




The effect of training on lumbar spine posture and intervertebral disc degeneration in active-duty Marines

Ana E. Rodriguez-Soto, David B. Berry, Rebecca Jaworski, Andrew Jensen, Christine B. Chung, Brenda Niederberger, Aziza Qadir, Karen R. Kelly & Samuel R. Ward


To cite this article: Ana E. Rodriguez-Soto, David B. Berry, Rebecca Jaworski, Andrew Jensen, Christine B. Chung, Brenda Niederberger, Aziza Qadir, Karen R. Kelly & Samuel R. Ward (2017) The effect of training on lumbar spine posture and intervertebral disc degeneration in active-duty Marines, *Ergonomics*, 60:8, 1055-1063, DOI: [10.1080/00140139.2016.1252858](https://doi.org/10.1080/00140139.2016.1252858)

To link to this article: <https://doi.org/10.1080/00140139.2016.1252858>


 View supplementary material [↗](#)

 Accepted author version posted online: 27 Oct 2016.
Published online: 28 Nov 2016.

 Submit your article to this journal [↗](#)


 Article views: 319

 View Crossmark data [↗](#)

 Citing articles: 3 View citing articles [↗](#)



The effect of training on lumbar spine posture and intervertebral disc degeneration in active-duty Marines

Ana E. Rodriguez-Soto^a , David B. Berry^a, Rebecca Jaworski^{b1}, Andrew Jensen^{b,c2}, Christine B. Chung^{d,e}, Brenda Niederberger^{b,c}, Aziza Qadir^f, Karen R. Kelly^{b,c} and Samuel R. Ward^{a,g,h3}

^aDepartment of Bioengineering, University of California, San Diego, CA, USA; ^bDepartment of Warfighter Performance, Naval Health Research Center, San Diego, CA, USA; ^cSchool of Exercise and Nutritional Sciences, San Diego State University, San Diego, CA, USA; ^dDepartment of Radiology, Veteran Administration San Diego Healthcare System, San Diego, CA, USA; ^eDepartment of Radiology, University of California, San Diego Medical Center, San Diego, CA, USA; ^fVital Imaging Center, San Diego CA, USA; ^gDepartment of Radiology, University of California, San Diego, CA, USA; ^hDepartment of Orthopaedic Surgery, University of California, San Diego, CA, USA

ABSTRACT

Military training aims to improve load carriage performance and reduce risk of injuries. Data describing the lumbar spine (LS) postural response to load carriage throughout training are limited. We hypothesised that training would reduce the LS postural response to load. The LS posture of 27 Marines was measured from upright MR images: with and without load (22.6 kg) at the beginning, middle, and end of School of Infantry (SOI) training. Disc degeneration was graded at L5–S1. No changes in posture and disc degeneration were found throughout training. During load carriage the LS became less lordotic and the sacrum more horizontal. Marines with disc degeneration had larger sacral postural perturbations in response to load. Our findings suggest that the postural response to load is defined more by the task needs than by the physical condition of the Marine.

Practitioner Summary: The effect of military training on lumbar spine posture is unknown. The lumbar posture of 27 Marines was measured from upright MR images, with and without load throughout infantry training. No changes in posture or IVD degeneration were found across training. Marines with degeneration at the L5–S1 level had larger sacral postural perturbations in response to load.

ARTICLE HISTORY

Received 1 October 2015
Accepted 19 October 2016

KEYWORDS

Military; training; load carriage; posture; lumbar spine; sacral slope

Introduction

Low back pain (LBP) in the military population has been associated with carrying heavy loads during training and operational tasks (Attwells et al. 2006; Heir and Glomsaker 1996; Knapik, Harman, and Reynolds 1996; Taanila et al. 2009). In an effort to reduce these adverse effects, the optimum balance between load carriage training, physical fitness and performance in the military population has been studied in terms of energy cost, distance and speed (Harman et al. 2008; Knapik et al. 1990; Swain et al. 2010). It is widely accepted that to improve high intensity load carriage performance, military training should consist of a combination of aerobic and resistance exercises (Knapik et al. 1990).

The United States Marine Corps (USMC) School of Infantry (SOI) West at Camp Pendleton, California, follows this training paradigm. The School of Infantry is the second

stage of Marine Corps training for infantrymen following 10 weeks of boot camp. Prior to this stage, Marines are naïve to heavy load carriage. The duration of SOI is 41 days, during which March distances are progressively increased – 5, 10, 15 and 20 km performed around days 12, 16, 28 and 40 – under load. All marches are conducted with a standard fighting load, which is approximately 33.6 kg. During the 15 and 20 km training marches, Marines are also required to carry their designated weapon system during training.


Despite the association between LBP, load carriage and the structured SOI training paradigm (Heir and Glomsaker 1996), which progressively increases intensity of load carriage via increased hike duration, there are no data documenting the behaviour of spinal structures as Marines progress through SOI. To date, one study by Aharony et al. measured the impact of Israeli Navy Special Forces training on lumbar spine (LS) pathology through

CONTACT Samuel R. Ward  srward@ucsd.edu

¹Present address: Office of the Naval Inspector General 1254 9th St. SE, Washington Navy Yard, DC 90374-5006.

²Present address: Department of Biological Sciences, University of Southern California PED 107 3560 Watt Way, Los Angeles, CA 90089-0652.

³Present address: 9500 Gilman Drive MC 0863 La Jolla, CA 92093-0863.

 The supplementary data for this paper is available online at <http://dx.doi.org/10.1080/00140139.2016.1252858>.

physical examination and radiological evaluation; however, no overuse changes or new injuries in the LS were noted (Aharony et al. 2008). In a previous study, whole LS and lumbar level-dependent postural changes were measured in active-duty Marines while posteriorly carrying a load of 50.8 kg (Rodríguez-Soto et al. 2013). These changes appeared to be responses to centre of mass realignment (subject and backpack). More locally in the lumbar spine, these observed changes originated from the disparate postural behaviour of the superior and inferior LS. However, the Marines who were evaluated in this study had already been in operation for 8–48 months and were conditioned to carry heavy loads while marching. Importantly, Marines participating in both studies (Aharony et al. and Rodríguez-Soto et al.) had measurable, pre-existing structural changes in muscles, vertebrae and intervertebral discs (IVDs) that may have affected load-carrying posture (Aharony et al. 2008; Rodríguez-Soto et al. 2013).

