Journal of Bodywork & Movement Therapies 23 (2019) 23–31

Contents lists available at ScienceDirect

Journal of Bodywork & Movement Therapies

journal homepage: www.elsevier.com/jbmt

Original Research

A descriptive analysis of shoulder muscle activities during individual stages of the Turkish Get-Up exercise

Eric St-Onge [a], Andrew Robb [b], Tyson A.C. Beach [c], Samuel J. Howarth [a, *]

[a] Division of Research and Innovation, Canadian Memorial Chiropractic College, Toronto, ON, Canada
[b] Private Practice, Waterloo, ON, Canada
[c] Faculty of Kinesiology and Physical Education, University of Toronto, Toronto, ON, Canada

ARTICLE INFO

Article history:
Received 4 August 2017
Received in revised form
10 January 2018
Accepted 18 January 2018

Keywords:
Kettlebell
Functional exercise
Electromyography
Motor pattern

ABSTRACT

The Turkish Get-Up (TGU) is a complex and multi-planar exercise; the performer begins in a supine lying position, progresses toward upright standing through a series of 7 stages while holding a mass overhead in one hand, and returns to the original supine lying position through a reversal of the same 7 stages. A descriptive analysis of shoulder muscle activity during the TGU may provide insight toward its use in training and rehabilitation contexts. Our objectives were to: (1) describe the activity patterns from a subset of muscles that span the glenohumeral joint during individual stages of the TGU, and (2) interpret these patterns through comparisons between left- and right-side muscles, and between the up and down phases of the TGU. Twelve individuals with at least one-year experience performing the TGU were included in this study. Surface electromyographic (EMG) recordings were bilaterally obtained from 8 glenohumeral muscle groups while participants performed ten trials of the TGU with a kettlebell in their right hand. Instants representing the start and end of each TGU stage were identified from a synchronized video for each trial, and EMG activities for each muscle were integrated over the duration of each stage. Average integrated EMG and within-participant coefficients of variation were calculated. Overall, the greatest muscular demand occurred during the second (press to elbow support) and fifth (leg sweep) stages. Activities from muscles on the ipsilateral side to the kettlebell (right-side) were greater during stages when the contralateral upper limb did not contribute to supporting the body; however, contralateral (left-side) muscles were invoked during stages when the non-kettlebell-bearing forearm or hand contributed to supporting the body. The results suggest the importance of training both phases of the TGU to gain the most benefit from the exercise and highlights the asymmetric nature of the exercise, which may be particularly relevant for athletes engaged in activities with rotational demands.

1. Introduction

The Turkish Get-Up (TGU) is an example of a complex and multi-planar progression-based exercise in which the individual begins in a supine lying position, progresses toward upright standing through a series of 7 stages while holding a mass overhead in one hand, and returns to the original supine lying position through a reversal of the same 7 stages (see Fig. 1) (Ayash and Jones, 2012; Liebenson and Shaughness, 2011). Although it is difficult to ascertain the exact origins of this exercise, it has been said that Turkish wrestlers would have to competently perform this exercise over 200 years ago as part of their training (Ayash and Jones, 2012). The TGU gained popularity in the early-2000s as fitness and health professionals began to teach this exercise in their various seminars and courses. Adaptations elicited by the TGU have been purported to improve glenohumeral joint stability by challenging the neuromuscular control system to maintain the humeral head within the glenoid fossa while loading the joint throughout its large range-of-motion (Ayash and Jones, 2012). Despite its increased popularity among fitness and health professionals, empirical evaluation of the TGU and investigation of claims made about the exercise have not been conducted to date. In particular, this investigation sought to provide preliminary data to address the claim that the TGU can improve glenohumeral joint stability.

The shoulder complex represents the articulation between the

* Corresponding author. Human Performance Laboratory, McMorland Family Research Chair in Mechanobiology, Canadian Memorial Chiropractic College, 6100 Leslie Street, Toronto, M2H 3J1, ON, Canada.
E-mail address: showarth@cmcc.ca (S.J. Howarth).

https://doi.org/10.1016/j.jbmt.2018.01.013
1360-8592/

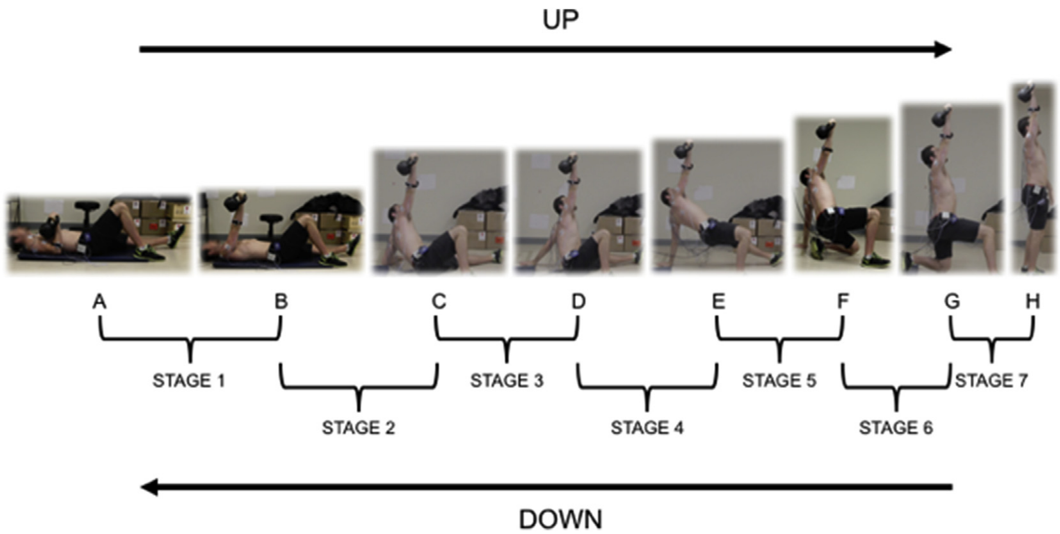

Fig. 1. Still-frame images that illustrate the participant positions at the start and end of each of the seven stages during the Turkish Get-Up exercise. Progressing from left to right illustrates the up phase of the exercise. The down phase is illustrated by progressing from right to left.

