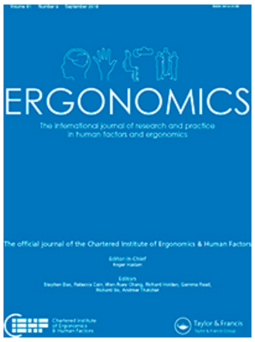

Ergonomics

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/terg20

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ERGONOMICS
https://doi.org/10.1080/00140139.2023.2186323

Cognitive dissonance increases spine loading in the neck and low back

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ABSTRACT

Cognitive dissonance refers to a state where two psychologically inconsistent thoughts, behaviours, or attitudes are held at the same time. The objective of this study was to explore the potential role of cognitive dissonance in biomechanical loading in the low back and neck. Seventeen participants underwent a laboratory experiment involving a precision lowering task. To establish a cognitive dissonance state (CDS), study participants were provided negative feedback on their performance running counter to a pre-established expectation that their performance was excellent. Dependent measures of interest were spinal loads in the cervical and lumbar spines, calculated via two electromyography-driven models. The CDS was associated with increases to peak spinal loads in the neck (11.1%, $p < .05$) and low back (2.2%, $p < .05$). A greater CDS magnitude was also associated with a greater spinal loading increase. Therefore, cognitive dissonance may represent a risk factor for low back/neck pain that has not been previously identified.

Practitioner summary: Upon establishing a cognitive dissonance state in a group of participants, spinal loading in the cervical and lumbar spines were increased proportional to the magnitude of the cognitive dissonance reported. Therefore, cognitive dissonance may represent a risk factor for low back and neck pain that has not been previously identified.

ARTICLE HISTORY
Received 11 January 2023
Accepted 27 February 2023

KEYWORDS
Musculoskeletal disorder; pain; biopsychosocial; cervical; lumbar

1. Introduction

Low back pain (LBP) and neck pain are the most predominant musculoskeletal conditions in industrialised societies. Up to 80% of people will report at least one episode of low back or neck pain in their lifetime (Rubin 2007), and although most recover within a short duration of time, some 10–40% of patients go on to develop chronic symptoms and suffer some level of disability (Alhowimel et al. 2018). Given the high prevalence of low back and neck pain, it is not surprising that treatment of these ailments comes with an immense economic burden. For example, the cost of treating low back pain in the United States alone ranges from $84.1 billion to $624.8 billion annually when accounting for both direct and indirect costs (Dagenais, Caro, and Haldeman 2008). Low back/neck pain was also one of two conditions for which medical expenditures increased the most between 1996 and 2013 in the United States (Dieleman et al. 2016).

A complete understanding of all the factors contributing to low back and neck pain and the overarching causal pathways for the development of a spine disorder could result in the establishment of more effective treatments. In what has been described as the biopsychosocial model of pain (Waddell 1987), it is now accepted that LBP and neck pain arise from complex interactions among physical stressors (e.g. accidents, heavy lifting, repetitive spine motions), social stressors (e.g. financial stress, poor social support, low job satisfaction), psychological stressors (e.g. anxiety, depression, negative affect), individual factors (e.g. obesity, tobacco use), and genetic factors (Hartvigsen et al., 2018). While these stressors have historically been studied in isolation, the recognition that they interact with one another necessitates the need to study these and other factors and their interactions together, rather than separately. To date, most of the research regarding psychological factors and low back/neck pain has revolved around depression,

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anxiety, fear-avoidance, and pain catastrophizing (Elbinoune et al. 2016, Gerrits et al. 2015, Gerrits et al. 2014, Ortego et al. 2016, Pinheiro et al. 2016, Pinheiro et al. 2015). However, another psychological factor, cognitive dissonance, may also play a meaningful role in the aetiology and maintenance of low back and neck pain.

Cognitive dissonance theory posits that when individuals hold two or more psychologically inconsistent thoughts, beliefs, values, emotional reactions, or behaviours at the same time, they experience a psychological discomfort that is not reduced until cognitive and behavioural effort is expended to restore psychological consistency (Festinger 1957). Since it was initially proposed, cognitive dissonance theory has drawn the attention of psychologists, neuroscientists, and others throughout the world. Scientists now have a clear understanding of how and why cognitive dissonance shifts our attitudes and beliefs, but less is understood about how cognitive dissonance might manifest itself physically. Namely, there is reason to believe that the cognitive dissonance state (CDS) may be associated with an increased risk for LBP and neck pain because activation of the human stress response system, consistent with the CDS, has been associated with increased muscle coactivity, reduced motor unit rotation, and increased muscle fatigue (Bloemsaat, Meulenbroek, and VAN Galen 2005, Davis et al. 2002, Minerbi and Vulfsons 2018, Marras et al. 2000). All represent factors that also subsequently increase the risk that an individual might experience low back pain, neck pain, myofascial pain, or other musculoskeletal pain conditions (Dommerholt, Bron, and Franssen 2006, Granata and Marras 1995, Jun et al. 2017, Marras et al. 2001).

A recent systematic review by Weston et al. (2022) proposed that there is likely a relationship between cognitive dissonance (more specifically, dissonance-related constructs of emotional labour and emotional dissonance) and musculoskeletal pain. However, the relationship between cognitive dissonance and musculoskeletal injury risk has yet to be investigated in a formal laboratory study. Therefore, the objective of the study was to explore the potential association between cognitive dissonance and biomechanical loading in the low back and neck.

2. Materials and methods

2.1. Approach

A laboratory study was designed and conducted to evaluate the effects of inducing a CDS on peak spinal loads in the cervical and lumbar spines. Due to the psychological nature of the study objective, it was necessary that study participants be blinded to the true study objective. Participants were told that the objective of the study was to evaluate the impact of a precision lowering task on low back and neck injury risk. Instead, a CDS was induced by providing participants with feedback on their performance that ran counter to their own assessment of their performance on the task.

During the study, psychological (i.e. affect), physiological (i.e. blood pressure, heart rate variability), and biomechanical (i.e. spinal loading) data were collected. Changes to psychological and physiological measures were used to indicate the magnitude of the CDS experienced by the participants, as the CDS is characterised by both increased psychological discomfort and increased physiological arousal, consistent with the human stress response (Elliot and Devine 1994, Harmon-Jones 2000, Cooper, Zanna, and Taves 1978). Likewise, increases in peak spinal loads in compression, anterior/posterior (A/P) shear, and lateral shear were assumed to be indicative increased risk for musculoskeletal conditions like LBP and neck pain. Spinal loads were estimated using two electromyography (EMG)-driven biomechanical models, one for the lumbar spine (Hwang et al. 2016a, Hwang et al. 2016b) and another for the cervical spine (Alizadeh et al. 2020). Lumbar model structure and validation have been extensively described in previous publications (Hwang et al. 2016a, Hwang et al. 2016b, Granata and Marras 1993, Marras and Sommerich 1991b, Marras and Sommerich 1991a). The cervical spine model was developed more recently, but model structure and validation are further described by Alizadeh et al. (2020).