The interaction between pelvic and LS posture has been previously investigated in the standing position (Jackson et al. 2000; Legaye et al. 1998; Vaz et al. 2002). The strongest association found exists between sacral slope and LS lordosis, which reveals that these two variables are proportional to each other (Jackson et al. 2000; Vaz et al. 2002). Meaning that in people with a more anteriorly rotated sacrum, the LS is more lordotic, and vice versa. Furthermore, reduced sacral slope and LS lordosis have been reported in the presence of IVD degeneration and LBP (Berthonnaud et al. 2005; Schwab et al. 2009). In the context of posterior load carriage, pelvic and LS orientation have been previously estimated using motion capture technology, but never measured directly.

Given the lack of data documenting LS posture, and structural changes for Marines exposed to posterior load carriage, the purposes of this study were to: (1) compare LS postural adaptations to load over the course of SOI training, (2) understand the effect of training on IVD degeneration and (3) understand the effect of IVD degeneration on LS postural adaptations during training. We hypothesised the following: (1) load carriage-induced LS posture will change with training, and (2) Marines with IVD degeneration will manage loads and adapt to training differently than Marines without IVD degeneration.

Methods

Subjects

Forty-one male Marines from three different companies enrolled at SOI West Marine Corps Base at Camp Pendleton, and with no recent history of LBP volunteered to participate in this study. The University of California, San Diego and Naval Health Research Center institutional review

boards approved this study, and all volunteers provided oral and written informed consent.

Imaging

Marines were scanned using an upright 0.6T magnetic resonance imaging (MRI) scanner (UPRIGHT® Multi-Position MRI, Fonar Corporation, Melville, NY, USA) and a planar coil. A soft sleeve was used to retain the coil behind the volunteer's back at the lumbar spine (L1–S1) level while standing. The sleeve was tight enough to keep the coil in place, yet loose enough not to alter the volunteer's natural standing position. A three-plane localizer and sagittal T2-weighted images (repetition time 1974 ms; echo time 160 ms; field of view 32 cm; 224 × 224 acquisition matrix; 1.43 × 1.43 mm² pixel size; 4.5 mm slice thickness; 0.5 mm gap; number of averages 1, scan duration 2 min 30 s) were acquired.

Load-carrying tasks

Marines were transferred from Camp Pendleton to MRI facilities at three time points: around day 1, day 20, and day 40 of SOI training. At each visit, Marines were first scanned standing without external load (unloaded) and after standing with a total load of 22.6 kg in an Improved Load Bearing Equipment (ILBE) backpack for 45 min (Figure 1). This load mass (22.6kg) was selected because it is operationally relevant and to avoid injuries induced by early overloading during SOI training. The magnitude of the load was kept constant during the experimental period to determine if training improved the ability to manage a constant load. During the standing period, Marines were allowed to move around the waiting room but were instructed not to lean on surfaces or against the wall. After the 45 min load-carriage period, Marines were scanned a second time while carrying the same load. All ILBE backpacks were previously screened for ferromagnetic components; no metal components were found; therefore, no alterations were needed to make the backpack MRI-safe. For this second scan, the coil was placed between the backpack and the Marine's spine. In addition, Marines were purposefully not given instructions on how to stand in the scanner, but they were instructed to remain still during the entire MRI acquisition.

Data analysis

Each image data-set was analysed as previously described (Rodríguez-Soto et al. 2013). Briefly, a set of markers was manually placed at the corners of each vertebra (L1–S1) and posterior elements to model vertebral position and orientation. Relative rotations in the axial and coronal planes between contiguous vertebrae were removed,

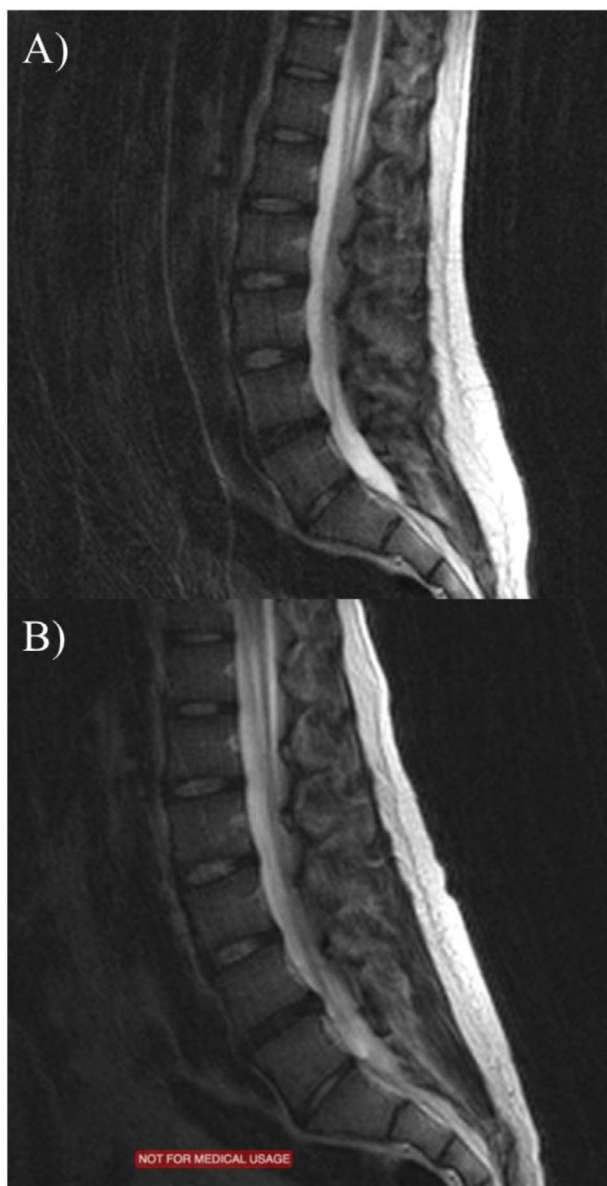


Figure 1. Representative sagittal magnetic resonance images of the lumbar spine without load (A) and with load (B).

and the resulting vertebral end-plate representations were used to generate postural measurements in the sagittal plane (Berry et al. 2015).