scapula, clavicle, sternum, humerus, and ribcage that comprise four joints (glenohumeral, acromioclavicular, sternoclavicular, and scapulothoracic). The musculature of the shoulder complex is modeled using a set of 38 muscle elements representing 23 muscles that act as stabilizers and movers (Dickerson et al., 2007; Escamilla et al., 2009; Hess, 2000). Of particular relevance to this study are the 11 muscles (biceps brachii, teres major, teres minor, subscapularis, supraspinatus, infraspinatus, latissimus dorsi, coracobrachialis, triceps brachii, deltoid, and pectoralis major) that, by virtue of their skeletal attachments and lines-of-action, directly influence the stability and biomechanical loading of the glenohumeral joint. Four of these muscles comprise the rotator cuff (teres minor, subscapularis, supraspinatus, and infraspinatus), which primarily provides intrinsic control to the humeral head on the glenoid fossa of the scapula. Weakness or impairment of the rotator cuff muscles likely decreases the capacity of the shoulder musculature to stabilize the glenohumeral joint (Hess, 2000). Other muscles that do not cross the glenohumeral joint (e.g. serratus anterior, trapezius, rhomboid major, rhomboid minor) can indirectly impact glenohumeral joint biomechanics by their attachments to the scapula. Proper patterns of neuromuscular coordination and control are particularly important for movements such as scapular upwards rotation, which is relevant to athletes and workers who are exposed to significant overhead demands (e.g. volleyball players, shot-putters, wrestlers, tactical officers) (Leatherwood et al., 2014); however, the TGU may not be appropriate for individuals with painful symptomatology in the shoulder. As suggested by the postures depicted in Fig. 1, moving through different stages of the TGU imposes significant demands on the neuromuscular control system to coordinate muscles that directly and indirectly stabilize the glenohumeral joint across a wide array of shoulder complex configurations.

There is a growing interest from preventive and rehabilitative perspectives to enhance stability of the glenohumeral joint through training, given that the glenohumeral joint is inherently unstable and is the most commonly dislocated joint in the body (Reinold et al., 2010). Neuromuscular contributions to joint stability and stiffness can be quantified, using detailed musculoskeletal models, by combining surface electromyographic (sEMG) recordings with additional kinetic and kinematic data (Favre et al., 2012; Labriola et al., 2005; Potvin and Brown, 2005); however, sEMG data by themselves are also useful for training and rehabilitation purposes to describe the magnitude, extent, and timing of muscular activity during exercise (Escamilla et al., 2009). Thus, a descriptive analysis of shoulder muscle activities when executing the TGU may provide new insights to direct its use in training and rehabilitation contexts.

Shoulder muscle activation has been descriptively analyzed during the performance of several exercises used to improve glenohumeral stability (Escamilla et al., 2009). Shoulder exercises (e.g. standing internal rotation at 90 degrees of humeral abduction to isolate the teres major, or abduction in the scapular place to isolate the supraspinatus) are often used to isolate a specific glenohumeral joint posture (e.g., isometric abduction), motion (e.g., internal/external rotation), and/or muscle group (e.g., abductors, internal/external rotators, etc.) (Decker et al., 2003, 1999; Ellenbecker and Cools, 2010; Reinold et al., 2004). Although isolation exercises may be justified in some cases (e.g., to facilitate blood flow after injury), these exercises may not elicit the adaptations in neuromuscular coordination patterns needed to safely and effectively control movement during activities of daily living and sport (Escamilla and Andrews, 2009). Consequently, it is advisable to progress to more complex exercises that challenge the ability of the performer to coordinate and control their body in a variety of positions, at multiple speeds, and with external load.

Recent pedagogy in rehabilitation and fitness training advocates that using exercises that combine complex and multiplanar movements are more likely train and reinforce motion and motor patterns that transfer to “functional” activities (Liebenson, 2002). Collectively, the 14 stages in the TGU can be viewed as a continuously varying set of functional movement “problems” that must be “solved” by the neuromuscular control system. Neuromuscular solutions are influenced by a host of dynamic and interacting task, environmental, and personal factors (Davids et al., 2003), but are observable via analysis of the patterns of sEMG activity from muscles that cross the glenohumeral joints. Thus, the primary goal of this investigation was to describe the activity patterns from a subset of muscles that span the glenohumeral joint during individual stages of the TGU. A secondary goal was to interpret these patterns through comparisons between left- and right-side muscles, and between the up and down phases of the TGU.

2. Methods

2.1. Participants

Twelve right-handed adults (6 men, 6 women) were recruited to participate in the current study (see Table 1). Participants were recruited from the institution's general student population, and through a call-to-action on the weekly Agatsu (a company for continuing education for personal trainers) electronic newsletter (October 7th, 14th, and 21st 2015). All participants had experience performing the TGU for at least 1-year, and reported not having sustained any known musculoskeletal injury within the 6-months prior to data collection. Each participant read and signed an informed consent document prior to data collection. The instrumentation and protocols for this investigation were approved by the institutional research ethics board prior to beginning data collection.

Fig. 2. Illustration of the bilateral anterior (A) and posterior (B) sEMG electrode placements.

2.2. Instrumentation

2.2.1. Surface electromyography

Activation from 8 bilateral muscles surrounding the shoulder complex were obtained using sEMG (see Fig. 2). Specific muscles were: pectoralis major (~2 cm below the clavicle, and medial to the axillary fold), anterior deltoid (muscle belly, anterior shoulder), posterior deltoid (muscle belly, posterior shoulder), upper trapezius (midway between the C7 spinous, and the acromion), latissimus dorsi (~4 cm below the inferior angle of the scapula), infraspinatus (~4 cm below the spine of the scapula), biceps (middle of the anterior arm), and triceps (posterior aspect of arm, and ~2 cm superior to the tendon portion of the triceps) (Cram et al., 1998).