2.2. Participants

Seventeen healthy participants (9 male, 8 female) were recruited from the Ohio State University population and surrounding community to participate in this study. This sample size was determined a priori via a power analysis and was deemed appropriate to detect a moderate effect size at a power level of 0.90, consistent with the results of a previous psychological/-biomechanical study implementing a similar study design to investigate job-personality mismatch (Chany et al. 2006). The age range of the participants was 19–44 years, with additional demographic characteristics for the participants provided in Table 1. Participants did not report a history of low back or neck pain in the last 12 months, spinal cancer/fracture/deformities,

Table 1. Demographic characteristics of the participants. Values are represented as mean (standard deviation).

	Age (years)	Stature (cm)	Mass (kg)	BMI (kg/m^2)
Males ($n=9$)	24.7 (3.6)	179.5 (6.5)	80.9 (15.0)	25.0 (4.2)
Females ($n=8$)	26.0 (8.5)	167.1 (7.4)	56.5 (10.3)	20.1 (2.7)
All participants ($n=17$)	25.3 (6.2)	173.7 (9.3)	69.4 (17.8)	22.7 (4.3)

previous spine surgery, serious psychiatric disorders including psychosis and bipolar disorder, known pregnancy, or a body mass index (BMI) greater than 30 kg/m^2. All participants provided informed consent to the research protocol as approved by the University's Behavioural and Social Sciences Institutional Review Board. The study also involved deception, which required an alteration of consent form and debriefing at the end of the study procedure.

2.3. Experimental design

2.3.1. Independent variables

The primary variable of interest in this study was the cognitive dissonance state (CDS). This independent variable was assessed across three trial blocks (A, B, and C). The first block (block A) allowed for participants to 'practice' the lowering task without receiving any audible feedback on their performance. During this time, baseline physiological and biomechanical data were collected. The second trial block (block B) involved delivering overwhelmingly positive feedback to the participants. This portion of the study sought to establish an expectation/belief in the participants that their performance on the precision lowering task was excellent. Finally, the third trial block (block C) attempted to establish a CDS via a mismatch between the participants' beliefs about their own performance and new information coming from external sources. Wherein the participants believed that their performance on the task was excellent based on the feedback they received in block B, audible feedback (i.e. electronic tones) provided to the participants began to indicate that the task had been completed unsatisfactorily much more frequently.

2.3.2. State variables

The magnitude of the CDS was expected to differ across study participants. Therefore, psychological and physiological variables were measured as proxy indicators of the magnitude of the CDS experienced by each of the participants. We refer to these psychological and physiological variables as state variables because they were not explicitly altered in the experimental design (i.e. not independent). However, changes to these psychological and physiological variables were also used as potential predictors of changes to the spinal loading variables (i.e. not dependent, either).

Psychological state variables were derived from two questionnaires administered to the participants, the Positive and Negative Affect Schedule (PANAS) (Watson, Clark, and Tellegen 1988) and Dissonance Thermometer (Elliot and Devine 1994). The PANAS yielded two sub-scores, including Positive Affect (PA; e.g. strong, inspired, excited) and Negative Affect (NA; e.g. distressed, ashamed, afraid), the score of each ranging 10–50. Likewise, the Dissonance Thermometer yielded three sub-scores, including the Discomfort Index (DI), positive self-affect (PosSelf), and negative self-affect (NegSelf), the score of each ranging 1–7. PANAS ratings were collected at baseline and after debriefing, while Dissonance Thermometer ratings were collected only after debriefing.

Physiological state variables included changes to blood pressure and heart rate variability (HRV). Blood pressure measurements were taken at three distinct time points (prior to trial block A, after trial block B, after trial block C), while HRV data were collected continuously throughout each trial block (A–C). Systolic and diastolic blood pressure (mmHg) was considered because acute physiological stress has been shown to elicit large increases in norepinephrine, thereby activating β-adrenergic receptor mediated signalling pathways, increasing vasoconstriction, and increasing blood pressure (Chu et al. 2021, Greaney et al. 2020). Regarding HRV, the heart demonstrates significant beat-to-beat variation under normal circumstances, as activations of the parasympathetic and sympathetic nervous systems fluctuate in a balance with one another. However, under high stress conditions as was expected with the CDS, sympathetic responses increase as parasympathetic responses decrease, reducing the amount of variability between the beats (Appelhans and Luecken 2008, Cohen et al. 2000, Thayer and Brosschot 2005, Thayer and Lane 2000, Thayer et al. 2009). HRV metrics were assessed in the time domain (RR, STDRR, RMSSD), frequency domain (LF_{abs}, HF_{abs}, LF/HF), and included other indices for sympathetic/parasympathetic nervous system activation (SI, SNS Index, PNS index) (metrics described further in Table 2).

2.3.3. Dependent variables

The dependent measures of interest were peak (i.e. maximum magnitude) spinal loads along each dimension of spinal loading (compression, A/P shear, lateral

Table 2. List of HRV metrics assessed during this study.

Measure	Units	Description	Expected Effect
Time Domain			
RR	ms	Mean IBI or RR interval over sample	Time domain metrics decrease with sympathetic nervous system activation
STDRR	ms	Standard deviation of RR intervals	
RMSSD	ms	Root mean square of successive RR interval differences	
Frequency Domain			
LF_{abs}	ms2	Absolute power of the low frequency band (0.04–0.15 Hz)	LF_{abs} and LF/HF expected to increase with sympathetic nervous system activation, while HF_{abs} was expected to remain constant or decrease (Appelhans and Luecken 2008, Akselrod et al. 1981, Bernston and Cacioppo 2004, Rajendra Acharya et al. 2006).
HF_{abs}	ms2	Absolute power of the high frequency band (0.15–0.40 Hz)	
LF/HF	–	Ratio of LF- to HF- power	
HRV Indices			
Stress Index (SI)	–	Baevsky's stress index	Reflects cardiovascular system stress, wherein higher values indicate higher sympathetic activation (Baevsky and Berseneva 2008)
PNS Index	–	Parasympathetic nervous system index	Weighted average of several measures compared to normal population averages (Brennan, Palaniswami, and Kamen 2001, Nunan, Sandercock, and Brodie 2010); score is number of standard deviations above or below the population average (Tarvainen et al. 2014).
SNS Index	–	Sympathetic nervous system index	

shear) in the neck and low back. Spinal loads were calculated using the EMG-driven biomechanical models and were calculated for all spinal levels extending from C0/C1 to C6/C7 and from T12/L1 to L5/S1. However, because spinal loading measures are highly correlated across vertebral levels, only the peak compressive, A/P shear, lateral shear, and resultant spinal loads in the neck and back are reported herein.