Measurements

The degeneration level of the IVDs was determined for all data-sets by an experienced radiologist (C.B.C.) using the Pfirrmann scoring system. This grading scale has five levels (I–V), where I corresponds to normal, II to mild degeneration, III to moderate degeneration, IV to severe degeneration and V to advanced degeneration (Pfirrmann et al. 2001). Marines were grouped based upon the degeneration of the L5–S1 level IVD; those graded with Pfirrmann scores of I and II were assigned to the ‘non-degenerated’

group, and those with scores of III, IV and V were in the ‘degenerated’ group (Fujiwara et al. 2000).

Postural measurements of the LS and pelvis in the sagittal plane were generated from vertebral endplates as previously described in the *Data Analysis* section. These variables were:

- *Angle with respect to the horizontal*: quantifies the overall position of the LS (L1–S1) with respect to the ground (i.e. flexion, extension); however, it does not convey relative postural information between LS levels. When the LS is flexed this angular variable is reduced; extension has the opposite effect on this variable.
- *Sacral slope (SS)*: defined as the angle between the superior endplate of S1 and the horizontal. We consider SS a surrogate measurement of pelvic tilt, assuming that the motion between sacrum and pelvis is negligible. This variable describes sacral inclination: a small SS value indicates that the overall orientation of the sacrum is close to the vertical (S1 endplate is more horizontal), while a larger value describes a more horizontal sacrum (S1 endplate is more vertical).
- *Lumbar angle*: defined as the angle formed by the planes corresponding to the superior end-plates of L1 and S1 in the sagittal plane. As such, an increase in LS lordosis will be reflected by an increase in this angular variable, and viceversa. It has been previously reported that superior and inferior sections of the LS have different postural adaptations to load; therefore, we defined the *superior lumbar angle* as the angle formed by the superior endplate of L1 and the inferior endplate of L3, and the *inferior lumbar angle* as the angle between the superior endplate of L4 and inferior endplate of S1 (Rodríguez-Soto et al. 2013).
- *Segmental intervertebral (IV) angles and regional disc heights* were measured between the planes of the inferior and superior endplates of adjacent vertebrae. Intervertebral heights were measured as the shortest distance between inferior and superior endplates anteriorly, centrally and posteriorly in the midsagittal plane.

Statistical analysis

All data distribution was tested for normality using Shapiro-Wilk test. The absolute values of all variables were compared over training time using two-way repeated-measures analyses of variance (ANOVA) with Sidak *post hoc* tests to identify significant differences as a function of task and time. Additionally, the effect of IVD degeneration

on the magnitude of change of each postural measurement throughout training was investigated using two-way repeated measures ANOVAs (IVD degeneration x time). Again, Sidak *post hoc* tests were used to identify significant differences between IVD degeneration and training time. The threshold for significance (α) was set at 0.05 for all analyses. Statistical analyses were performed using SPSS Statistics software (version 20.0, IBM, Armonk, NY), and all data are reported as mean \pm standard deviation (SD) values.

Results

Volunteer characteristics

Complete image data-sets for each time point were obtained from 27 Marines (mean \pm SD age, 19.5 \pm 1.8 years; age range 17–25 years; height, 178.4 \pm 5.6 cm; weight, 82.3 \pm 8.4 kg; body mass index, 25.8 \pm 1.8 kg/m²). Of the 41 Marines enrolled in the study, 14 (34%) missed at least one visit and those cases were omitted from analysis.

Measurement of IVD degeneration

The distribution of the Pfirrmann grades by lumbar level is shown in Table 1. The incidence of degenerated IVDs progressively increased from superior to inferior lumbar levels, but no progression in degeneration was observed during the training period. There were 16 volunteers in the non-degenerated group and 11 in the degenerated group, based on the Pfirrmann grades of the L5–S1 IVD.

Measurement of lumbar spine load-carriage postural changes

None of the measured variables changed between loading tasks throughout training. The overall position of the spine was significantly ($p < 0.05$) more flexed when carrying load compared with those without load, at all time points (Figure 2, Supplemental Table 1). Simultaneously, the sacral slope significantly increased ($p < 0.05$) when carrying load, compared to its orientation when standing unloaded (Figure 3A). Marines with L5–S1 IVD degeneration had a larger ($p < 0.05$) change in sacrum orientation (7.94° \pm 4.17°) between unloaded and loaded tasks, compared to Marines without degeneration at the same lumbar level (4.13° \pm 4.18°; Figure 3B). Absolute SS values suggest that this difference is attributed to the orientation of the sacrum when loaded (degenerated 43.39° \pm 4.01°, non-degenerated 38.38° \pm 7.56°).

Additionally, we found that simultaneously to the LS flexion and sacrum orientation changes observed during load carriage, there was a reduction on whole LS lordosis ($p < 0.05$, Figure 4A). No significant differences were

Table 1. Distribution of disc degeneration as scored by Pfirrmann grading, by lumbar level.

Level/Pfirrmann grade	I	II	III	IV	V	Total
L1–L2	3	23	1	0	0	27
L2–L3	3	22	2	0	0	27
L3–L4	4	19	3	1	0	27
L4–L5	1	21	1	4	0	27
L5–S1	1	15	4	6	1	27
Total	12	100	11	11	1	

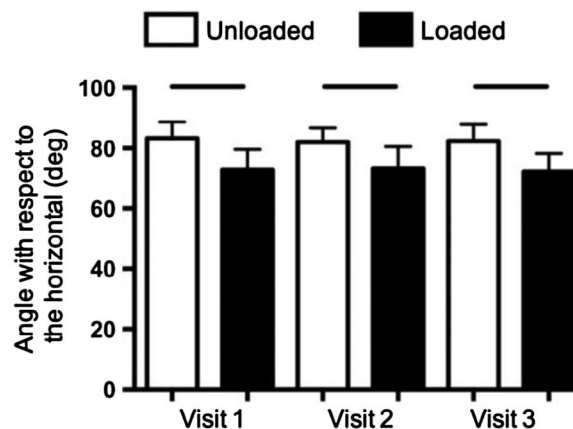


Figure 2. Trunk flexion measurements per task and visit.

