

Lumbar spine and hip flexibility and trunk strength in helicopter pilots with and without low back pain history

Takashi Nagai^{a,*}, John P. Abt^c, Timothy C. Sell^a, Karen A. Keenan^a, Nicholas C. Clark^b, Brian W. Smalley^c, Michael D. Wirt^d and Scott M. Lephart^e

^aWarrior Human Performance Research Center, Neuromuscular Research Laboratory, Department of Sports Medicine and Nutrition, University of Pittsburgh, PA, USA

^bSchool of Sport, Health and Applied Science, St Mary's University, UK

^cUS Army School of Aviation Medicine, Fort Rucker, AL, USA

^dUS Army Institute of Surgical Research, Fort Sam Houston, TX, USA

^eCollege of Health Sciences, University of Kentucky, KY, USA

Received 24 September 2014

Accepted 19 June 2015

Abstract.

BACKGROUND: Low back pain (LBP) is one of the most common musculoskeletal issues facing military helicopter pilots. It is clinically important to identify differences in musculoskeletal characteristics between pilots with and without a LBP history for formulating effective interventions.

OBJECTIVE: To compare lumbar spine and hip flexibility and trunk strength in pilots with and without a LBP history.

METHODS: A total of 30 pilots with a LBP history were matched with pilots without a LBP history. An isokinetic dynamometer and a digital inclinometer were used to evaluate trunk and hip strength and a range-of-motion (ROM), respectively. All tests were performed bilaterally, if applicable, and agonist/antagonist ratios and side-to-side (low/high) symmetries were calculated. Paired *t*-tests or Wilcoxon tests were used to assess group differences ($p < 0.050$).

RESULTS: The LBP group demonstrated significantly lower trunk extension strength and trunk extension/flexion strength ratio ($p < 0.008$). The LBP group demonstrated significantly less lateral flexion ROM as well as greater lateral flexion and rotation side-to-side asymmetry ($p < 0.009$). The LBP group demonstrated significantly greater total hip rotation side-to-side asymmetry ($p = 0.037$).

CONCLUSIONS: Given the results, specific exercises that are targeted to improve trunk strength, ROM, and side-to-side symmetries could be developed to reduce LBP in helicopter pilots.

Keywords: Range-of-motion, musculoskeletal, military, side-to-side symmetry, aviators

1. Introduction

Low back pain (LBP) is one of the most common musculoskeletal disorders experienced by military

personnel. In particular, a high prevalence of LBP has been reported in military helicopter pilots. Bridger et al. [6] and Thomae et al. [34] reported that 64–80% of pilots experience discomfort or pain in the lumbar spine. The high prevalence of LBP in military pilots could result in a large proportion of pilots requiring short- and long-term medical leave due to pain-induced

*Address for correspondence: Takashi Nagai, 3830 South Water Street, Pittsburgh, PA 15203, USA. Tel.: +1 412 246 0460; Fax: +1 412 246 0461; E-mail: tnagai@pitt.edu.

disability. Low back pain that distracts pilots from flight tasks or restricts the ability to perform critical duties can threaten the safety and overall force readiness of Aviation units. Nearly a half of aircrew believe that their LBP negatively influence their work [18]. Similarly, more than 50% of pilots with LBP felt that discomfort and pain interfered with concentration during flight missions [34].

Researchers have attempted to identify risk factors for LBP in military pilots. One military study has identified that a history of back injury was associated with LBP in military helicopter pilots, whereas other characteristics such as age, education, body mass index (BMI), posture, and flying hours were not [34]. Despite a high prevalence of LBP, there have been few studies evaluating musculoskeletal characteristics in helicopter pilots with and without a history of LBP. Civilian studies have demonstrated that impaired trunk muscle performance and lower extension/flexion ratios are associated with LBP [4, 10, 20, 22, 23, 36]. Reduced hip internal and external rotation range-of-motion (ROM) as well as greater side-to-side asymmetry in hip internal and external rotation ROM are often observed in individuals with LBP [3, 7, 8, 19]. Similarly, lumbar spine ROM and greater side-to-side asymmetry in ROM also have been investigated as potential contributors to LBP [17, 21, 25]. Given the uniqueness of the military culture [30] and exposure to many external factors (combat gear, long flight-hours, night flight-hours with night-vision goggles and counterweight, small cockpit space, awkward flight posture, engine vibration and noise, and environmental factors) [28], it was of interest to investigate if those musculoskeletal characteristics were found among military helicopter pilots with a history of LBP.