2.3.4. Experimental task

While standing on a force plate, participants lifted a 6.8 kg square box from a lift origin in front of the body at waist height and lowered the box onto a target on a lowering platform. The exact location of the lowering platform was predetermined by the study design and included combinations of lowering heights (3 levels: 83.0 cm, 97.0 cm, and 119.0 cm, corresponding to approximately knee, waist, and mid-chest heights), lowering asymmetry (2 levels: 45 degrees and 90 degrees of twisting), target size (2 levels: large and small), as shown in Figure 1. The targets were outlined on the lowering platform using coloured tape. The small target was an exact outline of the box that was lowered, whereas the low difficulty square was larger by 0.635 cm (0.25 inches) in all directions.

The lowering platform sat atop a load cell that detected when the box had been placed based on the rising edge of the force signal. Participants were told that the load cell could detect whether the box had been accurately lowered onto the target. Participants were subsequently provided with audible feedback in the form of a high-pitched 'correct' sounding tone for an acceptable lower and a low pitched 'incorrect' tone for an unacceptable lower. The load cell did in fact detect when the box had been placed, but the feedback provided to the participants was systematically altered by the study design/experimenter. As mentioned, no feedback was delivered to the participants during trial block A. During trial block B, no negative feedback was given for lowers to the large target, and negative feedback was provided to the participant after one of every seven lowers to the small target (chosen at random). During trial block C, no negative feedback was given for lowers to the large target, but negative feedback was now provided to the participants after three of every seven lowers to the small target.

2.4. Apparatus and instrumentation

A blood pressure monitor (Omron BP 5450, Omron Healthcare Inc., Lake Forest, IL, USA) and heart rate monitor (FirstBeat Bodyguard 2TM, FirstBeat Technologies, Jyväskylä, Finland) were used to gather blood pressure and HRV data, respectively. In addition, surface EMG was used to measure muscle activity of the neck and torso muscles during laboratory testing. Neck EMG data were collected using a wireless Delsys TrignoTM system (Natick, MA, USA) and AMBU BlueSensor N bipolar surface electrodes (Ambu, Copenhagen, Denmark) placed bilaterally onto the semispinalis capitis, upper trapezius, middle trapezius, splenius, levator scapula, sternocleidomastoid, and hyoid muscles (or muscle groups). Neck EMG data were collected at 1925.93 Hz. Likewise, lumbar EMG data were collected using a Motion Lab Systems MA300-XIV (Baton Rouge, LA, USA) and AMBU BlueSensor P bipolar surface electrodes (Ambu, Copenhagen, Denmark) placed bilaterally onto the lumbar erector spinae, internal oblique, latissimus

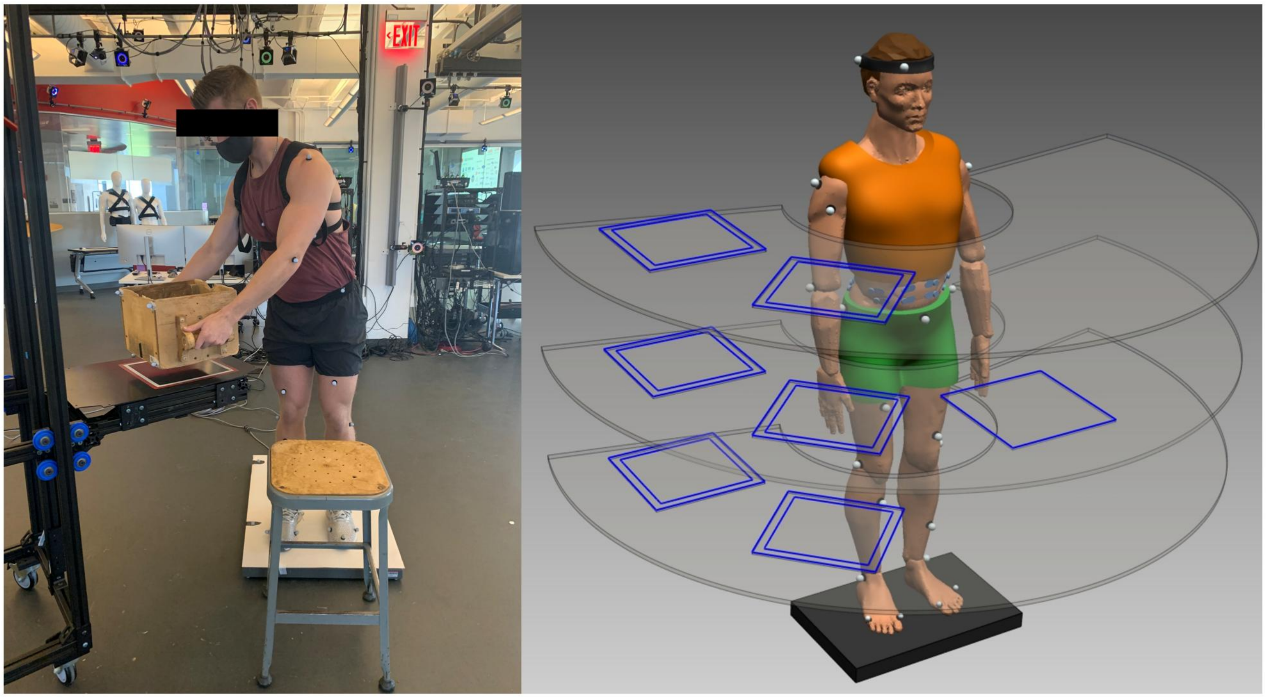

Figure 1. Experimental setup, showing the lift origin and various lowering destinations for each trial block (combinations of height, asymmetry, target size). A load cell was placed underneath the lowering platform to detect when the box had been placed and provide the participant audible feedback on their performance.