Notes: Significant differences ($p < 0.001$), were found between unloaded (white) and loaded (loaded) tasks but not throughout training. Horizontal bars represent statistical difference ($p < 0.05$).

found within the unloaded to loaded conditions between L5–S1 IVD degeneration groups (Figure 4B). However, we observed a trend ($p = 0.07$, observed power 46%) towards reduced change in lordosis in the group with degeneration (Figure 4B). This suggests that individuals with L5–S1 degeneration may change posture in response to loading less than individuals without degeneration.

In order to investigate which LS regions contributed to the lordosis changes induced by load exposure, we measured the curvature of both superior and inferior LS. The exposure to load did not cause any detectable changes in the curvature of the superior LS; however, the inferior LS became less lordotic in response to load (Figure 5A). The magnitude of change between tasks was not different between Marines regardless of the presence of degeneration at the L5–S1 IVD (Figure 5B).

The IV angles across lumbar levels are shown in Supplement Figure 1. We observed that overall, the magnitude of the response to load is larger at inferior lumbar levels than at superior levels (Figure S1). Specifically, the L1–L2 level became more lordotic (unloaded 5.05° \pm 1.63°, loaded 6.01° \pm 1.60°) in response to load – in contrast to inferior levels L3–L4 (unloaded 9.28° \pm 1.80°, loaded 8.3° \pm 2.45°), L4–L5 (unloaded 10.83° \pm 2.23°, loaded 7.48° \pm 3.56°) and L5–S1 (unloaded 10.83° \pm 4.04°, loaded 6.82° \pm 2.58°), which became less lordotic ($p < 0.05$, Figure S1 A–E). No

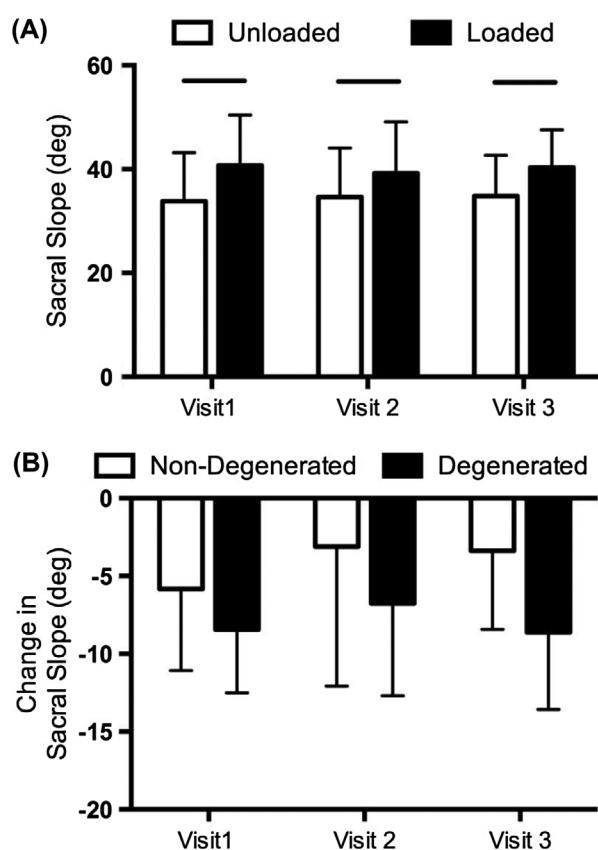


Figure 3. (A) Sacral slope (SS) per task and visit. Significant differences ($p < 0.001$), were found between unloaded (white) and loaded (loaded) tasks but not throughout training. (B) Change in sacral slope between tasks by L5–S1 IVD degeneration, throughout training.

Notes: A significant ($p < 0.05$) main effect of degeneration was found: Marines with degeneration had a larger change in SS between tasks. Horizontal bars represent statistical difference ($p < 0.05$).

postural changes were detected in response to load at the L2–L3, suggesting that it acts as a ‘transition’ level.

Anterior and posterior IV distances at the L1–L2, L4–L5 and L5–S1 levels changed significantly ($p < 0.05$) in response to load. Overall, changes in regional IVD distances reflect postural kinematics throughout lumbar levels (Figure S2). The L1–L2 IVD was anteriorly distracted ($p < 0.05$) and posteriorly compressed ($p < 0.05$); while, L4–L5 and L5–S1 were anteriorly compressed and posteriorly distracted when carrying load ($p < 0.05$). Centrally, only L4–L5 became significantly more compressed when carrying load ($p < 0.05$).

Discussion

The main objective of this study was to measure the postural changes of the LS with and without posterior load throughout USMC SOI training. In terms of physical condition, the School of Infantry training includes both aerobic and resistance exercise (e.g. long training marches

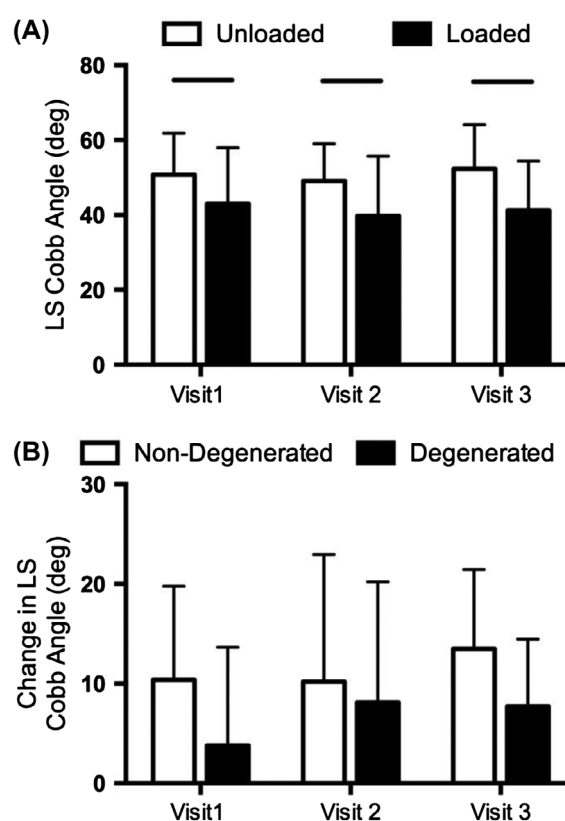


Figure 4. (A) Results for whole lumbar spine (LS) lordosis per task and visit. Overall LS became more straight during load carriage. (B) Change in LS lordosis between tasks by L5–S1 IVD degeneration groups.