Military helicopter pilots are at risk for LBP. It is necessary and useful to compare musculoskeletal characteristics of those with and without LBP in order to formulate rational prevention, assessment, and rehabilitation [29] that may be effective in reducing LBP prevalence, severity, and disability. Therefore, the purpose of this study was to compare selected trunk strength, lumbar spine ROM, and hip ROM characteristics between helicopter pilots with and without a self-reported history of LBP. It was hypothesized that pilots with a history of LBP would exhibit lower normalized trunk muscle strength, lower trunk extension/flexion strength ratio, lower trunk and hip ROM, and greater side-to-side asymmetry when compared to pilots without a history of LBP. The findings from the current investigation are clinically important because

any identified suboptimal musculoskeletal characteristics may be modifiable through targeted intervention programs that can contribute to prevent LBP in helicopter pilots.

2. Methods

2.1. Study design and subject characteristics

This study was a cross-sectional design. The study was approved by the human subject protection boards of the military medical center and the University. Prior to participation, verbal and written informed consent was provided. Active-duty helicopter pilots from a combat unit were recruited. Inclusion criteria were: age 18 to 55 years; no neurological or balance disorders; no current spinal, upper limb, or lower limb impairment that could affect test performance. An *a priori* sample size estimated 16 subjects were required in each group based on a previous study comparing golfers with and without a LBP history [36]; however, to account for the number of dependent variables, a total of 30 pilots with a self-reported history of LBP within the last 12 months (LBP group) were used in the current investigation. They were matched with a group of pilots without a history of LBP (no-LBP group) based on gender, age (± 5 years), and total-flight hours (± 500 hours). Additionally, to focus on flight-related LBP, all pilots have flown at least 100 hours to be qualified in the study. Demographics, flight characteristics, and physical fitness characteristics are shown in Table 1. For the LBP group, pain intensity, pain duration, and disability level at the worst episode of LBP were self-reported. For the current investigation, LBP was operationally defined as any pain, aches, and/or discomfort in the lower back region [37]. Pilots were asked about LBP intensity using the Numerical Pain Rating Scale (NPRS: 0 as no pain and 10 as worst pain imaginable) [9], pain duration (number of days), and disability level using the modified Oswestry Low Back Pain Disability Questionnaire (OSW) [15].

2.2. Instrumentation

A standard stadiometer and scale (Seca North America, East Hanover, MD) were used to assess height and mass. The Biodex Multi-Joint System 3 Pro (Biodex Medical Systems, Inc, Shirley, NY) was used to assess trunk flexion, extension, and right/left rotation isokinetic strength. A digital inclinometer (The Saunders

Table 1
Demographic, flight, physical fitness, and pain characteristics (means \pm standard deviations)

	LBP (<i>n</i> = 30)	No-LBP (<i>n</i> = 30)	<i>p</i>
Age (years)	31.6 \pm 5.9	31.6 \pm 6.0	0.970
Height (m)	1.77 \pm 0.06	1.77 \pm 0.09	0.813
Mass (kg)	84.5 \pm 11.5	83.1 \pm 14.8	0.674
BMI (kg/m ²)	26.9 \pm 3.0	26.3 \pm 3.9	0.463
Flight experience (years) [#]	6.6 \pm 5.8	5.9 \pm 4.5	0.175
Total flight-hours (hours) [#]	1302.6 \pm 1338.8	1304.9 \pm 1332.7	0.790
Total NVG flight-hours (hours) [#]	273.1 \pm 351.2	295.5 \pm 319.2	0.837
12-month flight-hours (hours) [#]	185.1 \pm 129.1	231.0 \pm 187.8	0.161
APFT push-ups (repetitions) [#]	67.4 \pm 9.9	70.0 \pm 18.0	0.795
APFT sit-ups (repetitions)	70.9 \pm 10.1	72.7 \pm 13.0	0.609
APFT 2-mile run (minutes:seconds) [#]	15:29 \pm 1:36	14:42 \pm 1:23	0.107
APFT score (points) [#]	262.0 \pm 29.9	268.2 \pm 29.3	0.556
Numerical pain rating scale (0–10)	5.3 \pm 2.2		
Pain duration (days)	2.4 \pm 4.1		
Oswestry disability index (0–100)	18.3 \pm 16.6		

LBP = low back pain; BMI = body mass index; NVG = night vision goggles; APFT = Army physical fitness test; [#]Wilcoxon tests were used.