dorsi, external oblique, and rectus abdominis muscles. EMG data from this second system were collected at 1000 Hz. All EMG signals (neck and back) were notch filtered between 30 and 450 Hz, rectified and smoothed, and low-pass filtered using a second-order Butterworth filter with a cut-off frequency of 1.599 Hz (chosen from a time constant of 100 ms). These signal processing steps are consistent with standards for reporting EMG data (Merletti 1999). Additionally, full body kinematics were quantified at a sampling frequency of 120 Hz using a 42-camera OptiTrack Prime 41 optical motion capture system (NaturalPoint, Corvallis, OR, USA). The accuracy of this system has been validated to be less than 200 μm in 97% of the capture volume (Aurand, Dufour, and Marras 2017). Finally, kinetic data were captured at a sampling frequency of 1000 Hz using (1) a Bertec 6090-15 force plate (Worthington, OH, USA) on the ground and (2) a custom Bertec load cell (HT0825, Worthington, OH, USA) mounted into the lowering platform. Kinematic and kinetic data were low-pass filtered using a fourth-order Butterworth filter with a cut-off frequency of 10 Hz. All biomechanical signals were gathered in custom software written in MATLAB (MathWorks Inc., Natick, MA, UA) and synchronised using a data acquisition board (USB-6225, National Instruments, Austin, TX, USA).

2.5. Procedure

Upon arrival to the laboratory, participants were given a tour of the testing facility and shown the experimental equipment for the study. The potential participant was told that the objective of the study was to quantify the effects of a precision lowering task on low back or neck injury risk, and the precision lowering task for the study was demonstrated. The participant was then given the consent form for the study and time to sit down and read over the form and ask questions as needed. While the true objective was masked from the participant until later in the study procedure, all the other sections of the consent form accurately reflected the study experience. After participants provided their written informed consent, the participant's stature, mass, and other anthropometric data were collected. Then, participants completed the PANAS questionnaire, which asked them to rate their affect generally to avoid suspicion of a psychological component to the study.

Next, sensors for collecting the physiological and biomechanical data were placed onto the participant. Two surface electrodes were placed onto the body for the heart rate monitor below the right collar bone and left rib cage. Surface electrodes were also placed onto cervical and lumbar spine muscles according to standard placement locations (Alizadeh, Knapik, and Marras 2018, Mirka and Marras 1993, Joines et al.

2006). Additionally, 55 reflective markers were placed onto the participant with double-sided tape for use with the motion capture system.

After preparation, participants performed a standard set of calibration procedures to calibrate the cervical and lumbar models via a no-max procedure previously described by Dufour, Marras, and Knapik (2013). To calibrate the neck model, participants were asked to move their neck through right lateral bending, left lateral bending, neck flexion, and neck extension up to four times at a comfortable pace and within a comfortable range of motion while standing on a force plate. To calibrate the lumbar model, participants were asked to stand on the force plate, lift a 9.07 kg medicine ball and move with it in the sagittal and lateral planes at a moderate but comfortable pace a total of three times. Then, participants performed three deep bending lifts, lifting the 9.07 kg medicine ball from the ground from a symmetrical lift origin, a 45-degree left lift origin, and a 45-degree right lift origin. After model calibration, baseline blood pressure data were collected from the participants. For this measurement, participants were asked to sit silently in a chair with their feet flat on the floor and the cuff wrapped around the left arm. The participants were told that these measurements were being taken to ensure that they were healthy enough to continue with the study.

Then, participants began the experimental task described above. Block A (i.e. baseline data) consisted of 24 trials (3 destination heights $\times$ 2 asymmetries $\times$ 2 target sizes $\times$ 2 repetitions) and lasted approximately 15 minutes, while blocks B and C (i.e. positive and negative feedback blocks) consisted of 78 trials (3 destination heights $\times$ 2 asymmetries $\times$ 2 target sizes $\times$ 6–7 repetitions depending on target size) and lasted approximately 45 minutes each. Participants received a 30-minute break between the two longer trial blocks to prevent fatigue. Blood pressure data were collected after each of the two longer trial blocks (B and C) consistent with the manner described at baseline.

To maximise the magnitude of the CDS encountered by the participants during trial block C, the study team relied on some scripted demonstration and communication. It was important that participants trusted that the feedback system was working properly because the assumption that 'the system is probably just broken' would reduce the magnitude of the CDS that was ultimately experienced. To prevent this issue, the data collector demonstrated 'correct' and 'incorrect' lowers prior to the first trial block alongside the 'correct' and 'incorrect' audible tones. Additionally, after some trials in which the participant was provided incorrect feedback in trial blocks B and C, the data collector approached the participant and re-lowered the box onto the surface. The 'correct' tone sounded as if the data collector had fixed the participant's error. Additionally, the data collector provided regular verbal encouragement during trial block B (e.g. 'you are doing great' or 'you're a natural, others have struggled way more than you have with this') to further reinforce the participants' cognition that their performance on the task was excellent. However, in trial block C, the dialogue between the data collector and participant was much more negative. Now, the data collector progressed the cognition that performance on the task was now poor (e.g. 'just do the task like you were doing it before' or 'are you sure you've never had a low back injury?'). Finally, an adaptation of cognitive dissonance theory posits that dissonance is more likely to be felt when an individual's behaviour is responsible for an aversive consequence (Cooper and Worchel 1970, Scher and Cooper 1989). Therefore, the experimenter on multiple occasions reiterated to the participant that 'we really need a complete data set' and suggested that the participant's inability to perform the task correctly could lead to poor data that would hold the student back from graduating.

Lastly, participants were debriefed on the true nature of the study. This was done by sitting with the participant and providing him/her with a form that contained additional information about why the study was truly being done and what happened as they were participating. Participants had the option to leave after debriefing or ask that all their data be withdrawn, but if the participants were comfortable finishing the study (all were), they were asked to complete a final set of questionnaires. At this time, the PANAS was recollected in addition to the Dissonance Thermometer. When completing these questionnaires, participants were asked to recall and rate how they were feeling during the final trial block.

2.6. Data processing and statistical analysis

HRV data was uploaded and processed in Kubios open-source software; this analysis software has been described in depth in Tarvainen et al. (2014). In alignment with best practices for HRV analysis (Malik 1996), data from each of the three trial blocks were sampled as 5-minute moving time windows (i.e. minutes 1–5, 2–6, 3–7, etc.). In the frequency domain, HRV metrics were based on the Fast-Fourier Transformation spectrum rather than autoregressive. The variables listed in Table 2 were extracted and averaged across each trial block. All time and frequency-domain HRV metrics and the SI were log-transformed to satisfy the normality assumption prior to the multivariate analysis described below.