Skin overlying the targeted muscles was shaved with a disposable razor and cleansed with rubbing alcohol prior to electrode application. Parallel bar electrodes with a fixed (10 mm) distance between the bars (DE-2.1, Delsys Inc., Boston, MA, USA; CMRR = 92 dB at 60 Hz, Input impedance = 10^6 GΩ) were affixed to the preconditioned areas of skin using custom double-sided adhesives, and Hypafix tape. Each electrode was oriented so that its parallel bars were perpendicular to the presumed direction of the underlying muscle's fibers. Analog sEMG signals were bandpass filtered (20–450 Hz), and amplified (Bagnoli-16, Delsys Inc., Boston, MA, USA) prior to being digitally sampled at a rate of 2048 Hz using a ±10V range on a 16-bit analog-to-digital conversion board (ODAUIII, Northern Digital Inc., Waterloo, ON, Canada).

2.2.2. Synchronized video

Video recordings for all TGU trials were also obtained at a rate of 60 Hz using a single digital video camera. The camera was positioned to capture video of the TGU trials in the sagittal plane (see Fig. 3). A light emitting diode (LED) was also visible in the video frame. The LED was connected to a trigger, which became active at the initiation of data collection on the computer that was responsible for recording the sEMG data.

2.3. Protocol

A consistent description of the TGU was reviewed with each participant by an investigator with 9 years of experience performing the TGU prior to instrumentation and data collection. This was done to increase homogeneity in TGU performance across study participants, due to minor variations of the TGU exercise that exist. Specifically, each repetition of the TGU was performed with participants holding a kettlebell in their right hand, and followed a sequence of 14 stages (7 progressing from lying supine to upright standing, and 7 progressing from upright standing to lying supine) (Liebenson and Shaughness, 2011). The exercise began with participants lying supine, and holding the kettlebell in their right hand. From this position, the kettlebell was pressed upwards (supine press – Stage 1, see Fig. 1A–B). Participants then raised their upper

Table 1
Descriptive participant demographics.

Participant	Gender	Age	Height (cm)	Mass (kg)	Experience (Years)	Study (kg)	1RM (kg)	Study percent of 1RM
1	Female	31	160	49.9	8.0	8	20	40
2	Female	46	156	51.3	8.0	8	16	50
3	Female	22	184	72.6	4.0	8	16	50
4	Female	26	163	70.3	2.5	8	20	40
5	Female	28	175	68.0	6.0	8	24	33
6	Female	44	160	60.8	5.0	8	24	33
7	Male	27	185	83.9	5.0	16	36	44
8	Male	44	175	87.5	7.0	16	32	50
9	Male	29	172	88.5	7.0	16	30	53
10	Male	26	180	84.4	4.0	16	32	50
11	Male	28	185	78.9	5.0	16	50	32
12	Male	28	175	72.6	1.0	16	30	53
Average (SD)		31.6 (8.2)	173 (10)	72.4 (13.2)	5.2 (2.1)		27.5 (9.7)	44 (8)

1RM = self-reported maximum mass used to complete a single repetition of the Turkish Get-Up exercise.

Fig. 3. Still-frame image obtained from video recording during a single repetition of the Turkish Get-Up exercise. The video recording and muscle activity data were synchronized by noting the timecode at which a light emitting diode indicator was activated (inset).

body off the ground by partially supporting their mass on their left elbow (press to elbow – Stage 2, see Fig. 1B–C). The left upper extremity support was changed from the elbow to the hand (Stage 3), and the hips were subsequently extended (high bridge – Stage 4) to allow the left leg to pass underneath the body (leg sweep – Stage 5) so that the participant was in a half-kneeling position (leg sweep to half-kneeling – Stage 6) (see Fig. 1C–G). Finally, the participant stood up from the half-kneeling position, while holding the kettlebell overhead (half-kneeling to stand – Stage 7, see Fig. 1G–H).

Participants practiced the TGU (self-selected number of repetitions with a minimum of one repetition), as described, prior to sEMG instrumentation. Each participant performed each repetition of the TGU at their self-selected pace. Males performed the TGU with a 16 kg kettlebell, whereas females used an 8 kg kettlebell. These masses were consistent with those recommended for individuals performing the TGU with an intermediate level of proficiency (Ayash and Jones, 2012). Our participants were considered to have had an intermediate level of proficiency given that they had a minimum of 1-year experience performing the TGU. The aforementioned investigator observed all practice and data collection trials of the TGU to ensure that the participants performed the exercise according to the aforementioned description.

After having completed the initial set of practice trials, and after application of the sEMG instrumentation, participants performed a series of maximal voluntary isometric contractions (MVICs) against manually applied matching resistance. Specific contractions were: elbow flexion with elbow flexed 90° (biceps), elbow extension with elbow flexed 90° (triceps), shoulder forward flexion with humerus in anatomical neutral position (anterior deltoid), shoulder backward extension with humerus in anatomical neutral position (posterior deltoid), humerus external rotation with humerus at neutral and elbow flexed 90° (infraspinatus), humerus adduction in transverse plane with humerus abducted 90° and elbow flexed 90° (pectoralis major), humerus adduction in frontal plane with humerus abducted 90° and elbow flexed 90° (latissimus dorsi), and shoulder elevation (trapezius). Each of these contractions were performed twice bilaterally with a minimum of 1-min of rest in between contractions to mitigate the potential for muscular fatigue. The goal of the MVICs was to record the maximum myoelectric voltage of voluntary contraction for each muscle, which were used as participant-specific normalization factors during post-processing of the sEMG data (Lehman and McGill, 1999). Resting myoelectric amplitudes, to allow for removal of baseline activity during post-processing, were also obtained from two trials where participants laid supine and prone on a treatment table surface.

