired proprioception, which refers to the ability to sense our body in space (Boucher et al. 2015; Tong et al. 2017). Similar alterations in trunk proprioception have been observed under the influence of back muscle fatigue (Boucher et al. 2012). Proprioceptive outputs are characterized by the information sent to the central nervous system, which provides a unique sensory component to optimize motor control (Riemann and Lephart 2002). Creep deformation has a high potential of changing such sensory information (Solomonow et al. 2003a). Indeed, mechanoreceptors are embedded in passive structures (ligaments) and send postural information (proprioception, position/angle, velocity) to the central nervous system (Holm et al. 2002; Petrie et al. 1998; Solomonow et al. 1998). Creep deformation has also been shown to induce compensatory phenomena, such as change in muscles recruitment with higher muscle activation, in order to compensate for the loss of passive structure stabilization (Arjmand and Shirazi-Adl 2006; Shin and Mirka 2007; Toosizadeh et al. 2013). Moreover, when creep deformation is combined to back muscle fatigue, alteration of back muscle activity recruitment pattern has been reported (Abboud et al. 2016b), confirming a potential impact of creep deformation on spine active components. Such adaptations could lead to changes in movement patterns while performing a motor task involving the paraspinal muscles (Hodges and Tucker 2011).

Overall, several neuromuscular adaptations occur under the influence of creep deformation. However, it remains unclear how these adaptations may or may not affect spine sensorimotor control. Since spinal instability may be associated with low back pain (Panjabi 2003), and proprioceptive acuity seems to have a direct impact on joint stability (Riemann and Lephart 2002), it is of great interest to identify the effect of creep deformation on trunk position sense. Therefore, the main purpose of this study was to assess spine sensorimotor control when active and passive components of the spine are altered following a long-lasting creep deformation. More specifically, this study aimed to quantify the accuracy and the regularity of asymptomatic participants in a trunk repositioning tasks (20- and 30-degrees trunk extension) before and after creep deformation. It was hypothesized that spinal structure alteration triggered by creep deformation would alter the proprioception of the trunk in healthy participants.

2. Methods

2.1 Participants

Twenty healthy participants, 11 men and 9 women, took part in this study (mean (SD): age = 26 years (7 years); height = 1.72 m (0.1 m); weight = 69 kg (8 kg); BMI = 23.5 kg/m^2 (2.8 kg/m^2)). Participants were excluded if they had experienced any episode of low back pain in the past 6 months, or they suffered from ankylosing spondylitis, trunk neuromuscular disease, inflammatory arthritis and previous spinal surgery. The study was approved by local ethics committee (CER-16-225-07.10). All participants provided written informed consent after carefully considering all aspects of the study.

2.2 Experimental Protocol

The experimentation was divided in three phases: [1] pre-creep proprioception tasks, [2] creep protocol and [3] post-creep proprioception tasks. Two or three isometric trunk extension maximal voluntary contractions (MVC) were performed before the first phase. The third trial of MVC was only performed if the participants' second MVC was superior to the first one. The MVC protocol was executed in a neutral seated position using an isokinetic device (The LIDO Active Loredan Biomedical, West Sacramento, CA). To minimize the contribution of lower limb muscles, flexions of 90° were required at the hip and the knees. Participants were asked to push as hard as possible for approximately five seconds against a resistance located approximately at the T7 vertebra. Verbal encouragements were provided by the assessors.

During the pre-creep proprioception protocol, participants were asked to reproduce trunk extension movements at two different angles: at 20° and 30°, initiated from a slightly flexed trunk position (5 degrees). The repositioning tasks were measured using an isokinetic device (The LIDO Active Loredan Biomedical, West Sacramento, CA). This device was used in the goniometer (range of motion) configuration. Using the same isokinetic device, joint angle at peak torque test-retest reliability was evaluated at the knee during extension movement at different velocity (Brown et al. 1992). Results have shown reliability values ranging from 0.5 to 0.9 (Pearson correlation), as well as no significant difference for joint angle values between days. Participants were strapped to the device using three different belts. The first belt was installed over the lower limbs, the second one over the hips and the last one over the trunk (**Fig. 1**). Participants were told to produce a single impulse at a constant speed and to make no attempt at correcting the speed once the contraction was initiated. All participants began with a familiarization protocol lasting 2 to 3 minutes, in order to be comfortable with the apparatus. They then had to execute 10 trials with a visual and verbal feedback of their accuracy, followed by 10 trials without any feedback. Participants were specifically asked to reproduce angles that were within 5% of the target goal set at 20° trunk extension. This protocol was the same for both 20° and 30° conditions. To avoid the introduction of confounding variables such as a "learning effect", half of participants started the testing protocol with the 30°, and the other half with 20° trunk extension. Since no effect of expectation was anticipated in this study, a counterbalancing strategy was chosen. Moreover, all participants were unaware about the effect of creep on reposition sense.

The creep deformation protocol began with the participants sitting on a bench and then bending forward while they remained attached at the hips. Participants were asked to bend forward at their maximum range of motion in trunk flexion that would not cause important discomfort, such as headaches or dizziness, as it would not be sustainable for the whole creep phase. Their legs were also flexed by approximately 90 degrees to limit the occurrence of hamstring muscles stretching. They maintained this position for 20 minutes. Before and immediately after the creep deformation protocol, the range of motion (ROM) of trunk flexions was measured by the same assessor. The trunk angle was measured by placing the digital dual inclinometer (Dualer IQ Pro™ Digital Inclinometer, JTECH Medical; USA) on the L2 and L5 vertebrae. Dual inclinometers are frequently used and are recommended to measure lumbar spinal mobility; they are known to be highly reliable and valid (Saur et al. 1996). Using similar landmarks (T12-L1 and L5-S1) results have shown a high to very high intra-trial reliability in trunk flexion (0.89> ICCs <0.96), as well as a moderate intra-rater reliability in trunk flexion (0.56> ICCs <0.74) and moderate inter-rater (0.47> ICCs <0.68) (MacDermid et al. 2014). In the present study, the same assessor was in charge of the ROM evaluation to minimize possible inter-rater bias. To evaluate trunk flexion ROM, the participants stood upright and then tilted the trunk forward as much as possible, without bending the knees. Three attempts were made, before and after the creep deformation protocol. The trial with the highest ROM was considered for the analysis. Finally, in the last phase (post-creep), the entire trunk proprioception protocol (20° and 30° trunk extension) was repeated a second time.