Regarding the state variables, changes to PA and NA between baseline and debrief were calculated. Likewise, changes to blood pressure and HRV metrics were calculated for trial the CDS condition (C) relative to baseline (A) and for the CDS condition (C) relative to the positive feedback block (B). Regarding spinal loading measures, biomechanical model inputs (EMG, kinematics, kinetics) were resampled and time synchronised as appropriate. A multibody dynamics solver (Adams MSC software, Santa Ana, CA, USA) generated time-series data for each trial, detailing full body kinematics, neck and torso muscle activations/-forces, external moments on the cervical and lumbar spine vertebrae, and 3-dimensional cervical and lumbar spinal loads (compression, A/P shear, lateral shear, resultant). Peak spinal loading (compression, A/P shear, lateral shear) in the low back and neck were extracted from the lowering portion of the trial and retained for statistical analysis. For the cervical model, spinal loads were predicted at the middle of the intervertebral disc, whereas for the lumbar model, spinal loads were predicted at the superior and inferior vertebral endplates.

All statistical analyses were performed in JMP 15.0 Pro software (SAS institute, Cary, NC, USA; RRID:SCR_014242), and results were interpreted relative to a significance level of 0.05. First, the effects of trial block on the spinal loading measures (cervical and lumbar) were assessed using a generalised linear mixed model. Trial block, height, asymmetry, target size, and two-way interactions involving trial block were introduced into the model as fixed effects, while participant and interactions involving participant were introduced as random effects. Effect details were assessed using a Student's t test or a least squares means Tukey HSD test where appropriate. Only main effects of trial block on spinal loading measures will be discussed herein.

Then, a multivariate analysis was conducted to determine if the magnitude of the psychological/physiological changes observed (as proxy for the CDS magnitude) were associated with changes to peak spinal loading. The multivariate analysis was conducted as a forward stepwise least-squares regression minimising the Akaike information criterion (AIC). A separate regression model was fit for each of the six spinal loading variables (compression, A/P shear, and lateral shear in the neck and low back). It should be noted that peak spinal loading values were normalised to participants' body weights in Newtons for the multivariate regression. Additionally, 'lagged' regression models were used herein, wherein the dependent variable used in the regression was peak spinal loading derived from trial block C alone. Lagged regression models are common because using a change measure (y–y0, or in this instance trial block C – trial block A) as the dependent variable of interest in regression may be unreliable and subject to regression effects (i.e. regression to the mean) (Allison 1990). Instead, the regression models accounted for baseline spinal loading from trial block A via the inclusion of the baseline spinal load as a model predictor. Other model predictors included changes in PA and NA from baseline to debrief, raw scores for the DI, PosSelf, and NegSelf (since only collected at one time point), and changes to the blood pressure and HRV metrics between the baseline and CDS trial blocks and positive feedback and CDS trial blocks. Model significance was assessed and reported via an F-test of overall significance. Model performance was assessed via the examination the Adjusted R^2. Finally, multicollinearity was assessed via examination of the variance inflation factor (VIF).

3. Results

The cervical model predicted peak compression, A/P shear, and lateral shear loads at C2/C3, C1/C2, and C0/C1 vertebral levels, respectively. Likewise, the lumbar spine model predicted peak compression, A/P shear, and lateral shear loads at the L4/L5 Inferior, L2/L3 Superior, and L5/S1 Superior endplates, respectively. As peak load is the best indicator for risk of injury and spinal loads are highly correlated across vertebral levels, these levels formed the basis of the rest of the biomechanical analysis.

3.1. Cervical spinal loading

Peak cervical spinal loads in compression, A/P shear, and lateral shear for each trial block are shown in Figure 2. A main effect of trial block was noted for all three variables ($p < .001$ for compression and A/P shear and $p = .003$ for lateral shear). The post-hoc tests revealed that peak cervical compression and peak cervical lateral shear were significantly increased for trial blocks B (positive feedback) and C (negative feedback) relative to trial block A (baseline). Peak cervical A/P shear loads were significantly higher in trial block C (negative feedback) than both trial blocks A (baseline) and B (positive feedback). Regarding the main comparison of interest (i.e. peak spinal loads for cognitive dissonance condition compared to baseline), peak spinal loads were on average 11.1% higher in spinal compression, 9.4% higher in A/P shear, and 19.3% higher in lateral shear for trial block C compared to trial block A. However, the change magnitude also differed highly across participants, ranging −3.5% to 51.7% in compression, −2.2% to 71.9% in A/P shear, and −12.7% to 120.8% in lateral shear.

3.2. Lumbar spinal loading

Peak lumbar spinal loads in compression, A/P shear, and lateral shear for each trial block are shown in Figure 3. A main effect of trial block was noted for peak lumbar compression ($p = .011$) and A/P shear ($p < .001$) but not for peak lateral shear loading ($p = .98$). The post-hoc tests revealed that both peak lumbar compression and A/P shear were increased for trial block C (negative feedback) relative to trial block A (baseline), though peak spinal loading values for block B (positive feedback) did not differ significantly from either blocks A or C. The magnitude of the increase was less that that observed for cervical spine loading. Whereas spinal compression and shear were increased by 11.1% and 9.4% (respectively) in the cervical spine, spinal compression and shear were increased by 1.7% and 2.2% (respectively) in the lumbar spine. Like the cervical spinal loading results, the magnitude of the change in lumbar spinal loading differed highly across participants, ranging −6.9% to 17.0% in compression and −13.5 to 32.2% in A/P shear.

3.3. Multivariate analysis

Results of the multivariate forward stepwise model selection process are shown in Table 3 below. As stated, the regression models describe predicted changes in peak spinal loading (normalised to body weight) in the low back and neck as a function of the psychological and physiological change measures (either between baseline and the CDS condition or mid-study and the CDS condition). All six models demonstrated statistical significance from the F-test for overall significance. The models describing changes to normalised cervical spinal loading performed the best, with Adjusted R^2 values of 0.94 and 0.93 for normalised peak cervical compression and A/P shear, respectively. Likewise, in the lumbar spine, the best model was that for normalised peak A/P shear that described 83% of the variability in the data.