Group Inc, Chaska, MN) was used to assess lumbar spine and hip ROM.

2.3. Procedures and data reduction

Pilots reported to the laboratory for a single two-hour testing session. After completing the consent forms, pilots were asked about their self-reported history of LBP by pain questionnaires (yes/no on LBP, NPRS, pain duration, OSW), flight characteristics (total flight-years, total flight-hours, total night-vision goggle flight-hours, 12-month flight-hours), and self-reported Army Physical Fitness Test (APFT) scores (push-ups, sit-ups, 2-mile run time, and combined score).

For trunk flexion, extension, and rotation strength measurements, subjects were positioned and stabilized according to the manufacturer's guidelines to ensure proper alignment for testing and to restrict accessory movements. Three practice trials at 50% of self-perceived maximum effort then were performed to ensure proper movement, warm-up, and comfort throughout the available motion, followed by a rest period of 60 seconds. Each subject then performed five repetitions of reciprocal concentric isokinetic trunk extension/flexion and right/left trunk rotation at 60°/sec. The procedures have previously been found to have acceptable reliability [11, 32]. The average of five peak torque trials was normalized to body weight (%BW). Trunk extension, flexion, right/left rotation, extension/flexion strength ratio, and trunk rotation strength side-to-side symmetry were used for statistical analyses. Side-to-side symmetry was

operationally defined as the ratio of low value over high value [35].

All lumbar spine ROM measurements were performed by the same certified athletic trainer. Lumbar spine ROM measurements using an inclinometer have been described previously [5, 21, 26, 33]. The inclinometer was placed on the following two reference points as recommended by the manufacturer's users' manual (The Saunders Group, Inc., Chaska, MN): T12 and L5, where T12 and L5 were operationally defined as the interspace between the twelfth thoracic vertebrae, and the first lumbar vertebrae and the mid-point between the inferior aspects of the posterior superior iliac spines, respectively. For lumbar spine flexion ROM, each subject sat on a chair and was asked to actively forward flex, trying to reach the knees with the nose as described by Mellin et al. [26] Lumbar spine extension ROM was assessed with the subject in the prone position. The subject pushed down on the table with the hands and actively arched the trunk into extension while maintaining contact of the anterior superior iliac spines with the table [26]. Right and left lumbar spine lateral flexion was assessed in a standing position. The subject actively slid the ipsilateral hand down the lateral aspect of the thigh without pelvic rotation or trunk flexion and while keeping the knees straight and the feet in full contact with the ground [26]. For right and left lumbar spine rotation ROM, the subject stood in a stooped position (trunk flexed to 90°), with the arms across the chest, feet in full contact with the floor, and knees straight. The subject then actively rotated the trunk to the right or the left, with right

side rotation operationally defined as rotating the right shoulder up [21]. These procedures have previously been found to have acceptable reliability [5, 21, 26]. All lumbar spine measurements were repeated three times and the average of the three trials was used for statistical analyses. Flexion, extension, lateral flexion, rotation, lateral flexion side-to-side symmetry, and rotation side-to-side symmetry were used for statistical analyses. Side-to-side symmetries were calculated as described above.

Hip internal and external rotation ROM were assessed as described by Van Dillen [38]. Two examiners were required for these assessments: one who passively rotated the subject's hip and the other who aligned the inclinometer with the long axis of the tibia and recorded the measurement. The same examiners performed the same task for all subjects. The inclinometer was zeroed in the vertical position prior to testing each subject. The subject was positioned prone with the test leg in neutral hip abduction/adduction and the knee at 90° of flexion. The non-test limb was positioned in slight hip abduction. The test limb then was passively moved into hip internal rotation until the pelvis began to rotate and the angle was recorded. The procedures were repeated for external rotation. These procedures have previously been found to have acceptable reliability [8, 27, 38]. The average of the three measurements was used for data analyses. For hip internal/external rotation ROM testing an angle (°) was recorded and the mean of three trials used for statistical analyses. Hip internal, external, total rotation, and rotation side-to-side symmetries in all directions were used for statistical analyses. Side-to-side symmetries were calculated as described above.