Note: Horizontal bars represent statistical difference ($p < 0.05$).

and heavy load carriage), presumably improving Marines’ endurance and strength while progressively exposing them to load carriage. Based on this paradigm, we hypothesised that it would become progressively easier to carry a fixed-load magnitude over the training period because of improvements in endurance, strength and motor learning. Additionally, we hypothesised that the presence of IVD degeneration would alter LS postural adaptations to posterior load carriage. Other authors have evaluated the outcomes of military training in terms of physical condition testing and radiological evaluation of the IVDs [5–8]. However, biomechanical data on the adaptation of the LS to load carriage as a function of SOI training progression was lacking. In this study, we applied novel and valid tools, which allow postural changes in response to load and training to be quantified. This strategy allowed us to document the changes in LS load carriage kinematics between a group of active-duty Marines with and without degeneration of the L5–S1 IVD.

Across all subjects, no differences were found in LS posture in response to load during the training period. However, differences between subjects with IVD degeneration and those without were observed. Specifically,

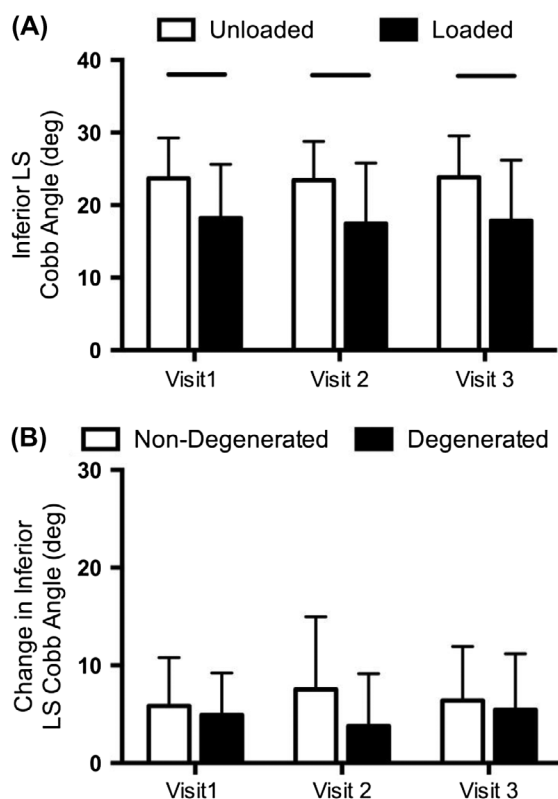


Figure 5. (A) Results for inferior lumbar spine (LS) lordosis per task and visit. Inferior LS became more straight during load carriage. (B) Change in inferior LS lordosis between tasks by L5–S1 IVD degeneration groups.

Notes: These data show that postural response to load is driven by changes in the inferior LS. Horizontal bars represent statistical difference ($p < 0.05$).

subjects with IVD degeneration demonstrated larger sacral perturbations and trended towards a smaller change in LS lordosis in response to load.

To quantify global LS posture, we measured LS flexion, whole LS and regional lordosis, and sacral slope. Intervertebral disc angles and heights were used to assess local lumbar postural changes. These data suggest that when external load is applied the LS becomes more flexed, which is in agreement with previous reports (Al-Khabbaz, Shimada, and Hasegawa 2008; Attwells et al. 2006; Bust and McCabe 2005). This increase in lumbar flexion may be a compensatory response used to reorient the centre of mass of the system (body + loaded pack) over the feet (Bloom and Woodhull-Mcneal 1987; Knapik, Harman, and Reynolds 1996); however, this idea needs to be tested explicitly. In this study, LS flexion was on average $72.74 \pm 5.04^\circ$ (or 17.26° anterior to vertical) when carrying a load of approximately 25% BW. In a previous study (Rodríguez-Soto et al. 2013), LS flexion was roughly 52° (or 38° anterior to vertical) when carrying a load of 50 kg (~68% BW). These findings suggest that there is a proportional increase in trunk flexion with increasing load, which is again consistent with previous literature (Knapik,

Harman, and Reynolds 1996; Knapik et al. 1990). For example, when using different methods (motion capture), Attwells et al. reported trunk flexion between 77° and 80° (with respect to the horizontal) when walking with loads of 15.95 kg (22% BW) on a waist belt and 20 kg (27% BW) in a backpack, respectively (Attwells et al. 2006). We attribute the variation in magnitude to the differences in measurement tools and experimental setups between these three studies. Of note, we have presented direct measurements of spinal elements versus LS surface measurements.

In order to understand the contribution of both pelvic and LS components to the overall LS posture, we measured SS. In the present study, the SS when standing without external load was $34.43^\circ \pm 8.3^\circ$, whereas most of the values previously reported in the literature range between 39° and 42° (Jackson et al. 2000; Vaz et al. 2002). The discrepancy between these data might be caused by the difference in measuring tools; values reported in the literature while standing were performed using X-rays, while we have used an MRI-based three-dimensional tool to measure posture. Another possible explanation might be related to high variation in postural characteristics of the population; the range of individual SS values reported in the literature varies around 20° – 65° . Furthermore, we directly measured SS during load carriage in a group of young active-duty Marines – data that were lacking in the literature. Other authors have previously studied the effect of load carriage on pelvic tilt during gait in a group of soldiers, female students and children (Birrell and Haslam 2009; PASCOE et al. 1997; Smith et al. 2006). In all cases, the authors used motion capture to perform measurements of the hip joint range of motion and did not report absolute values of pelvic tilt, making comparison to our data impossible.