Participants were then asked to practice the TGU again to familiarize themselves with the instrumentation for a minimum of one repetition. Acquisition of sEMG data during the TGU began after participants indicated that they were comfortable with performing the TGU, as described, and while wearing the sEMG instrumentation. sEMG data were obtained from each participant during 10 self-paced repetitions of the TGU, and supervised by the experienced investigator. After each trial, the investigator asked participants to subjectively rate their performance of the repetition as either satisfactory or unsatisfactory. If a repetition was deemed "unsatisfactory" by participants, an additional repetition was performed. Data from any "unsatisfactory" repetition were not used in subsequent post-processing and analyses. Participants were required to rest for a minimum of 2-min in between each repetition. Additional rest was provided at the request of participants to avoid fatigue.

2.4. Data processing and analysis

Initial post-collection processing of the sEMG data was performed using Visual3D (Version 5.02, C-Motion Inc., Germantown, MD, USA). All raw sEMG data from each MVIC, resting, and TGU trial were full-wave rectified and digitally filtered using a single pass of a Butterworth filter with a cutoff frequency of 2.5 Hz to create a linear envelope (Brereton and McGill, 1998). The minimum sEMG amplitudes from the linear envelopes of the data obtained during the resting trials, representing resting baseline activity, were subtracted from the sEMG data obtained during each MVIC and TGU trial. After removing the resting baseline activity, the linear envelopes of the sEMG data obtained during the TGU trials were normalized to the maximum sEMG amplitude for each muscle that was obtained during the MVIC trials. Thus, time-varying sEMG data from each TGU trial were expressed as a percentage of MVIC.

Timecodes for the occurrence of LED illumination, signifying the initiation of sEMG data collection, as well as the start and end of each TGU stage were visually identified and recorded from the video of all TGU trials by an investigator (see Fig. 3). Events representing the start and end of each stage for each TGU trial were then determined with respect to the time at which LED illumination occurred (see Fig. 4). These relative times represented the elapsed time in the sEMG data that coincided with the occurrence of the start and end of each stage for each TGU trial.

Normalized sEMG data from each TGU trial were then exported from Visual3D to Matlab (Version R2013b, The Mathworks Inc., Natick, MA, USA). sEMG data from each of the monitored muscles, and each TGU trial were numerically integrated across the durations of each stage using the start and end times for each stage (see Fig. 4). Integrated sEMG (iEMG) data were used to evaluate total demand imposed on each monitored muscle during each stage during each TGU trial.

For each participant, the average and standard deviation of iEMG values were determined across each of their 10 TGU trials for each of the monitored muscles, and for each of the 14 stages. Coefficients of variation (i.e., ratios of the standard deviations to the averages) were also calculated for each of the monitored muscles, and for each of the 14 stages. The coefficients of variation represented a measure of the within-participant consistency of iEMG during each stage between TGU trials. Average durations for each stage were also determined for each participant across the 10 TGU trials. Group averages and standard deviations for the average iEMG and coefficients of variation for each monitored muscle, as well as the durations for each of the 14 stages were determined.

3. Results

3.1. Integrated EMG

Summary measures of iEMG for individual stages during the up and down phases of the TGU are reported in Tables 2 and 3. Overall, the greatest muscular demand was imposed during the second (press to elbow support) and fifth (leg sweep) stages. Activities from muscles on the right side of the body were greater during stages where the left upper limb was not contributing to support the body; however, muscles on the left side were invoked during stages (2–5) when either the left forearm or hand contributed to supporting the body. In particular, the total muscular challenge on the left side was, on average, 42% greater during the fourth and fifth stages. The right triceps exhibited the greatest total challenge throughout the TGU, and the latissimus dorsi was the primary contributor on the left side of the body.

Muscular challenge during the up and down phases of the TGU were generally similar throughout the fourth to seventh stages. On average the overall activity in stages 1, 2, and 3 was 29% lower during the down phase of the TGU.

3.2. Within-participant coefficients of variation in integrated EMG

Summary measures for the within-participant coefficients of variation for individual stages during the up and down phases of the TGU are reported in Tables 4 and 5. The largest coefficients of variation were demonstrated for muscles that were minimally active during the given stage (e.g. left side muscles during stage 1). Consistency in activation was greater for muscles on the right side of the body with 51% (57/112; 8 muscles/stage * 14 stages = 112) of right side muscles throughout all stages having a coefficient of variation that was below 25%, compared to 27% (30/112) on the left side. The coefficient of variation was also larger in 75% (84/112; 16 muscles/stage * 7 stages = 112) of cases during the down phase of the TGU.

3.3. Stage durations

The second stage (press to elbow support) took the longest for participants to complete (see Fig. 5). Differences between the up and down phases were noted for stages 3, 4, and 6. Specifically, the