2.4. Statistical analyses

All statistical analyses were performed using SPSS 20.0 (IBM Corporation, Armonk, NY). Descriptive

statistics were calculated for all variables. Each dependent variable within each group was assessed for normality (Shapiro-Wilk test). Paired *t*-tests (normal data) or Wilcoxon tests (non-normal data) were used to compare between the groups. Significance was set at $p < 0.05$ *a priori*.

3. Results

Demographic, flight, physical fitness, and pain characteristics are presented in Table 1. There were no significant group differences in demographics, flight characteristics, and the most recent APFT scores. Means and standard deviations for trunk strength, lumbar spine active ROM, and hip rotation passive ROM are presented in Tables 2, 3, and 4, respectively. The LBP group demonstrated significantly lower trunk extension strength (LBP: 351.3 ± 72.2 %BW; no-LBP: 405.2 ± 67.0 %BW; $p = 0.008$) and trunk extension/flexion strength ratio (LBP: 1.50 ± 0.33 %BW; no-LBP: 1.75 ± 0.42 %BW; $p = 0.003$). Trunk rotation strength and side-to-side symmetry were not significantly different between groups ($p > 0.05$).

For lumbar spine ROM, the LBP group demonstrated significantly less right lateral flexion ROM (LBP: $21.6 \pm 4.1^\circ$; no-LBP: $26.2 \pm 4.6^\circ$; $p = 0.001$) and left lateral flexion ROM (LBP: $23.1 \pm 4.4^\circ$; no-LBP: $26.6 \pm 4.7^\circ$; $p = 0.009$). The LBP group also demonstrated significantly greater side-to-side asymmetry in lateral flexion (LBP: 0.91 ± 0.07 , no-LBP: 0.95 ± 0.05 , $p = 0.009$) and rotation ROM (LBP: 0.82 ± 0.15 , no-LBP: 0.92 ± 0.10 , $p = 0.003$). There were no significant differences on the lumbar spine extension, flexion, and rotation ROM ($p > 0.05$).

For hip ROM, the LBP group had significantly greater side-to-side asymmetry in the total hip rotation ROM (LBP: 0.95 ± 0.03 , no-LBP: 0.97 ± 0.04 ,

Table 2
Isokinetic Trunk Strength (means \pm standard deviations)

	LBP (n = 30)	No-LBP (n = 30)	p
Trunk extension (%BW)	351.3 \pm 72.2	405.2 \pm 67.0	0.008*
Trunk flexion (%BW) [#]	238.1 \pm 43.3	241.1 \pm 49.7	0.734
Trunk extension/flexion ratio [#]	1.50 \pm 0.33	1.75 \pm 0.42	0.003*
Trunk rotation right (%BW)	139.8 \pm 24.9	143.6 \pm 29.7	0.634
Trunk rotation left (%BW)	136.3 \pm 27.4	141.0 \pm 28.6	0.571
Trunk rotation side-to-side symmetry	0.93 \pm 0.06	0.91 \pm 0.06	0.294

%BW = percent body weight; *represents significant group differences; [#]Wilcoxon tests were used.

$p=0.037$). Other hip ROM variables were not statistically different between groups.

4. Discussion

The purpose of this study was to compare trunk strength, lumbar spine active ROM, and hip passive ROM between helicopter pilots with and without a self-reported history of LBP. It was hypothesized that pilots with a history of LBP would exhibit decreased muscle performance and ROM, and greater side-to-side asymmetry when compared to matched pilots without a self-reported history of LBP. The hypotheses were partially supported as trunk extension strength, trunk extension/flexion strength ratio, and lumbar spine lateral flexion ROM were significantly less and side-to-side asymmetries in lumbar spine lateral flexion and hip rotation ROM were significantly greater in the LBP group. The results from the current investigation are clinically important for developing pilot-specific interventions that are targeted to address trunk extension muscular strength and extension/flexion ratio, lumbar spine lateral flexion ROM, lumbar spine rotation, lateral flexion, and hip rotation side-to-side ROM differences to prevent LBP.