Changes to HRV indices (SNS Index, PNS Index, Stress Index) were common predictors in the six regression models, as one or more of these indices were used across five of the six models. Both positively oriented (change in PA, PosSelf) and negatively oriented (change in NA, DI, NegSelf) psychological measures were introduced into the regression models as well; however, psychological predictors were only included in three of the six models, whereas physiological predictors were included across all of them. The direction (i.e. sign) of the parameter estimates generally matched the study hypothesis, wherein an increase in negative affect and/or sympathetic nervous system activation was associated with an increase in normalised peak spinal load and an increase in positive affect and/or parasympathetic nervous system activation was associated with a decrease in normalised peak spinal load. The only exceptions to this

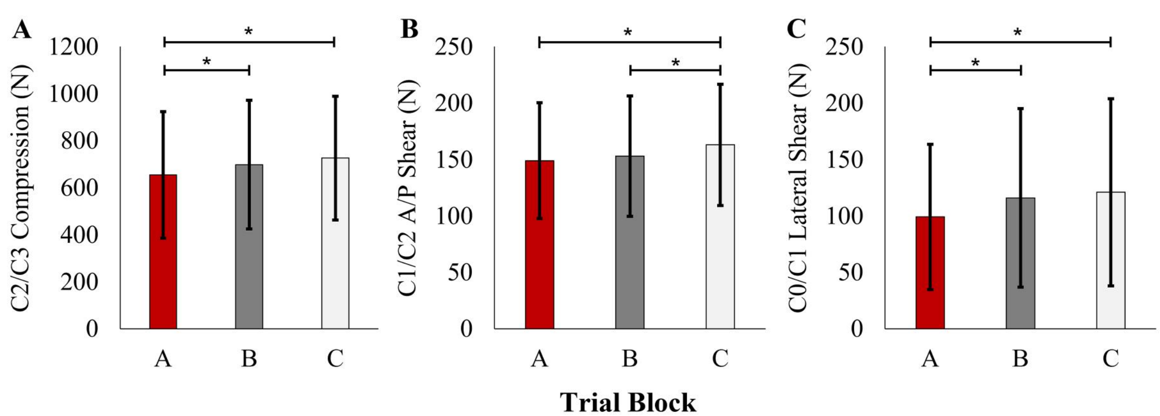

Figure 2. Peak cervical spinal loads in **(A)** compression, **(B)** A/P shear, and **(C)** lateral shear, stratified by trial block. Trial block A represents the baseline data (no feedback), trial block B represents the positive feedback trial block, and trial block C represents the cognitive dissonance state. *Denotes a statistically significant difference $p < .05$.

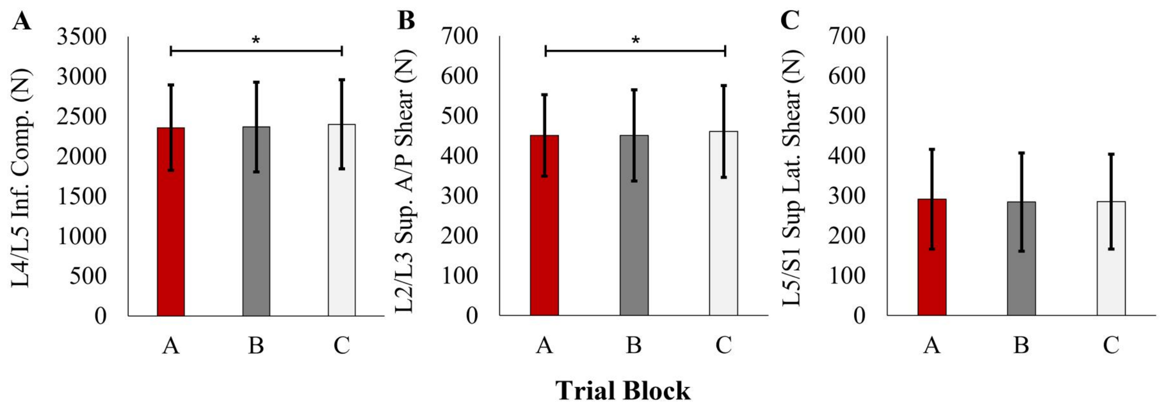

Figure 3. Peak lumbar spinal loads in **(A)** compression, **(B)** A/P shear, and **(C)** lateral shear, stratified by trial block. Trial block A represents the baseline data (no feedback), trial block B represents the positive feedback trial block, and trial block C represents the cognitive dissonance state. *Denotes a statistically significant difference $p < .05$.

Table 3. Results of forward stepwise regression describing changes to normalised peak spinal loading in the neck and low back as a function of the psychological physiological state variables.

Body weight normalised peak spinal load (*N/N*)	R_{Adj}^2	Overall F-test	*p value*	Predictor	Parameter Est.	Std. Error	T	*p value*	VIF
Cervical Compression	0.94	41.47	**<.001**	Intercept (a)	0.05	0.16	0.33	.747	–
				Baseline Spinal Load (y_0)	0.56	0.06	8.80	<.001	1.15
				log(RMSSD) Change A-C	1.47	0.34	4.34	.002	3.15
				log(LF/HF) Change B-C	1.15	0.21	5.52	<.001	1.85
				SNS Change B-C	−1.10	0.12	−9.03	<.001	2.51
				log(SI) Change A-C	4.54	0.48	9.51	<.001	3.22
Cervical A/P Shear	0.93	28.87	**<.001**	Intercept (a)	0.27	0.05	5.35	.001	–
				Baseline Spinal Load (y_0)	0.56	0.10	5.52	.001	1.52
				DI	−0.07	0.01	−6.56	<.001	5.89
				NegSelf	0.05	0.01	4.62	.002	5.03
				PosSelf	−0.03	0.01	−3.76	.006	1.54
				log(RR) Change B-C	1.81	0.35	5.17	.001	6.34
				PNS Change A-C	−0.06	0.03	−1.98	.083	2.31
				PNS Change B-C	−0.15	0.04	−3.37	.010	6.47
Cervical Lateral Shear	0.40	4.55	**.022**	Intercept (a)	0.00	0.07	0.01	.994	–
				Baseline Spinal Load (y_0)	0.54	0.26	2.10	.056	1.07
				NegSelf	0.04	0.02	2.35	.035	1.17
				Systolic Change A-C	0.01	0.00	2.95	.011	1.10
Lumbar Compression	0.53	9.99	**.002**	Intercept (a)	1.43	0.58	2.44	.028	–
				Baseline Spinal Load (y_0)	0.70	0.16	4.41	.001	1.27
				SNS Change A-C	1.32	0.49	2.68	.018	1.27
Lumbar A/P Shear	0.83	8.25	**.002**	Intercept (a)	0.10	0.14	0.73	.478	–
				Baseline Spinal Load (y_0)	0.40	0.29	1.37	.197	4.14
				NegSelf	0.05	0.02	2.24	.046	1.19
				Systolic Change A-C	0.02	0.01	2.21	.050	2.17
				SNS Change A-C	0.26	0.08	3.11	.010	1.26
Lumbar Lateral Shear	0.34	3.52	**.049**	Intercept (a)	0.65	0.15	4.33	.001	–
				Baseline Spinal Load (y_0)	−0.24	0.31	−0.76	.461	1.29
				Diastolic Change A-C	0.02	0.01	2.92	.013	1.21
				log(SI) Change B-C	0.65	0.37	1.76	.104	1.15

statement were for normalised peak cervical compression (log(RMSSD) change, SNS Index change) and normalised peak cervical A/P shear (DI, log(RR) change). Finally, the highest variance inflation factor (VIF) noted across all six models was 6.47, which suggests that multicollinearity was not an issue.