Insert figure 1 about here

2.3 Data Acquisition

Surface electromyography (EMG) was used to record the muscular activation of the lumbar erector spinae during the MVC protocol, as well as during the proprioception protocol. EMG consisted of two rigid bipolar electrodes located on each side of the third lumbar segments (L3) following the orientation of the muscular fibers, as described by (Criswell and Cram 2011). Surface EMG has been extensively used with the low back muscles. Its validity as well as its reliability have been shown in different functional tasks (Czaprowski et al. 2015; Lariviere et al. 2008; Mohseni Bandpei et al. 2014). At first, a skin preparation protocol was performed to prevent interference of the EMG signal. It consisted of shaving body hair, exfoliating skin softly with a fine-grade sandpaper (Red Dot Trace Prep, 3M; St. Paul, MN, USA) and wiping skin with alcohol on the recording sites. The ground was placed on the right acromion. Surface EMG sensors (Model DE2.1, Delsys Inc., Boston, MA, USA) were sampled at 1000 Hz with a 12-bit A/D converter. Data were recorded with LabView (National Instruments) and bandpass filtered in the frequency bandwidth 10 - 450 Hz, eight-order Butterworth filter. Surface EMG data were processed by MatLab (MathWorks, Natick, MA). Erector spinae myoelectric signals were normalized with respect to the trunk extension MVC value.

2.4 Dependent Variables

From the myoelectric signals, the mean normalized root mean square (RMS) of the 10 proprioception trials of each condition (20° and 30°; pre- and post-creep) was computed. Since no difference was identified between left and right sides, mean RMS values of left and right erector spinae muscles were used for the analyses. Four different variables were computed to assess the accuracy of the repositioning task, and compared between the 2 conditions (pre- and post-creep) in both 20° and 30°: the constant error (CE), the variable error (VE), the absolute error (AE) and the movement time (MT). MT is the amount of time the participant took to reach the target, starting from the first movement of trunk extension to the target. CE represents the positive or negative difference between the amplitude reached by the participants and the target (either 20° or 30°). VE is defined by the peak angle reached consistency compared with the participant average score (mean of the 10 attempts). Finally, AE represents the absolute accuracy regardless of direction, which represents the global accuracy of the participant (Schmidt and Lee 2005).

2.5 Statistical Analysis

Normality of distribution for each dependent variable was assessed using the Kolmogorov–Smirnov test and through visual inspection of the data. Trunk ROM was compared before and after the creep deformation using a *t*-test for dependent samples. Dependent variables (RMS, CE, VE, AE and MT) data were compared between the two conditions (pre- and post-creep) and the two angles (20 and 30°) using a two-way repeated-measure analysis of variance (ANOVA). When necessary, the Tukey post hoc test was performed as the post hoc analysis for pairwise comparisons. Effect size estimates were calculated by partial eta-squared (ηp^2; 0.01 = small effect; 0.06 = medium effect; 0.14 = large effect). For all the results, $p < 0.05$ was considered to be statistically significant.

3. Results

3.1 ROM

The *t*-test for dependent samples comparing the trunk ROM before creep (mean = 44.4°; SD = 6.4°) and after creep (mean = 47.1°; SD = 6.4°) revealed a significant increase of trunk flexion ROM after the creep deformation protocol ($p < 0.001$).

3.2 EMG

A main significant effect of creep deformation was observed, with higher RMS values in the post-creep condition [F(1, 16) = 5.99, $p = 0.03$]. There was no significant main effect on the mean RMS values due to angle [F(1, 16) = 0.08, $p = 0.78$] or interaction effect creep x angle [F(1, 16) = 0.001, $p = 0.97$]. Mean values and standard deviations of the EMG variable are presented in Table 1.

3.3 CE

The ANOVA revealed no significant main effect of angle [F(1, 19) = 1.19, $p = 0.29$] or creep deformation [F(1, 19) = 3.49, $p = 0.08$] on CE. However, the creep x angle interaction effect was significant [F(1, 19) = 5.6493, $p = 0.03$] as illustrated in **Fig. 2**. Post hoc analyses revealed a significant increase of CE only for the 20° condition after the creep protocol ($p = 0.01$). Moreover, higher, yet not significant ($p = 0.06$) CE values, were observed under the 30° versus the 20° repositioning tasks before the creep protocol.

3.4 VE

No significant main effect of angle [F(1, 19) = 2.55, $p = 0.13$], creep deformation [F(1, 19) = 0.22, $p = 0.65$] or creep x angle interaction effect [F(1, 19) = 0.14, $p = 0.72$] was revealed by the ANOVA for VE variable.

3.5 AE

The results showed a significant main effect of creep deformation [F(1, 19) = 6.70, $p = 0.02$], with higher AE values after the creep protocol. On the other hand, the ANOVA revealed no significant main effect of angle [F(1, 19) = 0.01, $p = 0.93$] on AE. Finally, a significant creep x angle interaction effect was observed [F(1, 19) = 7.92, $p = 0.01$] on AE. Finally, post hoc analyses revealed significant an increase of AE only for the 20° repositioning task after the creep deformation ($p = 0.001$) (**Fig. 2**). Mean values and standard deviations of all repositioning error variables (CE, VE and AE) are presented in Table 1.

3.6 MT

As for the MT variable, a significant main effect of angle was observed [F(1, 19) = 36.09, p <0.001], with longer MT values under the 30° condition. In contrast, no significant main effect of creep deformation [F(1, 19) = 2.77, p = 0.11] or interaction effect was found [F(1, 19) = 0.30, p = 0.59]. Finally, the Table 1 presents the MT mean values and standard deviations.