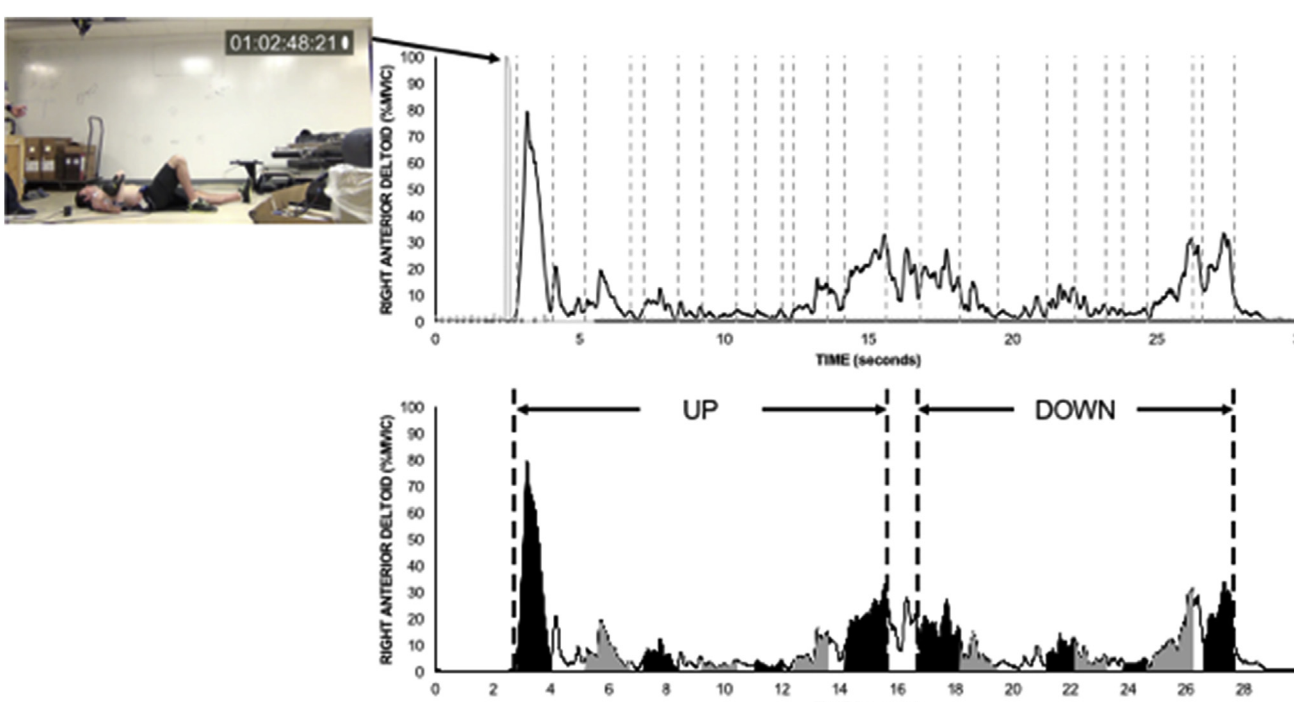

Fig. 4. Exemplar time-series data for activation of the right anterior deltoid during a single repetition of the Turkish Get-Up exercise. The solid gray line indicates the onset of the light emitting diode for synchronizing the video and muscle activity data. Vertical gray dashed lines represent the start and end instants for individual stages. Black and gray shaded regions illustrate the area underneath the muscle activation time-series data between the start and end instants for each stage (i.e. integrated muscle activity).

Table 2
Average integrated muscle activities during each stage of the upward phase of the Turkish Get-Up exercise. Standard deviations are presented within parentheses.

Stage	Muscle															
	Right								Left							
	PM	AD	BIC	TRI	PD	UT	INF	LD	PM	AD	BIC	TRI	PD	UT	INF	LD
1	29.5	38.4	7.7	31.4	5.2	4.8	21.0	3.9	1.5	1.5	0.3	1.5	1.1	0.5	0.9	2.5
	(12.3)	(12.6)	(6.5)	(37.9)	(3.7)	(4.0)	(10.7)	(4.1)	(1.0)	(1.7)	(0.2)	(1.0)	(1.9)	(0.6)	(0.8)	(2.9)
2	16.9	24.8	12.9	43.5	36.6	32.5	47.2	11.7	10.1	11.7	4.0	21.8	40.6	45.2	19.6	60.7
	(11.8)	(16.4)	(7.7)	(26.0)	(17.2)	(21.3)	(12.4)	(9.7)	(4.1)	(8.8)	(2.0)	(8.2)	(13.6)	(21.7)	(6.8)	(26.5)
3	6.2	23.7	10.6	28.7	28.6	37.7	21.7	7.0	4.8	3.4	5.0	49.1	17.4	14.6	18.1	42.1
	(10.9)	(14.8)	(6.1)	(16.6)	(15.1)	(19.7)	(9.6)	(7.9)	(3.3)	(2.4)	(3.1)	(10.9)	(8.5)	(7.1)	(9.2)	(18.2)
4	3.9	12.2	7.5	23.5	16.1	17.2	13.6	3.8	5.4	29.8	17.7	29.8	13.5	10.3	12.1	26.0
	(4.3)	(9.6)	(6.7)	(11.0)	(8.1)	(13.6)	(7.6)	(3.3)	(3.2)	(20.0)	(15.7)	(10.6)	(8.3)	(6.2)	(6.3)	(14.3)
5	6.3	8.7	12.4	27.6	33.5	19.1	22.5	15.2	6.9	41.7	34.4	39.0	33.9	11.8	26.4	19.3
	(8.8)	(6.6)	(9.1)	(14.7)	(20.5)	(16.9)	(12.4)	(10.7)	(3.8)	(33.4)	(35.6)	(15.5)	(17.7)	(9.9)	(14.4)	(15.3)
6	8.9	25.6	12.6	24.8	24.2	33.8	15.1	8.8	3.3	2.9	4.0	11.3	4.8	10.8	5.4	6.0
	(9.2)	(14.9)	(9.5)	(15.5)	(16.6)	(21.7)	(5.4)	(6.6)	(1.9)	(2.5)	(3.6)	(4.7)	(3.1)	(4.1)	(3.3)	(4.2)
7	11.5	51.3	13.9	23.4	23.5	54.7	14.8	9.0	2.4	3.8	2.0	2.6	3.8	21.8	4.6	6.8
	(13.2)	(26.5)	(10.6)	(11.8)	(12.8)	(33.7)	(6.1)	(8.8)	(1.1)	(2.8)	(1.9)	(1.1)	(2.0)	(1.1)	(3.8)	(5.2)

PM = Pectoralis Major; AD = Anterior Deltoid; BIC = Biceps Brachii; TRI = Triceps Brachii; PD = Posterior Deltoid; UT = Upper Trapezius; INF = Infraspinatus; LD = Latissimus Dorsi.

Table 3
Average integrated muscle activities during each stage of the downward phase of the Turkish Get-Up exercise. Standard deviations are presented within parentheses.