4. Discussion

Until now, the psychological phenomenon of cognitive dissonance has not been studied relative to its potential contribution to the aetiology of musculoskeletal disorders including LBP and neck pain. To test the relationship between these variables, a CDS was elicited in a group of participants in a laboratory setting by providing them with feedback counter to their own expectations of their performance. Significant increases in spinal loading were observed between baseline and the CDS trial blocks across the participants, particularly in the cervical spine. Neither external demands on the body (i.e. external moments) nor participant kinematics differed across the trial blocks.

Therefore, the observed changes to spinal loading are attributable to the body's internal response (i.e. muscle coactivity). A greater CDS magnitude, indicated by greater changes to the psychological and physiological state variables, was also associated with greater changes to peak spinal loading. Collectively, these results suggest that cognitive dissonance may represent a risk factor for low back and neck pain that has previously been overlooked.

There are several environments, many occupationally related, in which the cognitive dissonance state may be experienced. For example, individuals in jobs involving emotional labour (i.e. effort required to express organisationally desired emotions during interpersonal transactions) like call centre work may experience a specific form of cognitive dissonance (i.e. emotional dissonance) when the organisationally-desired emotions do not align with how individuals are feeling in that moment (Andrews, Karcz, and Rosenberg 2008, Hülsheger and Schewe 2011, Simpson and Stroh 2004). Weston et al. (2022) confirmed that there is likely a relationship between the experience of emotional labour or emotional dissonance and musculoskeletal pain. Likewise, in healthcare settings, practitioners who value providing excellent patient care must come to terms with other factors (e.g. competing priorities, limited resources, limited authority) that prevent them from delivering the quality of care they would like to provide (Cronqvist et al. 2001). Cognitive dissonance and its related constructs of emotional labour and emotional dissonance may be worth quantifying as psychosocial risk factors for occupational injury in the future. As such, the results obtained herein have implications for improved occupational injury risk prevention in the future, for example, through the establishment of a more positive workplace culture.

The magnitude of spinal loading increases attributable to the CDS observed herein in the cervical spine approximate changes to spinal loading observed previously for a similar experimental design investigating a job-personality mismatch (Chany et al. 2006). However, this job-personality mismatch study investigated changes in the lumbar spine only. Herein, relative increases to spinal loading during the CDS were more pronounced in the cervical spine than the lumbar spine. On average and across all participants, relative peak cervical compression was increased by 11.1% between trial blocks A and C compared to 1.7% in the lumbar spine, and peak cervical A/P shear was increased by 9.4% compared to 2.2% in the lumbar spine. This increased biomechanical response in the neck relative to the back is in alignment with prior studies that have shown that muscle coactivity tends to decrease in a caudal direction in reaction to a psychological stressor (Bloemsaat, Meulenbroek, and VAN Galen 2005, Waersted and Westgaard 1996). However, increased biomechanical loading in the neck may have also been more apparent because the neck was not subjected to physical stress from the experimental lowering task. Because the lumbar spine was directly involved in the experimental task, the demand on the physical system may have overridden the cognitive effects of the CDS as a psychological stressor, causing lumbar muscle coactivity and peak lumbar spinal loading changes to be diminished. This is a particularly interesting finding given that cognitive dissonance is also likely to impact workers in jobs with a wide range of physical demands. Therefore, the importance of the CDS as a risk factor for occupational injury may also depend on the occupational situation. Cognitive dissonance may represent more of a risk factor in jobs with lower physical stress and a less important risk factor in jobs with higher physical stress.

Interestingly, in addition to the observation of increased spinal loading the CDS trial block (C) relative to baseline (A), there were also instances in which peak spinal loads were increased for the positive feedback trial block (B) relative to baseline (A). This result was unexpected because a cognitive inconsistency had not yet been introduced at that time, so physiological arousal, muscle coactivity, and spinal loading were expected to be low during this trial block, more consistent with trial block A. After some further consideration, there are a few plausible explanations for why this increase may have been observed. One explanation for these results could be related to physical fatigue. Participants proceeded right from trial block A into trial block B, performing the task for over an hour across the two trial blocks. However, an alternative explanation could be that the lowering task was associated with some physiological arousal from a more *positive* state that comes from enjoying the work being done. That state can result in very different biomechanical changes via the same pathway. Mihaly Csikszentmihalyi introduced the concept of a 'flow state' in 1975, which is now more commonly known as being 'in the zone'. This mental state is associated with energised focus, full involvement, and enjoyment in the activity (Csikszentmihalyi and Larson 1987, Csikszentmihalyi and Wong 2014, Emerson 1998). Although the CDS and flow share increased physiological arousal, the psychological impacts of these two concepts may differ. The CDS is likely to cause psychological disturbance, while a flow state is likely to increase positive affect. While neither explanation of the results can be confirmed by the data collected, a future study using a similar study design could assess psychological affective states at three time-points (baseline, post-positive feedback, post-negative feedback) rather than only baseline-debrief to confirm the flow state hypothesis. Increases to positive affect would be expected after receiving positive feedback from the study team, while increases to negative affect would be expected after getting negative feedback.

As stated previously, the magnitude of the response across participants was highly variable. To provide an estimate of the maximum effect of the CDS, however, peak cervical and lumbar spinal loads for the study's 'top responder' is shown in Figure 4. As shown, peak cervical compression and A/P shear were increased by 40% and 73% respectively, for the CDS trial block relative to baseline. Likewise, peak lumbar compression and A/P shear were increased by 10% and 35%, respectively. More importantly, all six of the forward stepwise regression models predicting changes to normalised peak spinal loading in the neck and back displayed overall significance, suggesting that changes to peak spinal loading could indeed be predicted by changes to the psychological and physiological measures. In each regression model, individual parameter estimates denote the change in normalised peak spinal load that would be expected from a one-unit change in the predictor, assuming all other predictors in the model are held constant. Though multicollinearity was not an issue in any of the models, it should be noted that correlation among the psychological and physiological measures are such that in reality, it would be nearly impossible to vary just one factor at a time. Thus, individual parameter estimates should be interpreted with caution. Instead, we believe that it is better to look at each model wholistically, rather than make conclusions on its individual components. For example, the model for normalised peak cervical compression includes log(RMSSD) change and SNS change terms with positive and negative parameter estimates, respectively. Individually, these factors suggest that spinal loading would be increased with an increase in time-based HRV and decreased with an increase in the sympathetic nervous system index, opposite the hypothesised relationship.