Insert table 1 and figure 2 about here

4. Discussion

The main goal of this study was to identify trunk proprioception adaptations following a 20-minute long creep deformation session. The results showed that both angles and the creep deformation had significant effects on the accuracy and the variability of participants throughout the trunk repositioning task. Such results support the hypothesis that spinal structures play a role in the trunk proprioception. A static full flexion of the trunk was used to induce creep deformation. The choice of a 20-minute duration for the creep protocol was based on previous data which have shown that a static full flexion of the trunk lasting 5 (Shin et al. 2009), 16 (Hendershot et al. 2011) or 20 minutes (McGill and Brown 1992) was enough to produce creep in the lumbar structures. Moreover, the present study observed an increase of almost three degrees in full trunk flexion angle. Furthermore, an increase of EMG amplitude following the creep protocol was observed during the trunk repositioning tasks. The increase of EMG amplitude could be required to generate more active forces to compensate for the loss of the passive structures' contribution to spinal stability (Abboud et al. 2016b; Olson et al. 2004). Based on these observations, it seems reasonable to suggest that participants from the current study experienced creep effects during the experiment.

Trunk repositioning sense was evaluated using two reaching targets of respectively 20° and 30° trunk extension. These two targets were chosen based on range of motion physiological limits of the trunk extension. Physiological limits in trunk extension are estimated to be around 25 to 30 degrees (Andersson et al. 2002). As mentioned in the methods section, participants initiated the trunk extension movements from a slightly flexed position (5 degrees). This position was used to ensure that none of the participants reached their physiological limits. In this study, trunk repositioning was only tested in extension.

Although posterior passive structures are known to be stretched during flexion, studies have shown that they can also be loaded during trunk extension. For instance, during pure extension, the anterior longitudinal ligament was shown to experience tension, whereas the posterior ligaments (supra-, interspinous and ligamentum flavum) were subject to compression (Panjabi et al. 1982). However, it could be argued that the loading experienced by the ligaments during extension is significantly smaller than the ones experienced by the facet joints, intervertebral disc and even the vertebral body of the lower vertebra. In addition to spinal passive components, the musculotendinous complex play an important role in proprioception mechanisms (Cordo et al. 1995; Proske and Gandevia 2012). During trunk extension movements, erector spinae tendons are loaded (in tension) and consequently provide proprioceptive information mostly through Golgi tendon organ and IIb afferences.

Before the creep deformation protocol, significant differences in repositioning errors, as well as MT, were observed between the two reaching targets (20° and 30° trunk extension). Results of this study are in accordance with the Fitts law, which states that increasing the distance between the target should result in increased MT or repositioning errors (Fitts 1954). Moreover, using a similar experimental paradigm, Boucher et al reported similar increases in MT and/or repositioning errors (Boucher et al. 2012). The current study is the first one to assess the effect of creep deformation on trunk repositioning sense. Overall, the results indicate that creep deformation has a minimal effect on repositioning error when the distance between the targets is higher (30° trunk extension). In contrast, when participants were asked to extend their trunk at 20°, their performance was worse under the influence of spinal creep. Despite this significant creep effect, the difference observed in repositioning errors could be considered small (between 2 and 3 degrees). In a recent systematic review, comparing trunk reposition sense in chronic low back pain patients versus healthy controls, the authors have shown that in a sitting position, the absolute error in patients with chronic low back pain ranged from 1.5 to 7.7°, whereas in healthy controls, it ranged from 0.7 to 3.1° (Tong et al. 2017). Therefore, the difference observed between our two conditions (creep/no creep) seems to reach the threshold for clinical relevance.

Based on the results of the present study, it would be an overstatement to suggest that the neurophysiological effects observed are only due to the creep protocol. Moreover, this is the first study assessing the effect of creep deformation during a back extension repositioning task. It has been shown that a creep deformation induced by a passive cyclic flexion desensitizes the mechanoreceptors, and represents a direct manifestation of the laxity in the passive structures of the spine (Solomonow et al. 1999). Alteration of the viscoelastic tissue properties has also been reported following a static prolonged full flexion during trunk flexion or at rest (McGill and Brown 1992; Solomonow et al. 2003b). The interplay between active and passive component of the spinal system has also been assessed following creep deformation (Shin and Mirka 2007). During a lifting task, results have shown increased back muscle activity as well as increased full trunk flexion, confirming an alteration of both active and passive systems under the influence of creep deformation (Shin and Mirka 2007). Since laxity gradually increases in viscoelastic tissues and decreases baseline tensions, the trigger threshold of afferents gradually shifts so that fewer motor units are activated as loading time increases (Solomonow 2012). In the present study, creep deformation in flexion triggered changes in muscle activity during trunk extension movements.

It is also important to note that the counterbalanced design used in this study ensured that learning effects were not responsible for such creep effects. Recovery from the creep deformation protocol could be considered as a possible alternative explanation for our results. However, McGill and Brown showed that following a 20-minute creep deformation protocol, similar to the one used in the present study, 25 minutes were required for the participant to recover 50% of their initial trunk flexion ROM, and even after 50 minutes of rest, 30% of the creep effect was still present (McGill and Brown 1992). Based on these findings, it could be suggested that participants were in a similar state of creep effect for both angle-repositioning tasks, and that recovery is less likely to explain the current effects on EMG and proprioception.

Three hypotheses will be proposed in an effort to explain the different effects of creep deformation on 20° versus 30° trunk extension repositioning tasks. The first hypothesis is based on the theory of the neutral and the elastic zones (Panjabi 1992b). All physiological movements performed in their full range of motion include a neutral zone and an elastic zone. The neutral zone corresponds to the initiation of the motion, starting from the neutral position to the occurrence of a low resistance in the movement. From there, movement enters an elastic zone where the resistance to movement increases linearly until the physiological limit is reached. Unlike the neutral zone, the elastic zone is a zone of high stiffness. Panjabi created the analogy of the ball in a bowl to explain how the neutral and elastic zone work in spinal motion (Panjabi 1992b). He associated the bottom of the bowl to the neutral zone where the ball can move freely with minimal resistance, whereas the sides of the bowl should be associated with the elastic zone, which offers a high resistance for the ball to move. The elastic zone is mainly controlled by the passive structures and encompasses mechanoreceptors, which send continuous proprioceptive information to the central nervous system, improving sensory-motor control via appropriate and coordinated motor action (Panjabi 1992a). An in-vitro study has shown that the neutral zone increased by more than 30% following a prolonged flexion of the trunk (Busscher et al. 2011). This study also observed that 30 minutes of recovery did not appear to be sufficient to return to the neutral zone baseline. Based on Panjabi's theory of (Panjabi 1992b) and the results of the current study, it could be hypothesized that the narrower the neutral zone is, following creep deformation, the lesser such deformation will impact proprioceptive acuity. Since no effect of creep deformation was found when participants were asked to reproduce a 30° trunk extension, it could be argued that movement predominately occurred in the elastic zone, and consequently generated sufficient tension to generate proprioceptive feedback from passive structures. Conversely, since the neutral zone increased following creep deformation, when participants were asked to reproduce a 20° trunk extension, movement may have not reached the elastic zone, and consequently generated less tension and feedback from passive structures (**Fig. 3**).