4.1. Trunk strength

The current trunk flexion and extension strength values were comparable with a previous study we performed examining trunk strength in groups of individuals with LBP [36]. Tsai et al. [36] compared isokinetic trunk flexion, extension, and rotation strength between golfers with and without a history of LBP. Similar to the current findings, the authors reported that golfers with LBP exhibited significantly weaker trunk extension strength while no differences were observed in other trunk strength variables [36]. The current investigation also revealed that the trunk extension/flexion strength ratio was significantly lower in the LBP group. Lower trunk extension/flexion strength ratio was identified as a risk factor for LBP in a prospective study [22]. Based on the current results, lower trunk strength ratio is likely a reflection of significant deficit in trunk extension strength in pilots with a history of LBP.

Trunk extensor muscles play a critical role in minimizing excessive loading on the lumbar spine while in helicopters. Due to the confined cockpit space, pilots must flex the trunk forwards, inducing thoracic and

lumbar spine flexion [28]. It has been suggested that the trunk extensor muscles must be activated isometrically to limit excessive flexion and abnormal spinal alignment [28]. Clinically, adequate trunk extensor muscle performance likely plays an essential role in preventing excessive flexion displacement of the spine. Limiting excessive flexion displacement can limit excessive tensile forces being imposed on posterior structures of the spine and limit excessive compression forces being imposed on the anterior structures of the spine. Thus, adequate trunk extensor muscle performance can be important in shielding the lumbar spine from excessive loading that potentially contributes to repetitive microtrauma and ongoing LBP.

Contrary to our hypothesis, trunk rotation strength and side-to-side symmetry were not significantly different between groups. The current trunk rotation strength values were comparable with our previous studies [31, 36]. The absence of between-group differences in trunk rotation strength may be explained by the predominant plane-of-motion in which helicopter pilots function. Greater trunk rotation strength side-to-side asymmetry has been reported in professional golfers [2]. When compared to a golf swing, flying a helicopter does not require as much trunk rotation peak muscular strength. Instead, helicopter pilots must maintain awkward sitting posture in a confined cockpit for an extended period of time, resulting gradual increases lumbar muscle activities more on the right side than the left side [24].

4.2. Lumbar spine and hip flexibility

Previous research has produced conflicting results in terms of ROM in subjects with LBP. Gomez [17] and Keeley et al. [21] have reported an overall trend of increased lumbar spine ROM in individuals with current LBP. In contrast, Mellin [25] and Boline et al. [5] have reported decreased lumbar spine ROM in those with a history of LBP and current LBP. Differences in definitions of LBP as well as population differences and methodological differences to measure lumbar spine ROM may be responsible for mixed findings. With the subjects and methodology used in the current study, lumbar spine ROM values were comparable with previous studies [21, 26, 33]. Reduced lumbar spine ROM in all directions was observed when comparing the LBP group to the no-LBP group; however, only lateral flexion ROM was significantly different between groups. The current results were partially in line with the study by Mellin [25] who reported lumbar extension and

Table 3
Lumbar Spine Active Range-of-Motion (means \pm standard deviations)

	LBP (n = 30)	No-LBP (n = 30)	p
Extension ($^{\circ}$)	47.6 \pm 8.1	49.9 \pm 7.3	0.239
Flexion ($^{\circ}$)	17.1 \pm 7.3	19.7 \pm 8.5	0.241
Right lateral flexion ($^{\circ}$)	21.6 \pm 4.1	26.2 \pm 4.6	0.001*
Left lateral flexion ($^{\circ}$)	23.1 \pm 4.4	26.6 \pm 4.7	0.009*
Lateral flexion side-to-side symmetry	0.91 \pm 0.07	0.95 \pm 0.05	0.009*
Right rotation ($^{\circ}$) [#]	9.4 \pm 3.3	11.4 \pm 4.0	0.066
Left rotation ($^{\circ}$) [#]	9.5 \pm 3.0	10.8 \pm 3.8	0.114
Rotation side-to-side symmetry [#]	0.82 \pm 0.15	0.92 \pm 0.10	0.003*

*Represents significant group differences; [#]Wilcoxon tests were used.