In addition to increased lumbar flexion and sacral slope, LS lordosis was reduced when carrying a load, which is also consistent with previous observations. Neuschwander et al. measured lumbar lordosis in children carrying backpacks of 10, 20 and 30% BW from images acquired using an upright MRI scanner. These authors reported $\sim 60^\circ$ of lordosis when standing without load and $\sim 55^\circ$ of lordosis when carrying 30% BW (Neuschwander et al. 2010). These values were obtained using a similar definition of the lumbar angle used in this study, but they were measured two dimensionally. In this study, we have found 50° of lordosis when standing without load and 40° after 45 min of standing with $\sim 25\%$ BW. Such findings are also in agreement with our previous study, for which LS lordosis was 52° when standing without load and 40° after standing for 45 min with 50 kg of load (Rodríguez-Soto et al. 2013). Interestingly, whole LS lordosis values reported by Neuschwander et al. (2010), Rodríguez-Soto et al. (2013), and in the present study are very similar despite the differences in the magnitude of the load carried. However, when comparing the local lordosis

at each lumbar level previously reported by our group (Rodríguez-Soto et al. 2013) and those of the present study, we identified that the superior LS had a larger increase in lordosis when carrying 50 kg of load than when carrying 26 kg. Similarly, the reduction in inferior LS lordosis was larger when carrying the heavier load; resulting in a similar value in whole LS lordosis, but with different contributions from each lumbar level.

Local LS posture measurements indicate that the overall reduction in LS lordosis is primarily driven by the changes that occurred at the L4–L5 and L5–S1 levels. These data also suggest that the LS experiences two opposing motions under load-carrying conditions. The L1–L2 increment in lordosis may potentially cause the inferior endplate of L1 and the superior endplate of L2 to become parallel, as superior lumbar vertebral bodies are commonly kyphotic in nature (taller posterior than anteriorly). Contrastingly, inferior levels (L3–L4, L4–L5 and L5–S1) become more straight. The lack of postural changes at the L2–L3 level suggests it serves as transition level between superior and inferior LS. Interestingly, the location of these transition levels appears to depend on the presence and magnitude of load. In our previous study, we reported that the transition level was L3–L4 when carrying 50 kg of load. However, in that evaluation, Marines wore body armor as part of their total load, while in the present study they did not. This is a limitation to comparing relative changes of the LS since the body armor may (or may not) have affected how the LS changes with load. Future work is being conducted to elucidate the effects of body armor on LS posture both with and without load. Additionally, the location of transition levels during load carriage might be associated with the location of the lumbar lordosis apex of each person when standing unloaded. The variation in the apex location ranges from the base of L3 to the middle region of L5 depending on the pelvic and lumbar sagittal alignment of each person (Herkowitz and International Society for Study of the Lumbar Spine 2004).

Another aim of this study was to evaluate the effect of SOI training on the degenerative state of IVDs and its relation to LS posture. The incidence of IVD degeneration (at least one degenerated IVD) among these Marines was 47.5%, while the incidence of degeneration at the L5–S1 level was 40.7%. This has been previously attributed to the greater forces acting on these levels through the LS (Alexander et al. 2007; Pal and Routal 1987).

Marines were grouped into 'degeneration' and 'no-degeneration' based on the degenerative state of L5–S1. Although L5–S1 may not reflect the degenerative state of all lumbar IVDs this level was chosen because during load carriage the largest motion in the LS occurs at L4–L5 and L5–S1. Therefore, the idea that the presence of degeneration at these levels may influence the

posture of other regions of the LS was explored. In fact, we found that Marines with degeneration at the L5–S1 level demonstrated larger sacral postural perturbations in response to load as well as a trend of reduced change in lumbar angle. Absolute values of SS and LS lordosis of the L5–S1 degeneration group suggest that during load carriage, two postural differences exist compared to the non-degenerated group: (1) sacral slope is greater, and (2) LS lordosis is retained. Together, these data suggest that overall LS posture (with respect to the ground) is similar in these two groups, but individuals with degeneration achieve that position with more pelvic movement and less lumbar spine deformation. This interpretation of the data during load carriage is counterintuitive to that previously reported when standing without external load in the presence of degeneration. In that case, a more vertical sacrum (more horizontal S1 endplate) and reduced LS lordosis were reported (Barrey et al. 2007). Additionally, it has been suggested that in the presence of IVD degeneration at inferior lumbar levels a compensatory mechanism of increased lordosis occurs at superior lumbar levels (Lee et al. 2014; Rodríguez-Soto et al. 2013). However, no evidence of this phenomenon was found in this population.

Although only young men were included in the present study, it is relevant to discuss the LS postural response in other contexts; for example, the postural adaptations that the LS of women undergo during pregnancy. In this case, the LS of women progressively extends as the magnitude of the foetal load increases (Whitcome, Shapiro, and Lieberman 2007). Similar to the postural adaptations shown in the present study, it has been hypothesised that these adjustments allow realigning the position of the centre of mass in order to maintain balance. Interestingly, in both cases (soldiers posteriorly carrying load and pregnant women anteriorly carrying foetal load) the LS curvature is at extreme standing flexion/extension, during which increased incidence of back pain has been reported (Dumas et al. 1995; Östgaard et al. 1993 and Taanila et al. 2009). Consequently, future work should focus on identifying the biomechanical effect of LS posture. These data would help elucidate injury mechanisms and their impact on health outcomes.

In order to understand the biomechanical association between postural responses, it is necessary to consider both general orientation and lordosis of the LS. For instance, in the results presented here, although there were changes in IVD flexion that may alter the fraction of total compressive load resisted by IVD and facet joints, overall all levels remained in approximately 6–8° of flexion. This suggests that compressive load distribution between these two structures may be similar throughout the LS. However, in this case, the role of the orientation of each IVD with respect to the ground may be more relevant in determining the distribution of compressive and shear forces between

these structures. Nonetheless, the interplay between local lordosis and overall orientation of a vertebral joint with respect to the horizontal remains unknown.