Insert figure 3 about here

The second hypothesis, which could explain why the presence of spinal tissue creep had no impact on a 30° trunk extension repositioning task, is based on the anatomical properties of the spine. Indeed, soft tissues surrounding the spine, as well as bony structures (spinous processes), could limit the range of motion in trunk hyperextension. Consequently, almost reaching the physiological limit of movement could provide increased proprioceptive feedback (Blasier et al. 1994) in spinal structures that were not targeted by creep deformation (anterior longitudinal ligament and anterior muscles). Moreover, even though no significant difference was found, lower values of VE in the 30° were observed pre- and post-creep protocol in comparison to the 20° trunk extension. The lower variability observed at 30° could result from increased proprioceptive information, as more tension in passive structures are generated towards the physiological limits of movement (Rogol et al. 1998). Indeed, the normal reference range for mechanoreceptors could be modified following creep deformation, consequently altering muscle recruitment patterns aimed at stabilizing the spine. Similar modifications have been suggested during pregnancy, which is associated with relaxation of the pelvic joints (MacLennan et al. 1986).

The third hypothesis is based on the muscle activity recruitment pattern. In the present study, no effect of angle was found on the erector spinae muscles EMG amplitude, while a similar increase of EMG amplitude was reported in both angles following the creep protocol. This might suggest that, for both repositioning task (20 and 30° trunk extension), participants used a similar co-contraction recruitment strategy in order to globally increase spinal stability. However, only two EMG electrodes were used in the current study. In a previous study for which high-density EMG was used, alternative muscle activity recruitment patterns within the same muscle was observed following a spinal tissue creep protocol (Abboud et al. 2016b). It could be hypothesized that, despite a similar increase in erector spinae muscle activity following a prolonged trunk flexion, participants may have used different muscle recruitment strategies in each of repositioning tasks. When performing a 20° trunk extension, active components (muscles) may be the predominant contributor to spinal proprioception with limited input originating from passive tissues, especially following a creep deformation, as previously described for the neutral and elastic zone hypothesis. Given such a hypothesis, stabilizing the spine during the 20° task, in the presence of creep deformation, would require a different muscle recruitment strategy, whereas, only a modulation of the strategy would be needed to stabilize the spine at 30° under a creep deformation. However, we were unable to confirm or infirm this hypothesis with only two EMG electrodes. This could be considered as one of this study's limitations, and future research should focus on muscle activity recruitment patterns to better understand the effect of spinal tissue creep on trunk proprioception in various movements and ranges of motion. Another limitation could be the absence of direct measurement of the creep deformation. Adding other measures such as the angle at the onset of flexion-relaxation could have better supported the presence of spinal tissue creep (Howarth et al. 2013b). A third limitation of the current study is the demographic characteristics of the participants (young and healthy), which may limit the generalization of results. Three participants were also excluded from EMG analyses due to high levels of EMG noise during MVC recordings, which made EMG data normalization impossible. Finally, four participants experienced a slight numbness in the legs, which caused a short delay (no longer than five minutes) between the end of the creep protocol and the following repositioning task. None of these participants experienced discomfort during the repositioning protocol. Furthermore, as it was mentioned earlier, the creep effect could last more than 30 minutes (McGill and Brown 1992).

5. Conclusion

This study has shown that trunk proprioception can be altered under the influence of creep deformation, especially in small range of motion. Creep deformation seems to modify proprioceptive feedback mechanisms, which are mainly controlled by the passive structures. Reduced ability to perceive our joint movements and joint positions may have negative consequences on spinal stability and may increase the risk of low back pain or injury. Future studies should focus on making recommendations to minimize the occurrence of creep deformation in the workplace. Furthermore, different trunk angle repositioning task in extension as well as in flexion should be tested to confirm the hypothesis of smaller impact of creep when doing large trunk range of motions.

Conflict of interest

The authors declare that they have no conflicts of interest.

References

Abboud J, Lardon A, Boivin F, Dugas C, Descarreaux M (2016a) Effects of Muscle Fatigue, Creep, and Musculoskeletal Pain on Neuromuscular Responses to Unexpected Perturbation of the Trunk: A Systematic Review Front Hum Neurosci 10:667 doi:10.3389/fnhum.2016.00667

Abboud J, Nougarou F, Descarreaux M (2016b) Muscle Activity Adaptations to Spinal Tissue Creep in the Presence of Muscle Fatigue PloS one 11:e0149076 doi:10.1371/journal.pone.0149076

Andersson G, Cocchiarella L, American Medical A (2002) Guides to the evaluation of permanent impairment. AMA Press, [Chicago]

Arjmand N, Shirazi-Adl A (2006) Model and in vivo studies on human trunk load partitioning and stability in isometric forward flexions Journal of biomechanics 39:510-521

Blasier RB, Carpenter JE, Huston LJ (1994) Shoulder proprioception. Effect of joint laxity, joint position, and direction of motion Orthop Rev 23:45-50

Boucher JA, Abboud J, Descarreaux M (2012) The influence of acute back muscle fatigue and fatigue recovery on trunk sensorimotor control Journal of manipulative and physiological therapeutics 35:662-668 doi:10.1016/j.jmpt.2012.10.003

Boucher JA, Abboud J, Nougarou F, Normand MC, Descarreaux M (2015) The Effects of Vibration and Muscle Fatigue on Trunk Sensorimotor Control in Low Back Pain Patients PloS one 10:e0135838 doi:10.1371/journal.pone.0135838

Brown LE, Whitehurst M, Bryant JR (1992) Reliability of the LIDO Active Isokinetic Dynamometer Concentric Mode ISOKINETICS AND EXERCISE SCIENCE 2:191