Table 4
Hip Passive Range-of-Motion (means \pm standard deviations)

	LBP (n = 30)	No-LBP (n = 30)	p
Right internal rotation ($^{\circ}$)	46.9 \pm 9.0	46.9 \pm 10.4	0.994
Left internal rotation ($^{\circ}$) [#]	46.7 \pm 9.2	45.8 \pm 11.3	0.704
Internal rotation side-to-side symmetry	0.92 \pm 0.06	0.92 \pm 0.06	0.589
Right external rotation ($^{\circ}$)	60.1 \pm 7.7	60.6 \pm 9.3	0.845
Left external rotation ($^{\circ}$)	60.7 \pm 7.9	61.3 \pm 9.8	0.837
External rotation side-to-side symmetry	0.95 \pm 0.05	0.95 \pm 0.04	0.749
Right total rotation ($^{\circ}$) [#]	107.0 \pm 14.5	107.5 \pm 17.6	0.593
Left total rotation ($^{\circ}$) [#]	107.4 \pm 14.9	107.1 \pm 17.6	0.905
Total rotation side-to-side symmetry	0.95 \pm 0.03	0.97 \pm 0.04	0.037*

*Represents significant group differences; [#]Wilcoxon tests were used.

lateral flexion ROM were significantly reduced in young civilian males with a history of LBP. It was interesting to note that the LBP group also had greater side-to-side asymmetry in lateral flexion and rotation ROM than the no-LBP group. In a helicopter, the left arm and hand are used to control a lift/drop lever located to the left of the pilot's seat [16]. Sideways reaching is associated with side-bending and rotation to the ipsilateral side in order to correctly and more easily position the hand for the task [1]. It is possible that the current observation might be related to adaptations that result from a task-induced need to side-bend and rotate to the left more than the right, resulting in greater asymmetry.

In addition to lumbar spine ROM, hip internal, external, and total rotation ROM were evaluated. Contrary to our hypothesis, most hip ROM variables were not statistically different between groups, except for total rotation side-to-side symmetry. The current hip rotation ROM values were comparable with one study [8]; however, the values were higher when compared other studies [19, 27]. Based on previous work, individuals with a history of LBP consistently demonstrate decreased hip rotation ROM when compared to individuals without a history of LBP [19, 27]. Civilians with a history of LBP typically possess more external

rotation ROM than internal rotation [19, 27]. Subjects in these studies were civilian athletes predominantly engaged in standing-related physical activities (e.g., golf, racquet sports) [19, 27]. In contrast, subjects in the current study were engaged in seated physical activities for prolonged periods of time. Thus, the biomechanical contributors to LBP in the present sample may be different to those in athletes or members of the general population, and may explain the lack of significant findings when compared to past work. The only significant variable (side-to-side symmetry in total hip rotation ROM) may require continued investigation to see if the hip asymmetry in military pilots might predict future recurrence or increased severity of LBP.

4.3. Limitations

There are several limitations to the current study. Military helicopter pilots face external factors that are unique to their occupation (i.e., combat gear, long flight-hours, night flight-hours with night-vision goggles and counterweight, small cockpit space, awkward flight posture, engine vibration and noise, and environmental factors). All pilots in the LBP group had a history of self-reported LBP, but everyone was free of LBP at the

time of testing. Pilots with severe or ongoing LBP may have different musculoskeletal characteristics. Differences in subject samples (military helicopter pilots vs. civilian non-pilots) and LBP (a history of LBP in 12 months vs. current LBP) make comparisons between studies difficult. It also is important to acknowledge that musculoskeletal characteristics in the LBP group could have changed over time, and so their physical presentation at the time of testing may have been different than their presentation during a recurrent episode of LBP. The current pain group reported their past worst episode of LBP scored a mean 18.3% on OSW disability index, which can be interpreted as 'minimal disability' [12]. Another limitation of this study is the use of subjects' self-report of their LBP experience. The OSW is typically intended for use with patients and/or research subjects with a current episode of LBP versus a past episode of LBP [13]. Recall bias could have influenced subjects' perception of their LBP experience. Future studies of military pilots should expand subject selection to include those who currently suffer LBP.

5. Conclusion

The current investigation revealed differences in musculoskeletal characteristics between military helicopter pilots with and without a self-reported history of LBP. These deficits in trunk strength, lumbar spine, and hip ROM as well as greater bilateral asymmetry, however, cannot be identified as a cause or as an effect of LBP. Nevertheless, it is useful to compare musculoskeletal characteristics of those with and without LBP in order to formulate clinical interventions that may, in turn, be effective in reducing LBP prevalence, severity, and disability. Interventions that are targeted to address lumbopelvic muscle performance and ROM impairments have been shown to be clinically effective in reducing the effects of LBP [14]. Additional research on potentially modifiable sensorimotor characteristics (e.g., trunk proprioception, trunk muscle activation patterns, seated balance) also is warranted to develop a more complete picture of the physical status of military helicopter pilots with and without history of LBP.