There are a number of limitations to this study. An inherent limitation of *in vivo* MRI studies is the trade-off between voxel dimensions and scan duration. It was imperative to maintain the short scan duration because Marines had to stand still in the scanner while donning load. We have previously demonstrated that the LS posture measured from high-resolution images is not significantly different from those measured from images at the voxel dimensions ($1.43 \times 1.43 \times 4.5 \text{ mm}^3$) used in this study (Rodríguez-Soto et al. 2013). However, this resolution does not allow for proper measurement of IVD bulging or protrusion, which would complement our IVD distance measurements. Another constraint of this study was the attrition rate (~35%), which limited the number of complete data-sets available for analysis and reduced the power of some of our non-significant findings. A final limitation is that all of our subjects were pain-free at the time of enrollment and graduated from SOI. It is possible that the presence of pain would profoundly alter LS posture in the presence of load – a topic of ongoing research in the laboratory.

Conclusions

In conclusion, when Marines carry a 22.6 kg load in a standard military load carriage system without wearing body armor, there is an observable compensatory forward lean and an overall reduction in the LS lordosis. Locally, L1–L2 becomes more lordotic, L2–L3 does not change, and L3–L4, L4–L5, and L5–S1 become more kyphotic. Moreover, the anterior and central IVD regions of inferior lumbar levels experience compression, while the posterior disc region becomes distracted, leading to postural changes after standing for 45 min with load. The contribution of each intervertebral level is reflected in lumbar spine flexion and reduced lordosis during load-carrying tasks. Additionally, training did not induce further progression of IVD degeneration in any participant of this study. However, Marines with degenerated IVDs at L5–S1 exhibited a larger sacral postural perturbations and smaller lumbar angle changes in response to load. These data suggest that LS postural adaptations to load may not be regulated by physical conditioning as much as they are inherent strategies to manage the overall load over the base of support. However, this concept needs to be tested explicitly.

Acknowledgements

The authors would like to thank 1st Marine Expeditionary Force (I MEF) for approval and support of the project especially CAPT Reichard (I MEF Surgeon), Maj Thrasher (Division G3), Lt-Col Kenney (XO, SOI-West), LtCol LeCroix (CO, Infantry Training

Battalion, SOI-West) and Capt Johnson (XO, Infantry Training Battalion, SOI-West). We would also like to thank the company commanders and staff from Alpha, Bravo, Charlie, Echo and Delta companies from SOI-West and the Marine Corps students from the SOI-West training from February 2011–November 2011. Additional thanks go to Ricardo Martinez, Jarrott Mayfield, Jonathan Cunha, Jessica Sacks and Jessica Pate for their assistance during data collection.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Navy Bureau of Medicine and Surgery Wounded, Ill, and Injured programme under Work Unit No. 61016. The views expressed in this article are those of the authors and do not reflect the official policy or position of the Department of the Navy, Department of the Marine Corps, Department of Defense or the US Government. Approved for public release; distribution unlimited. This research has been conducted in compliance with all applicable federal regulations governing the protection of human subjects in research (protocol NHRC.2011.0023).

ORCID

Ana E. Rodriguez-Soto  <http://orcid.org/0000-0002-9544-547X>

References

- Aharony, S., C. Milgrom, T. Wolf, Y. Barzilay, Y. H. Applbaum, Y. Schindel, A. Finestone, and N. Liram. 2008. "Magnetic Resonance Imaging Showed No Signs of Overuse or Permanent Injury to the Lumbar Sacral Spine during a Special Forces Training Course." *The Spine Journal* 8 (4): 578–583. doi:10.1016/j.spinee.2007.01.001.
- Alexander, L. A., E. Hancock, I. Agouris, F. W. Smith, and A. MacSween. 2007. "The Response of the Nucleus Pulposus of the Lumbar Intervertebral Discs to Functionally Loaded Positions." *Spine* 32 (14): 1508–1512. doi:10.1097/BRS.0b013e318067dccb.
- Al-Khabbaz, Y. S., T. Shimada, and M. Hasegawa. 2008. "The Effect of Backpack Heaviness on Trunk-Lower Extremity Muscle Activities and Trunk Posture." *Gait Posture* 28 (2): 297–302. doi:10.1016/j.gaitpost.2008.01.002.
- Attwells, R. L., S. A. Birrell, R. H. Hooper, and N. J. Mansfield. 2006. "Influence of Carrying Heavy Loads on Soldiers' Posture, Movements and Gait." *Ergonomics* 49 (14): 1527–1537. doi:10.1080/00140130600757237.
- Barrey, C., J. Jund, O. Nosedá, and P. Roussouly. 2007. "Sagittal Balance of the Pelvis-spine Complex and Lumbar Degenerative Diseases. A Comparative Study about 85 Cases." *European Spine Journal* 16 (9): 1459–1467. doi:10.1007/s00586-006-0294-6.
- Berry, D. B., A. E. Rodriguez-Soto, J. R. Tokunaga, S. P. Gombatto, and S. R. Ward. 2015. "An Endplate-based Joint Coordinate System for Measuring Kinematics in Normal and Abnormally Shaped Lumbar Vertebrae." *Journal of Applied Biomechanics* 31 (6): 499–503. doi:10.1123/jab.2015-0008.