Stage	Muscle															
	Right								Left							
	PM	AD	BIC	TRI	PD	UT	INF	LD	PM	AD	BIC	TRI	PD	UT	INF	LD
1	20.0	15.7	12.6	20.7	3.7	4.9	11.6	4.5	2.0	2.6	1.2	1.5	1.2	0.9	1.8	3.3
	(9.7)	(7.1)	(8.5)	(22.5)	(2.1)	(3.9)	(3.0)	(4.9)	(1.3)	(2.6)	(1.7)	(1.2)	(1.6)	(0.8)	(1.2)	(4.6)
2	21.9	27.4	12.6	36.5	20.4	18.2	35.9	12.4	12.8	9.6	3.7	17.8	21.6	20.9	13.9	27.7
	(10.4)	(13.8)	(8.6)	(30.7)	(11.9)	(14.2)	(15.2)	(11.0)	(9.1)	(6.1)	(3.8)	(12.5)	(13.1)	(16.3)	(9.8)	(18.5)
3	5.2	15.7	9.0	22.9	21.7	24.3	16.5	5.0	3.5	5.8	4.8	22.8	17.2	12.4	10.6	26.2
	(10.5)	(11.4)	(7.3)	(16.9)	(10.5)	(16.9)	(8.3)	(5.9)	(2.8)	(6.1)	(3.3)	(9.7)	(10.0)	(8.6)	(7.2)	(15.0)
4	5.6	15.4	10.2	28.3	19.8	26.0	18.3	5.4	6.4	25.9	19.7	31.7	12.2	9.2	13.7	29.7
	(7.7)	(13.0)	(8.0)	(15.5)	(10.5)	(19.1)	(8.6)	(5.7)	(4.0)	(20.8)	(15.7)	(12.5)	(8.6)	(7.1)	(7.3)	(12.8)
5	7.2	10.2	13.5	29.2	24.9	13.2	21.8	9.0	5.7	29.3	30.5	41.0	31.5	20.3	22.3	22.9
	(8.4)	(7.0)	(10.2)	(17.1)	(13.8)	(10.2)	(15.1)	(6.4)	(3.4)	(22.1)	(30.9)	(17.1)	(14.9)	(9.9)	(11.7)	(16.9)
6	6.5	18.2	10.5	27.3	29.2	26.3	17.3	9.4	2.3	3.6	4.5	13.5	13.4	16.2	9.8	4.1
	(10.2)	(12.2)	(8.1)	(15.2)	(16.8)	(15.4)	(8.4)	(7.6)	(1.2)	(1.9)	(4.3)	(4.9)	(7.5)	(5.9)	(5.6)	(2.6)
7	10.6	48.5	12.9	22.8	25.4	50.7	14.5	8.9	1.9	1.2	3.1	2.7	3.6	21.9	6.0	7.3
	(12.4)	(29.3)	(10.2)	(10.4)	(15.6)	(27.7)	(7.3)	(10.5)	(1.4)	(6.2)	(6.7)	(1.7)	(2.5)	(12.4)	(11.2)	(9.9)

PM = Pectoralis Major; AD = Anterior Deltoid; BIC = Biceps Brachii; TRI = Triceps Brachii; PD = Posterior Deltoid; UT = Upper Trapezius; INF = Infraspinatus; LD = Latissimus Dorsi.

Table 4
Average within-participant coefficients of variation for integrated muscle activities during each stage of the upward phase of the Turkish Get-Up exercise. Standard deviations are presented within parentheses.

Stage	Muscle															
	Right								Left							
	PM	AD	BIC	TRI	PD	UT	INF	LD	PM	AD	BIC	TRI	PD	UT	INF	LD
1	13.0	11.8	22.7	17.6	22.1	19.2	26.8	44.8	32.3	58.9	65.2	67.4	48.2	40.0	43.6	27.9
	(3.8)	(3.7)	(8.9)	(7.7)	(4.7)	(4.9)	(15.8)	(27.2)	(22.1)	(26.0)	(29.6)	(15.7)	(21.3)	(28.1)	(25.2)	(15.7)
2	30.1	25.2	26.8	20.4	20.1	19.6	19.5	36.2	30.7	31.8	32.6	27.1	24.8	24.8	23.2	20.1
	(14.0)	(5.8)	(8.3)	(5.6)	(8.8)	(9.5)	(7.5)	(25.9)	(12.7)	(11.8)	(10.5)	(9.3)	(11.1)	(13.2)	(17.5)	(9.5)
3	33.6	22.6	22.6	20.4	20.6	19.3	21.0	24.2	23.3	45.2	23.1	13.5	23.1	28.1	20.9	19.1
	(23.0)	(8.6)	(9.0)	(6.5)	(7.8)	(6.9)	(8.4)	(14.1)	(13.7)	(15.6)	(10.3)	(4.2)	(8.4)	(9.6)	(10.9)	(5.6)
4	31.4	33.3	29.5	23.8	29.3	33.3	23.0	33.3	22.7	22.9	31.9	16.4	32.7	35.4	19.6	24.1
	(12.5)	(11.5)	(13.2)	(10.2)	(15.3)	(11.2)	(10.7)	(24.0)	(8.7)	(8.2)	(14.4)	(6.9)	(12.5)	(8.2)	(7.0)	(8.6)
5	28.2	31.8	23.8	24.4	26.4	31.6	24.5	28.5	23.6	25.9	24.9	17.4	27.1	29.0	21.6	31.3
	(13.9)	(12.4)	(10.1)	(13.3)	(11.5)	(11.1)	(9.2)	(8.6)	(7.8)	(12.0)	(9.6)	(6.1)	(8.0)	(13.1)	(6.4)	(13.6)
6	42.4	24.7	27.4	21.1	26.2	22.2	20.3	21.1	33.1	57.6	41.9	31.0	42.9	20.8	30.8	30.7
	(28.9)	(8.7)	(10.9)	(11.1)	(8.9)	(9.4)	(7.6)	(7.2)	(10.1)	(24.9)	(14.8)	(16.5)	(10.5)	(4.4)	(7.1)	(12.0)
7	31.7	18.7	18.7	20.1	17.4	15.2	20.7	19.8	29.2	41.1	45.1	41.4	34.9	17.8	23.4	20.2
	(12.6)	(3.4)	(5.3)	(6.6)	(4.8)	(6.2)	(7.1)	(5.0)	(8.2)	(24.2)	(24.9)	(16.6)	(17.5)	(5.5)	(7.9)	(4.7)

PM = Pectoralis Major; AD = Anterior Deltoid; BIC = Biceps Brachii; TRI = Triceps Brachii; PD = Posterior Deltoid; UT = Upper Trapezius; INF = Infraspinatus; LD = Latissimus Dorsi.