Acknowledgments

This work was supported by the U.S. Army Medical Research and Materiel Command under Award No. W81XWH-11-2-0097. Opinions, interpretations, conclusions, and recommendations are those of the

author and are not necessarily endorsed by the U.S. Army.

References

- [1] Allread WG, Marras WS, Parnianpour M. Trunk kinematics of one-handed lifting, and the effects of asymmetry and load weight. *Ergonomics* 1996;39(2):322-34.
- [2] Bae JH, Kim DK, Seo KM, Kang SH, Hwang J. Asymmetry of the isokinetic trunk rotation strength of Korean male professional golf players. *Ann Rehabil Med* 2012;36(6):821-7.
- [3] Barbee Ellison J, Rose SJ, Sahrman SA. Patterns of hip rotation range of motion: A comparison between healthy subjects and patients with low back pain. *Phys Ther* 1990;70(9):537-41.
- [4] Bayramoglu M, Akman MN, Kilinc S, Cetin N, Yavuz N, Ozker R. Isokinetic measurement of trunk muscle strength in women with chronic low-back pain. *Am J Phys Med Rehabil* 2001;80(9):650-5.
- [5] Boline PD, Keating JC, Jr, Haas M, Anderson AV. Interexaminer reliability and discriminant validity of inclinometric measurement of lumbar rotation in chronic low-back pain patients and subjects without low-back pain. *Spine* 1992;17(3):335-8.
- [6] Bridger RS, Groom MR, Jones H, Pethybridge RJ, Pullinger N. Task and postural factors are related to back pain in helicopter pilots. *Aviat Space Environ Med* 2002;73(8):805-11.
- [7] Chesworth BM, Padfield BJ, Helewa A, Stitt LW. A comparison of hip mobility in patients with low back pain and matched healthy subjects. *Physiother Can* 1994;46(4):267-74.
- [8] Cibulka MT, Sinacore DR, Cromer GS, Delitto A. Unilateral hip rotation range of motion asymmetry in patients with sacroiliac joint regional pain. *Spine* 1998;23(9):1009-15.
- [9] Cleland JA, Childs JD, Whitman JM. Psychometric properties of the Neck Disability Index and Numeric Pain Rating Scale in patients with mechanical neck pain. *Arch Phys Med Rehabil* 2008;89(1):69-74.
- [10] Davarian S, Maroufi N, Ebrahimi I, Farahmand F, Parnianpour M. Trunk muscles strength and endurance in chronic low back pain patients with and without clinical instability. *J Back Musculoskelet Rehabil* 2012;25(2):123-9.
- [11] Delitto A, Rose SJ, Crandell CE, Strube MJ. Reliability of isokinetic measurements of trunk muscle performance. *Spine* 1991;16(7):800-3.
- [12] Fairbank JC, Couper J, Davies JB, O'Brien JP. The Oswestry low back pain disability questionnaire. *Physiotherapy* 1980;66(8):271-3.
- [13] Fairbank JC, Pynsent PB. The Oswestry Disability Index. *Spine* 2000;25(22):2940-52; discussion 52.
- [14] Fritz JM, Delitto A, Erhard RE. Comparison of classification-based physical therapy with therapy based on clinical practice guidelines for patients with acute low back pain: A randomized clinical trial. *Spine* 2003;28(13):1363-71; discussion 72.
- [15] Fritz JM, Irrgang JJ. A comparison of a modified Oswestry Low Back Pain Disability Questionnaire and the Quebec Back Pain Disability Scale. *Phys Ther* 2001;81(2):776-88.
- [16] Gaydos SJ. Low back pain: Considerations for rotary-wing aircrew. *Aviat Space Environ Med* 2012;83(9):879-89.
- [17] Gomez TT. Symmetry of lumbar rotation and lateral flexion range of motion and isometric strength in subjects with and without low back pain. *J Orthop Sports Phys Ther* 1994;19(1):42-8.