- Berthonnaud, E., J. Dimnet, P. Roussouly, and H. Labelle. 2005. "Analysis of the Sagittal Balance of the Spine and Pelvis Using Shape and Orientation Parameters." *Journal of Spinal Disorders & Techniques* 18 (1): 40–47.
- Birrell, S. A., and R. A. Haslam. 2009. "The Effect of Military Load Carriage on 3-D Lower Limb Kinematics and Spatiotemporal Parameters." *Ergonomics* 52 (10): 1298–1304. doi:10.1080/00140130903003115.
- Bloom, D., and Ann P. Woodhull-Mcneal. 1987. "Postural Adjustments While Standing with Two Types of Loaded Backpack." *Ergonomics* 30: 1425–1430.
- Bust, P. D., and P. T. McCabe. 2005. "Proceeding of the International Conference on Contemporary Ergonomics (CE 2005)." Contemporary Ergonomics 2005, Hatfield, April 5–7.
- Dumas, G. A., J. G. Reid, L. A. Wolfe, and M. J. Griffin. 1995. "Exercise, Posture, and Back Pain during Pregnancy." *Clinical Biomechanics* 10 (2): 98–103.
- Fujiwara, A., T. H. Lim, H. S. An, N. Tanaka, C. H. Jeon, G. B. Andersson, and V. M. Haughton. 2000. "The Effect of Disc Degeneration and Facet Joint Osteoarthritis on the Segmental Flexibility of the Lumbar Spine." *Spine* 25 (23): 3036–3044.
- Harman, E. A., D. J. Gutekunst, P. N. Frykman, B. C. Nindl, J. A. Alemany, R. P. Mello, and M. A. Sharp. 2008. "Effects of Two Different Eight-week Training Programs on Military Physical Performance." *Journal of Strength and Conditioning Research* 22 (2): 524–534. doi:10.1519/JSC.0b013e31816347b6.
- Heir, T., and P. Glomsaker. 1996. "Epidemiology of Musculoskeletal Injuries among Norwegian Conscripts Undergoing Basic Military Training." *Scandinavian Journal of Medicine & Science in Sports* 6 (3): 186–191.
- Herkowitz, Harry N., and International Society for Study of the Lumbar Spine. 2004. *The Lumbar Spine*. 3rd ed. Philadelphia, PA: Lippincott Williams & Wilkins.
- Jackson, R. P., T. Kanemura, N. Kawakami, and C. Hales. 2000. "Lumbopelvic Lordosis and Pelvic Balance on Repeated Standing Lateral Radiographs of Adult Volunteers and Untreated Patients with Constant Low Back Pain." *Spine* 25 (5): 575–586.
- Knapik, J. J., M. Bahrke, J. Staab, K. Reynolds, J. Vogel, and J. O'Connor. 1990. "Frequency of Loaded March Training and Performance on a Loaded Road March." *US Army Research Institute of Environmental Medicine* 52 Report no: T13–90.
- Knapik, J., E. Harman, and K. Reynolds. 1996. "Load Carriage Using Packs: A Review of Physiological, Biomechanical and Medical Aspects." *Applied Ergonomics* 27 (3): 207–216.
- Lee, E. S., C. W. Ko, S. W. Suh, S. Kumar, I. K. Kang, and J. H. Yang. 2014. "The Effect of Age on Sagittal Plane Profile of the Lumbar Spine according to Standing, Supine, and Various Sitting Positions." *Journal of Orthopaedic Surgery and Research* 9 (1): 11. doi:10.1186/1749-799X-9-11.
- Legaye, J., G. Duval-Beaupere, J. Hecquet, and C. Marty. 1998. "Pelvic Incidence: A Fundamental Pelvic Parameter for Three-dimensional Regulation of Spinal Sagittal Curves." *European Spine Journal* 7 (2): 99–103.
- Neuschwander, T. B., J. Cutrone, B. R. Macias, S. Cutrone, G. Murthy, H. Chambers, and A. R. Hargens. 2010. "The Effect of Backpacks on the Lumbar Spine in Children." *Spine* 35 (1): 83–88. doi:10.1097/BRS.0b013e3181b21a5d.
- Östgaard, H. C., G. B. J. Andersson, A. B. Schultz, and J. A. A. Miller. 1993. "Influence of Some Biomechanical Factors on Low-back Pain in Pregnancy." *Spine* 18 (1): 61–65.
- Pal, G. P., and R. V. Routal. 1987. "Transmission of Weight through the Lower Thoracic and Lumbar Regions of the Vertebral Column in Man." *Journal of Anatomy* 152: 93–105.
- Pascoe, D. D., D. E. Pascoe, Y. T. Wang, D. M. Shim, and C. K. Kim. 1997. "Influence of Carrying Book Bags on Gait Cycle and Posture of Youths." *Ergonomics* 40 (6): 631–640. doi:10.1080/001401397187928.
- Pfirrmann, C. W., A. Metzendorf, M. Zanetti, J. Hodler, and N. Boos. 2001. "Magnetic Resonance Classification of Lumbar Intervertebral Disc Degeneration." *Spine* 26 (17): 1873–1878.
- Rodríguez-Soto, A. E., R. Jaworski, A. Jensen, B. Niederberger, A. R. Hargens, L. R. Frank, K. R. Kelly, and S. R. Ward. 2013. "Effect of Load Carriage on Lumbar Spine Kinematics." *Spine* 38 (13): E783–E791. doi:10.1097/BRS.0b013e3182913e9f.
- Schwab, F., V. Lafage, A. Patel, and J. P. Farcy. 2009. "Sagittal Plane Considerations and the Pelvis in the Adult Patient." *Spine* 34 (17): 1828–1833. doi:10.1097/BRS.0b013e3181a13c08.
- Smith, B., K. M. Ashton, D. Bohl, R. C. Clark, J. B. Metheny, and S. Klassen. 2006. "Influence of Carrying a Backpack on Pelvic Tilt, Rotation, and Obliquity in Female College Students." *Gait Posture* 23 (3): 263–267. doi:10.1016/j.gaitpost.2005.02.009.
- Swain, D. P., J. A. Onate, S. I. Ringleb, D. N. Naik, and M. DeMaio. 2010. "Effects of Training on Physical Performance Wearing Personal Protective Equipment." *Military Medicine* 175 (9): 664–670.
- Taanila, H., J. Suni, H. Pihlajamäki, V. M. Mattila, O. Ohrankämnen, P. Vuorinen, and J. Parkkari. 2009. "Musculoskeletal Disorders in Physically Active Conscripts: A One-year Follow-up Study in the Finnish Defence Forces." *BMC Musculoskeletal Disorders* 10: 89–100. doi:10.1186/1471-2474-10-89.
- Vaz, G., P. Roussouly, E. Berthonnaud, and J. Dimnet. 2002. "Sagittal Morphology and Equilibrium of Pelvis and Spine." *European Spine Journal* 11 (1): 80–87.
- Whitcome, K. K., L. J. Shapiro, and D. E. Lieberman. 2007. "Fetal Load and the Evolution of Lumbar Lordosis in Bipedal Hominins." *Nature* 450 (7172): 1075–1078.