Busscher I, van Dieen JH, van der Veen AJ, Kingma I, Meijer GJ, Verkerke GJ, Veldhuizen AG (2011) The effects of creep and recovery on the in vitro biomechanical characteristics of human multi-level thoracolumbar spinal segments Clin Biomech (Bristol, Avon) 26:438-444 doi:10.1016/j.clinbiomech.2010.12.012

Callaghan JP, Gunning JL, McGill SM (1998) The relationship between lumbar spine load and muscle activity during extensor exercises Physical therapy 78:8-18

Chaffin DB, Park KS (1973) A longitudinal study of low-back pain as associated with occupational weight lifting factors Am Ind Hyg Assoc J 34:513-525 doi:10.1080/0002889738506892

Cordo P, Gurfinkel VS, Bevan L, Kerr GK (1995) Proprioceptive consequences of tendon vibration during movement Journal of neurophysiology 74:1675-1688

Crisco JJ, 3rd, Panjabi MM (1992) Euler stability of the human ligamentous lumbar spine. Part I: Theory Clin Biomech (Bristol, Avon) 7:19-26 doi:10.1016/0268-0033(92)90003-M

Criswell E, Cram JR (2011) Cram's introduction to surface electromyography. Jones and Bartlett, Sudbury, MA

Czaprowski D, Kolwicz A, Afeltowicz A, Pawlowska P, Oleksy L (2015) Reliability of measurements of the extension-flexion ratio with surface EMG J Back Musculoskelet Rehabil 28:827-832 doi:10.3233/BMR-150590

Fitts PM (1954) The information capacity of the human motor system in controlling the amplitude of movement J Exp Psychol 47:381-391

Freddolini M, Strike S, Lee RY (2014) Stiffness properties of the trunk in people with low back pain Human movement science 36:70-79 doi:10.1016/j.humov.2014.04.010

Guo HR (2002) Working hours spent on repeated activities and prevalence of back pain Occup Environ Med 59:680-688

Hendershot B, Bazrgari B, Muslim K, Toosizadeh N, Nussbaum MA, Madigan ML (2011) Disturbance and recovery of trunk stiffness and reflexive muscle responses following prolonged trunk flexion: influences of flexion angle and duration Clin Biomech (Bristol, Avon) 26:250-256 doi:10.1016/j.clinbiomech.2010.09.019

Hodges P, van den Hoorn W, Dawson A, Cholewicki J (2009) Changes in the mechanical properties of the trunk in low back pain may be associated with recurrence Journal of biomechanics 42:61-66

Hodges PW (1999) Is there a role for transversus abdominis in lumbo-pelvic stability? Manual therapy 4:74-86 doi:10.1054/math.1999.0169

Hodges PW, Tucker K (2011) Moving differently in pain: a new theory to explain the adaptation to pain Pain 152:S90-S98 doi:10.1016/j.pain.2010.10.020

Holm S, Indahl A, Solomonow M (2002) Sensorimotor control of the spine Journal of electromyography and kinesiology : official journal of the International Society of Electrophysiological Kinesiology 12:219-234

Howarth SJ, Glisic D, Lee JG, Beach TA (2013a) Does prolonged seated deskwork alter the lumbar flexion relaxation phenomenon? Journal of electromyography and kinesiology : official journal of the International Society of Electrophysiological Kinesiology 23:587-593 doi:10.1016/j.jelekin.2013.01.004

Howarth SJ, Kingston DC, Brown SH, Graham RB (2013b) Viscoelastic creep induced by repetitive spine flexion and its relationship to dynamic spine stability Journal of electromyography and kinesiology : official journal of the International Society of Electrophysiological Kinesiology 23:794-800 doi:10.1016/j.jelekin.2013.04.002

Lariviere C, Gagnon D, Gravel D, Bertrand Arsenault A (2008) The assessment of back muscle capacity using intermittent static contractions. Part I - Validity and reliability of electromyographic indices of fatigue Journal of electromyography and kinesiology : official journal of the International Society of Electrophysiological Kinesiology 18:1006-1019 doi:10.1016/j.jelekin.2007.03.012

MacDermid JC, Arumugam V, Vincent JI, Carroll KL (2014) The reliability and validity of the computerized double inclinometer in measuring lumbar mobility Open Orthop J 8:355-360 doi:10.2174/1874325001408010355

MacLennan AH, Nicolson R, Green RC, Bath M (1986) Serum relaxin and pelvic pain of pregnancy Lancet 2:243-245

Marras WS, Lavender SA, Leurgans SE, Rajulu SL, Allread WG, Fathallah FA, Ferguson SA (1993) The role of dynamic three-dimensional trunk motion in occupationally-related low back disorders. The effects of workplace factors, trunk position, and trunk motion characteristics on risk of injury Spine 18:617-628

McGill SM, Brown S (1992) Creep response of the lumbar spine to prolonged full flexion Clin Biomech (Bristol, Avon) 7:43-46 doi:10.1016/0268-0033(92)90007-Q

Mohseni Bandpei MA, Rahmani N, Majdoleslam B, Abdollahi I, Ali SS, Ahmad A (2014) Reliability of surface electromyography in the assessment of paraspinal muscle fatigue: an updated systematic review Journal of manipulative and physiological therapeutics 37:510-521 doi:10.1016/j.jmpt.2014.05.006

Moseley GL, Hodges PW, Gandevia SC (2002) Deep and superficial fibers of the lumbar multifidus muscle are differentially active during voluntary arm movements Spine 27:E29-36

Olson MW, Li L, Solomonow M (2004) Flexion-relaxation response to cyclic lumbar flexion Clin Biomech (Bristol, Avon) 19:769-776 doi:10.1016/j.clinbiomech.2004.05.007

Panjabi MM (1992a) The stabilizing system of the spine. Part I. Function, dysfunction, adaptation, and enhancement Journal of spinal disorders 5:383-389; discussion 397

Panjabi MM (1992b) The stabilizing system of the spine. Part II. Neutral zone and instability hypothesis Journal of spinal disorders 5:390-396; discussion 397

Panjabi MM (2003) Clinical spinal instability and low back pain Journal of electromyography and kinesiology : official journal of the International Society of Electrophysiological Kinesiology 13:371-379

Panjabi MM, Goel VK, Takata K (1982) Physiologic strains in the lumbar spinal ligaments. An in vitro biomechanical study 1981 Volvo Award in Biomechanics Spine 7:192-203