- [18] Hansen OB, Wagstaff AS. Low back pain in Norwegian helicopter aircrew. *Aviat Space Environ Med* 2001;72(3):161-4.
- [19] Harris-Hayes M, Sahrman SA, Van Dillen LR. Relationship between the hip and low back pain in athletes who participate in rotation-related sports. *J Sport Rehabil* 2009;18(1):60-75.
- [20] Holmstrom E, Moritz U, Andersson M. Trunk muscle strength and back muscle endurance in construction workers with and without low back disorders. *Scand J Rehabil Med* 1992;24(1):3-10.
- [21] Keeley J, Mayer TG, Cox R, Gatchel RJ, Smith J, Mooney V. Quantification of lumbar function. Part 5: Reliability of range-of-motion measures in the sagittal plane and an *in vivo* torso rotation measurement technique. *Spine* 1986;11(1):31-5.
- [22] Lee JH, Hoshino Y, Nakamura K, Kariya Y, Saita K, Ito K. Trunk muscle weakness as a risk factor for low back pain. A 5-year prospective study. *Spine* 1999;24(1):54-7.
- [23] Lee JH, Ooi Y, Nakamura K. Measurement of muscle strength of the trunk and the lower extremities in subjects with history of low back pain. *Spine* 1995;20(18):1994-6.
- [24] Lopez-Lopez JA, Vallejo P, Rios-Tejada F, Jimenez R, Sierra I, Garcia-Mora L. Determination of lumbar muscular activity in helicopter pilots: A new approach. *Aviat Space Environ Med* 2001;72(1):38-43.
- [25] Mellin G. Decreased joint and spinal mobility associated with low back pain in young adults. *J Spinal Disord* 1990;3(3):238-43.
- [26] Mellin G, Kiiski R, Weckstrom A. Effects of subject position on measurements of flexion, extension, and lateral flexion of the spine. *Spine* 1991;16(9):1108-10.
- [27] Murray E, Birley E, Twycross-Lewis R, Morrissey D. The relationship between hip rotation range of movement and low back pain prevalence in amateur golfers: An observational study. *Phys Ther Sport* 2009;10(4):131-5.
- [28] Pelham TW, White H, Holt LE, Lee SW. The etiology of low back pain in military helicopter aviators: Prevention and treatment. *Work* 2005;24(2):101-10.
- [29] Ravenek MJ, Bryson-Campbell MM, Shaw L, Hughes ID. Perspectives on prevention, assessment, and rehabilitation of low back pain in WORK. *Work* 2010;35(3):269-82.
- [30] Redmond SA, Wilcox SL, Campbell S, Kim A, Finney K, Barr K, et al. A brief introduction to the military workplace culture. *Work* 2015;50(1):9-20.
- [31] Sell TC, Abt JP, Crawford K, Lovalekar M, Nagai T, Deluzio JB, et al. Warrior Model for Human Performance and Injury Prevention: Eagle Tactical Athlete Program (ETAP) Part I. *J Spec Oper Med* 2010;10(4):2-21.
- [32] Sell TC, Tsai YS, Smoliga JM, Myers JB, Lephart SM. Strength, flexibility, and balance characteristics of highly proficient golfers. *J Strength Cond Res* 2007;21(4):1166-71.
- [33] Sullivan MS, Dickinson CE, Troup JD. The influence of age and gender on lumbar spine sagittal plane range of motion. A study of 1126 healthy subjects. *Spine* 1994;19(6):682-6.
- [34] Thomae MK, Porteous JE, Brock JR, Allen GD, Heller RF. Back pain in Australian military helicopter pilots: A preliminary study. *Aviat Space Environ Med* 1998;69(5):468-73.
- [35] Thomas TR, Zebas CJ, Bahrke MS, Araujo J, Etheridge GL. Physiological and psychological correlates of success in track and field athletes. *Br J Sports Med* 1983;17(2):102-9.
- [36] Tsai YS, Sell TC, Smoliga JM, Myers JB, Learman KE, Lephart SM. A comparison of physical characteristics and swing mechanics between golfers with and without a history of low back pain. *J Orthop Sports Phys Ther* 2010;40(7):430-8.
- [37] van den Oord MH, De Loose V, Meeuwse T, Sluiter JK, Frings-Dresen MH. Neck pain in military helicopter pilots: Prevalence and associated factors. *Mil Med* 2010;175(1):55-60.
- [38] Van Dillen LR, Bloom NJ, Gombatto SP, Susco TM. Hip rotation range of motion in people with and without low back pain who participate in rotation-related sports. *Phys Ther Sport* 2008;9(2):72-81.

Copyright of Work is the property of IOS Press and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.