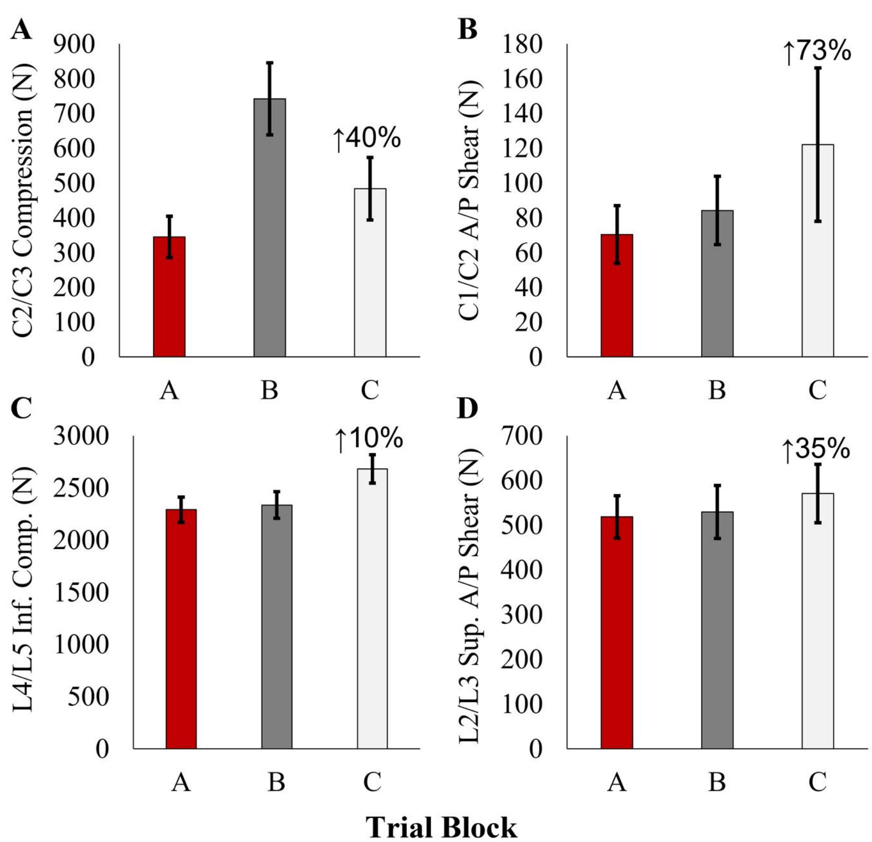

Figure 4. Peak spinal loads stratified by trial block for the top responder in the study, including **(A)** C2/C3 Compression, **(B)** C1/C2 A/P Shear, **(C)** L4/L5 Inferior Compression, and **(D)** L2/L3 Superior A/P Shear. Trial block A represents the baseline data (no feedback), trial block B represents the positive feedback trial block, and trial block C represents the cognitive dissonance state. Percent differences represent trial block C relative to trial block A.

However, this model also includes log(LF/HF) change and the log(SI) change as predictors with rather large and positive parameter estimates. Collectively, then, this model is still likely to predict changes to spinal loading in the direction expected.

The results of this study should be placed in context with its limitations. First off, this study did not include a control group. Comparison to a group of participants that were not subjected to the cognitive dissonance state or deception would have strengthened the argument that the psychological, physiological, and biomechanical changes observed were truly due to the CDS. Moreover, due to the nature of the study design, the trial blocks needed to be presented to the participants in the same order for every participant (i.e. baseline, positive feedback, break, negative feedback). This introduced the potential of an order effect in the data that might otherwise be prevented via randomisation. In future studies, it may be interesting to see if an opposite cognitive inconsistency yields similar effects (i.e. whether overwhelmingly positive feedback after participants were accustomed to poor performance yields the same effect as overwhelmingly negative feedback after the participants were accustomed to excellent performance).

The CDS was elicited across a 45-minute trial block for all participants. In contrast, the CDS can be experienced and resolved rather quickly, and the reduction in psychological discomfort and physiological arousal occur on slightly time scales (Devine et al. 1999). If participants were able to resolve the CDS during the CDS trial block, psychological and physiological change measured at the conclusion of the trial block were unlikely to accurately represent the psychological discomfort and/or physiological arousal that the participant was feeling in the height of the CDS. Additionally, as HRV and peak spinal loads were averaged across the trial blocks, the means presented here may indeed represent an underestimation of the true CDS effect. Moreover, when completing the final set of questionnaires, participants were asked to recall how they were feeling when they were likely experiencing cognitive dissonance rather than rate their affect at that given instant in time. By this point participants were also aware of the true purpose of the study, which may have influenced their ratings. However, because the PANAS and Dissonance Thermometer scales assessed variables that were directly associated with the CDS, none of these questionnaires could feasibly be administered to the participants at an earlier timepoint at the risk of revealing the true study objective to the participants too early. Finally, it is possible that the participants tested herein were not perfectly representative of the general population. The sample size tested was rather small, especially given the wide range in responses observed from the participants to the CDS stimulus. In addition, the population tested represented a convenience sample from the local University community, and the participants tested were generally young and white or Asian. Because age and culture have been shown to play a role in the experience of the CDS (Brown, Asher, and Cialdini 2005, Hoshino-Browne et al. 2005), a more variable age range or more diverse racial makeup would have better represented the biomechanical effects of the CDS in the general population.

5. Conclusion

These findings represent a new avenue for understanding and expanding the causal pathways for musculoskeletal disorders and spinal injury. Our results suggest that the effects of cognitive dissonance expand beyond physiological arousal and negative affect and have physical, particularly, biomechanical effects. More specifically, increases to spinal loading (via increased muscle coactivity) were proportional to the magnitude of the cognitive dissonance state experienced by the participants. Therefore, cognitive dissonance may represent a risk factor for low back and neck pain that has not been previously identified.

Acknowledgements

The authors would like to acknowledge Dylan Aery and Halle Harris, who assisted with data collection for the study.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This research was funded using internal Spine Research Institute funds. No specific grant was received for this work from any funding agency.

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Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors upon request.

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