Petrie S, Collins JG, Solomonow M, Wink C, Chuinard R, D'Ambrosia R (1998) Mechanoreceptors in the human elbow ligaments J Hand Surg Am 23:512-518 doi:10.1016/S0363-5023(05)80470-8

Proske U, Gandevia SC (2012) The proprioceptive senses: their roles in signaling body shape, body position and movement, and muscle force Physiological reviews 92:1651-1697 doi:10.1152/physrev.00048.2011

Riemann BL, Lephart SM (2002) The Sensorimotor System, Part II: The Role of Proprioception in Motor Control and Functional Joint Stability Journal of athletic training 37:80-84

Rogol IM, Ernst G, Perrin DH (1998) Open and closed kinetic chain exercises improve shoulder joint reposition sense equally in healthy subjects Journal of athletic training 33:315-318

Saur PM, Ensink FB, Frese K, Seeger D, Hildebrandt J (1996) Lumbar range of motion: reliability and validity of the inclinometer technique in the clinical measurement of trunk flexibility Spine 21:1332-1338

Schmidt RA, Lee TD (2005) Motor control and learning : a behavioral emphasis. Human Kinetics, Champaign, IL

Shin G, D'Souza C, Liu YH (2009) Creep and fatigue development in the low back in static flexion Spine 34:1873-1878 doi:10.1097/BRS.0b013e3181aa6a55

Shin G, Mirka GA (2007) An in vivo assessment of the low back response to prolonged flexion: Interplay between active and passive tissues Clin Biomech (Bristol, Avon) 22:965-971 doi:10.1016/j.clinbiomech.2007.06.003

Solomonow M (2012) Neuromuscular manifestations of viscoelastic tissue degradation following high and low risk repetitive lumbar flexion Journal of electromyography and kinesiology : official journal of the International Society of Electrophysiological Kinesiology 22:155-175 doi:10.1016/j.jelekin.2011.11.008

Solomonow M, Baratta RV, Zhou BH, Burger E, Zieske A, Gedalia A (2003a) Muscular dysfunction elicited by creep of lumbar viscoelastic tissue Journal Of Electromyography And Kinesiology: Official Journal Of The International Society Of Electrophysiological Kinesiology 13:381-396

Solomonow M, Zhou BH, Baratta RV, Burger E (2003b) Biomechanics and electromyography of a cumulative lumbar disorder: response to static flexion Clin Biomech (Bristol, Avon) 18:890-898

Solomonow M, Zhou BH, Baratta RV, Lu Y, Harris M (1999) Biomechanics of increased exposure to lumbar injury caused by cyclic loading: Part 1. Loss of reflexive muscular stabilization Spine 24:2426-2434

Solomonow M, Zhou BH, Harris M, Lu Y, Baratta RV (1998) The ligamento-muscular stabilizing system of the spine Spine 23:2552-2562

Tong MH, Mousavi SJ, Kiers H, Ferreira P, Refshauge K, van Dieen J (2017) Is There a Relationship Between Lumbar Proprioception and Low Back Pain? A Systematic Review With Meta-Analysis Archives of physical medicine and rehabilitation 98:120-136 e122 doi:10.1016/j.apmr.2016.05.016

Toosizadeh N, Bazrgari B, Hendershot B, Muslim K, Nussbaum MA, Madigan ML (2013) Disturbance and recovery of trunk mechanical and neuromuscular behaviours following repetitive lifting: influences of flexion angle and lift rate on creep-induced effects Ergonomics 56:954-963 doi:10.1080/00140139.2013.785601

Table 1. Mean (SD) normalized EMG RMS (in percentage), MT (in milliseconds), AEs (in degree), CEs (in degree), and VEs (in degree) in target angle for pre- and post-creep conditions in trunk extension at 20° and 30° (ηp^2: partial eta-squared; CI: confidence interval). *p* values from the repeated measures ANOVA (Cond: conditions pre/post-creep; Angle: angles 20°/30°; Inter: interaction conditions x angles).

	Pre-creep		**Post-creep**							
	Mean (SD)	95% CI	Mean (SD)	95% CI	*p* Cond	ηp^2	*p* Angle	ηp^2	*p* Inter	ηp^2
20° extension										
CE	0.9 (1.5)	[0.2, 1.6]	2.5 (2.8)	[1.2, 3.8]	0.08	0.16	0.29	0.06	0.03	0.23
AE	2.0 (0.8)	[1.7, 2.4]	3.5 (1.6)	[2.8, 4.2]	0.02	0.26	0.93	0.000	0.01	0.29
VE	1.6 (0.7)	[1.3, 1.9]	1.7 (0.7)	[1.3, 2.0]	0.65	0.01	0.13	0.12	0.72	0.007
MT	110 (18)	[102, 119]	106 (19)	[97, 115]	0.11	0.13	0.001	0.66	0.59	0.02
EMG	36 (7)	[21, 50]	37 (7)	[23 51]	0.03	0.27	0.78	0.005	0.97	0.000
30° extension										
CE	2.2 (2.3)	[1.1, 3.3]	2.2 (2.2)	[1.2, 3.3]						
AE	2.7 (1.9)	[1.8, 3.6]	2.9 (1.5)	[2.2, 3.6]						
VE	1.4 (0.5)	[1.2, 1.6]	1.5 (0.6)	[1.2, 1.8]						
MT	125 (18)	[116, 133]	122 (20)	[113, 132]						
EMG	35 (6)	[22 49]	37.0 (6.8)	[22 51]						

Figure captions

Fig. 1 Illustration of the repositioning tasks measured using the isokinetic device (The LIDO Active Loredan Biomedical, West Sacramento, CA).

Fig. 2 Mean MT (in milliseconds), AEs, CEs, and VEs in target angle for pre- and post-creep conditions in trunk extension at 20° and 30°. Error bars indicate standard errors. Post hoc results are illustrated by numbers (1 vs 2 = $p < 0.05$ and 3 vs 4 = $p < 0.01$).

Fig. 3 Hypothetical model, based on the analogy of the ball in a bowl (Panjabi 1992b), to explain how the spinal tissue creep influences the trunk proprioception in extension at different angles. Note that after the creep protocol, the neutral zone (NZ) is increased and consequently, the elastic zone (EZ) is reduced, especially for 20° of trunk extension.