Table 5
Average within-participant coefficients of variation for integrated muscle activities during each stage of the downward phase of the Turkish Get-Up exercise. Standard deviations are presented within parentheses.

Stage	Muscle															
	Right								Left							
	PM	AD	BIC	TRI	PD	UT	INF	LD	PM	AD	BIC	TRI	PD	UT	INF	LD
1	24.5	24.3	30.2	27.0	30.4	37.1	27.0	51.3	37.0	62.7	68.2	60.3	60.5	44.3	35.8	32.4
	(4.7)	(8.6)	(10.0)	(11.1)	(16.6)	(12.1)	(9.2)	(54.2)	(26.2)	(35.5)	(31.2)	(34.7)	(25.2)	(18.8)	(13.2)	(13.3)
2	36.5	26.0	30.7	26.3	28.8	34.3	19.2	45.7	39.7	43.8	45.2	45.9	37.2	31.1	34.0	37.4
	(38.4)	(13.1)	(15.5)	(9.7)	(9.9)	(29.6)	(5.6)	(43.6)	(39.2)	(24.5)	(36.8)	(37.7)	(14.2)	(11.5)	(13.1)	(13.9)
3	41.6	38.5	31.4	26.5	27.6	33.0	26.1	30.7	27.4	50.0	36.6	26.9	26.6	39.4	23.5	25.4
	(21.8)	(13.6)	(12.8)	(8.9)	(9.2)	(10.2)	(10.7)	(11.7)	(8.3)	(13.2)	(16.6)	(7.1)	(10.4)	(17.1)	(5.8)	(7.0)
4	32.6	35.9	28.7	24.2	31.7	30.6	23.7	30.4	24.8	31.2	30.6	22.3	41.4	39.7	24.2	24.0
	(13.4)	(10.6)	(9.7)	(8.2)	(20.4)	(19.2)	(9.9)	(13.1)	(7.5)	(13.9)	(10.2)	(10.0)	(12.8)	(17.4)	(8.9)	(10.6)
5	42.7	39.8	25.3	25.6	32.7	36.6	24.4	30.4	23.7	25.6	24.3	18.7	28.4	30.3	20.6	43.2
	(21.7)	(14.2)	(6.1)	(6.5)	(10.2)	(14.5)	(6.7)	(11.7)	(9.1)	(6.8)	(9.8)	(5.7)	(9.0)	(10.5)	(7.5)	(14.3)
6	35.4	35.7	23.4	24.1	30.7	28.4	26.4	32.8	29.8	44.1	43.3	29.5	24.1	24.3	27.5	36.6
	(11.2)	(10.3)	(7.0)	(7.3)	(9.7)	(10.6)	(6.4)	(19.3)	(12.0)	(39.1)	(47.2)	(16.1)	(6.6)	(11.3)	(16.7)	(14.3)
7	30.9	20.4	21.9	16.4	15.4	17.0	22.9	20.3	20.3	43.7	31.4	33.6	33.7	13.2	22.5	21.8
	(9.3)	(7.6)	(9.4)	(4.9)	(4.4)	(5.9)	(13.6)	(10.5)	(6.0)	(34.4)	(11.7)	(12.3)	(15.3)	(2.3)	(12.1)	(9.8)

PM = Pectoralis Major; AD = Anterior Deltoid; BIC = Biceps Brachii; TRI = Triceps Brachii; PD = Posterior Deltoid; UT = Upper Trapezius; INF = Infraspinatus; LD = Latissimus Dorsi.

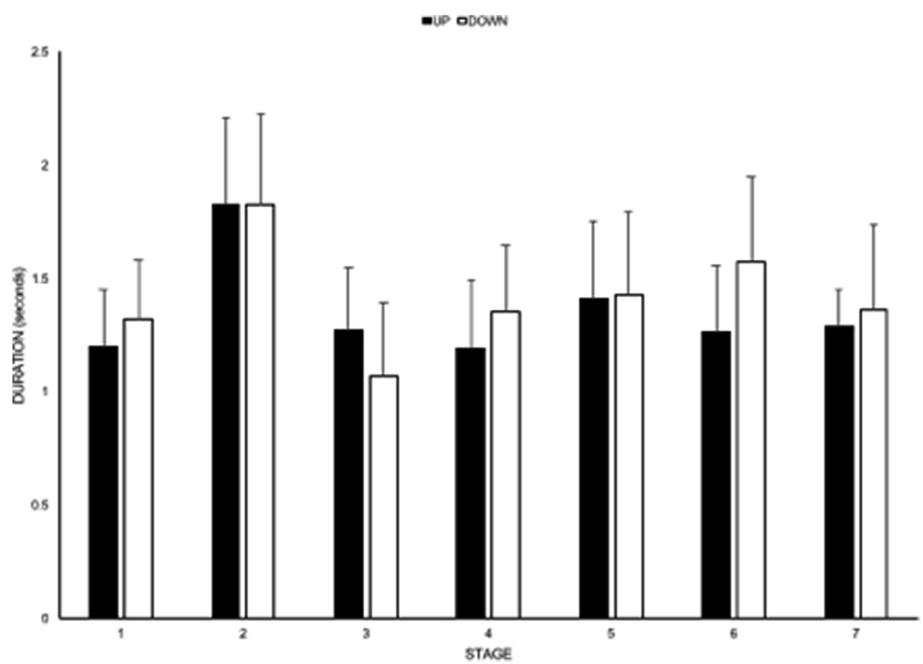

Fig. 5. Average durations for individual stages during the up (black bars) and down (white bars) phases of the Turkish Get-Up exercise. Error bars represent the standard deviation.

transition from hand to elbow support during the up phase (stage 3) was longer in duration than the reverse transition during the down phase. Both the high bridge (stage 4), and the half-kneeling (stage 6) stages were shorter in duration during the up phase.