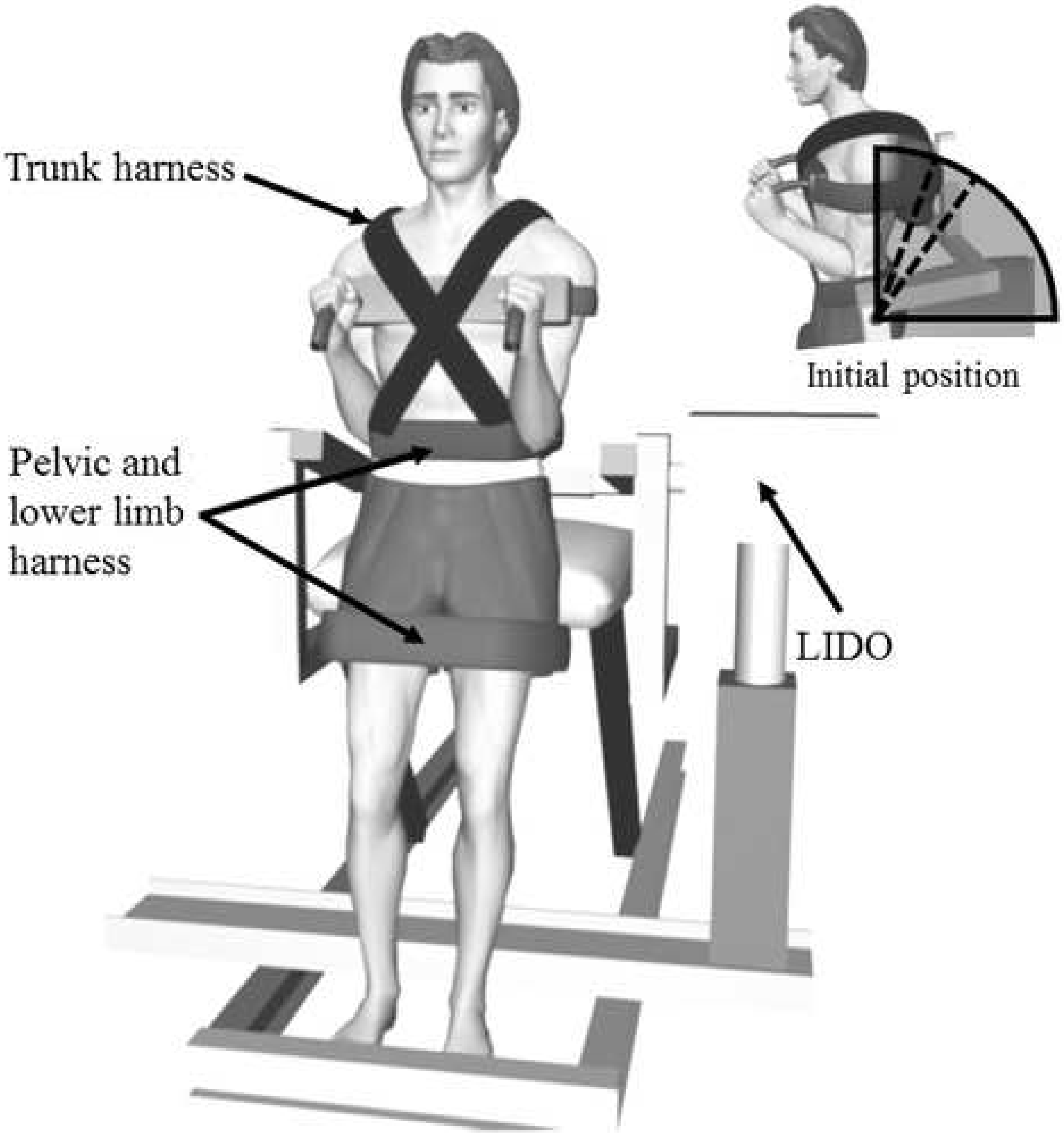
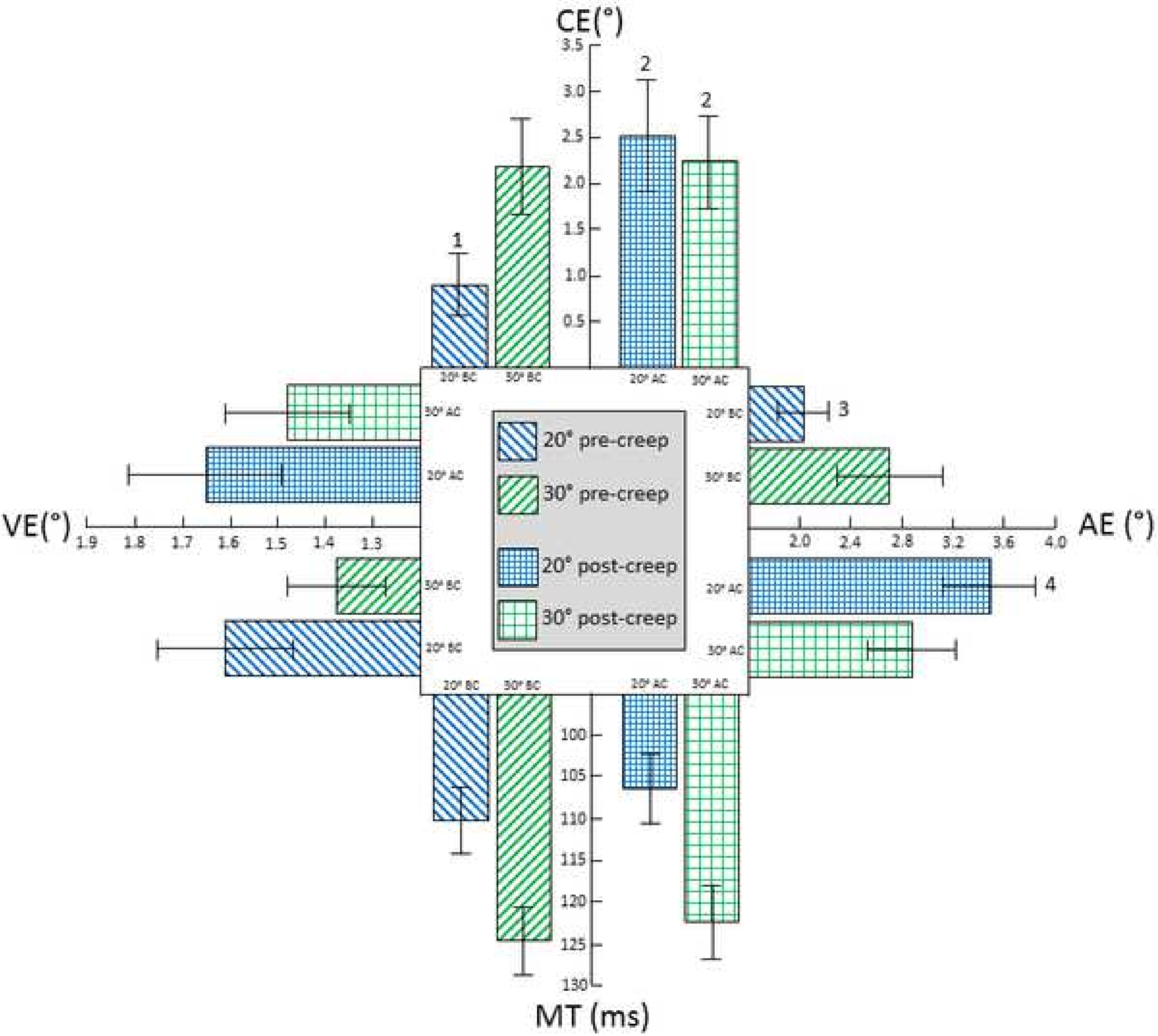
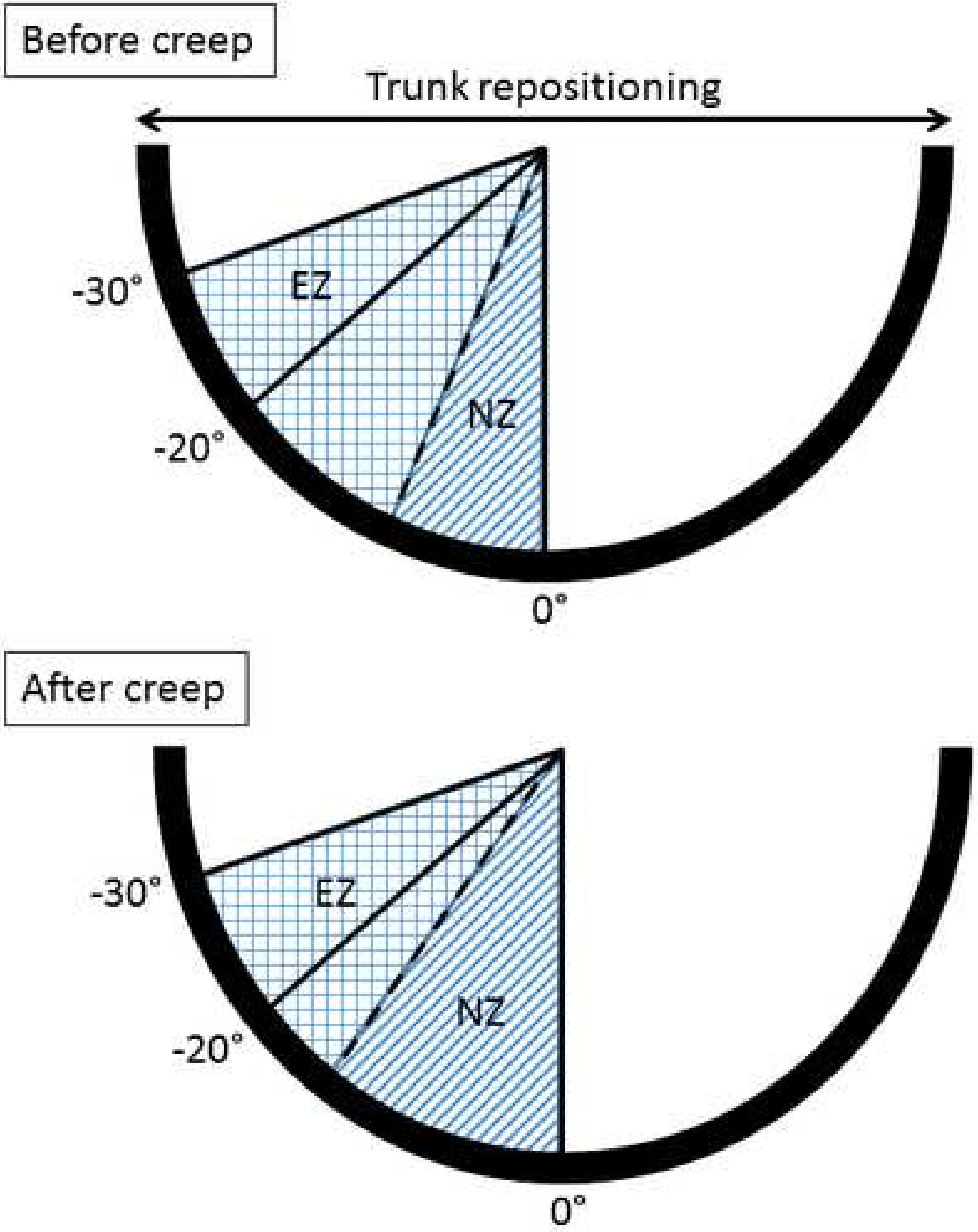

Trunk harness
Initial position
Pelvic and lower limb harness
LIDO

Figure2


CE(°)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
1
2
2
20° BC
30° BC
20° AC
30° AC
30° AC
20° AC
30° BC
20° BC
20° BC
30° BC
20° AC
30° AC
3
4
VE(°)
1.9
1.8
1.7
1.6
1.5
1.4
1.3
2.0
2.4
2.8
3.2
3.6
4.0
AE (°)
🟦 20° pre-creep
🟩 30° pre-creep
🟦 20° post-creep
🟩 30° post-creep
20° BC
30° BC
20° AC
30° AC
100
105
110
115
120
125
130
MT (ms)


Before creep
Trunk repositioning
-30°
-20°
0°
EZ
NZ
After creep
-30°
-20°
0°
EZ
NZ