4. Discussion

This investigation sought to describe the activity patterns from a subset of muscles that span the glenohumeral joint during individual stages of the TGU. Patterns of muscle activity were interpreted by qualitatively comparing between muscles on the sides of the body that were ipsilateral (right), and contralateral (left) to the hand holding the kettlebell, and between the up and down phases of the TGU. Overall muscle activity was higher for the ipsilateral upper limb during the stages when the contralateral upper limb was not contributing to support the body; however, activation of the contralateral musculature was greater during the fourth and fifth stages when the contralateral upper limb was required to support the body. Motor pattern consistency was greater during the up phase of the TGU. These descriptive findings collectively provide insight to the neuromuscular control strategies to "solve" the varying set of movement "problems" posed by the TGU, which can be useful for training and rehabilitation purposes (Escamilla et al., 2009).

Ayash and Jones (2012) have suggested that the TGU can be used as an exercise to improve and reinforce glenohumeral joint stability by training muscles and motor patterns that control scapular position and movement. Muscles that cross the glenohumeral joint, but do not directly control scapular position and movement, also contribute to glenohumeral joint stability (Favre et al., 2012; Labriola et al., 2005). Seven of the eight muscles that were monitored in this investigation cross the glenohumeral joint by at least one of their anatomical attachments, and would have directly contributed to glenohumeral joint stability. The upper trapezius, a significant contributor to scapular elevation, was the only monitored muscle that did not cross the glenohumeral joint (Escamilla et al., 2009). A muscle's instantaneous contribution to joint stability is a function of its length, origin and insertion locations, moment arm length from the joint, as well as the muscle's active force and stiffness (Potvin and Brown, 2005). Despite the approximately linear relationship between muscle activation and force (Lawrence and De Luca, 1983), and the subsequent relationship between a muscle's force and stiffness (Bergmark, 1989), the data recorded and presented in this study cannot be directly related to the stabilizing contribution of individual muscles spanning the glenohumeral joint. This is because we neither measured glenohumeral kinematics, nor employed a biomechanical model of the shoulder joint and its musculature.

Notwithstanding the abovementioned challenges associated with making inferences about muscular contributions to joint stability based solely on measures of muscle activation, muscular activities reported during individual stages of the TGU can be compared to those measured in other shoulder rehabilitation exercises. For example, activity of the right infraspinatus during the up phase of the TGU was qualitatively similar to reported activity from the same muscle during humeral external rotation exercises with varying amounts of humeral abduction (Myers et al., 2005; Townsend et al., 1991). Activities of the upper trapezii (right – stage 7 during up and down phases; left – stage 2 during up phase), anterior deltoids (right – stage 7 during up and down phases; left – stage 5 during up phase), left latissimus dorsi (stages 2 and 3 during up phase), and left posterior deltoid (stage 2 during up phase) at different points during the TGU were also similar to a collection of shoulder rehabilitation exercises reviewed by Escamilla and colleagues (Escamilla et al., 2009). Such comparisons are very useful if the objective is to target specific muscle groups for a specific purpose (e.g., to direct blood flow to rotator cuff muscles after acute injury/surgery). However, as explained in the paragraph above, direct inferences regarding muscle function are challenging to make between exercises without having corresponding kinematic and kinetic data to use in musculoskeletal models (e.g. Dickerson et al., 2007). Given the variation in body positions and muscle activity reported in the current study, detailed biomechanical analyses of the TGU are warranted if attempting to use it as a modality to improve and reinforce glenohumeral joint stability and/or to facilitate training transfer across a variety of functional contexts.

There are several study (de)limitations that should be considered when interpreting the results. First, the data in the current investigation (iEMG) represents the total muscular activity across a stage of the TGU, whereas most studies report peak EMG (Escamilla et al., 2009). The decision to report iEMG was based on the intention to provide an overall measure of neuromuscular demand imposed using all data collected, as opposed to extracting instantaneous data points to represent complex patterns. Second, the TGU can be performed at varying speeds and with various masses, and it is conceivable that magnitudes and patterns of muscle activity reported in the current investigation would not be representative across all such variations. Third, study participants were asymptomatic, and had at least 1-year of performing the TGU exercise. The inclusion criteria was based on the expectation that inexperienced participants would require substantial training to achieve acceptable performance standards, and that symptomatic participants may have restrictions that could prevent them from meeting these same standards. Fourth, activities from a subset of muscles within the shoulder complex were measured due to their accessibility for measurement with sEMG. Since the TGU is presented as a whole-body exercise (Ayash and Jones, 2012; Liebenson and Shaughness, 2011), it would be justified in future studies to measure activities from the lower limb and trunk musculature, in addition to other muscles surrounding the shoulder complex. Lastly, glenohumeral kinematic data were not obtained alongside the sEMG data. As suggested above, simultaneous recording of shoulder muscle activities and glenohumeral kinematic data would provide an opportunity to interpret the activities with respect to the functional roles of the muscles during each stage of the TGU.

5. Conclusion

Our study described activities of the superficial torque-producing muscles of the shoulder throughout the TGU. Torques produced by muscles spanning the glenohumeral joint, through their activation, provide mechanical advantages to create stability during a loaded overhead exercise. Thus, the data from the current investigation provide insight and implications on the necessary neuromuscular control strategies necessary to tolerate the demands of an overhead movement such as a TGU. The data also provides insight for implementation of the TGU into training and the latter stages within rehabilitation protocols for athletes with significant overhead demands. Results of this study are directly applicable to athletic populations of healthy individuals that have experience with kettlebell training; however, strength and conditioning professionals can add the TGU to the programming of their overhead athletes (e.g. volleyball players and shot-putters) since it likely mimics the sport-specific glenohumeral joint torque and stability demands placed on these athletes. Strength and conditioning specialists should be aware that: (1) the neuromuscular control strategies for a given stage of the TGU are not the same between the up and down phases; and, (2) the contralateral (i.e. non-kettlebell) glenohumeral joint is significantly challenged due to its weight-bearing demands during stages 2–5 of the TGU. The first point emphasizes the importance that athletes train both phases of the TGU to gain the most benefit from the exercise. Our second point highlights the asymmetric nature of the exercise, which may be particularly relevant for athletes engaged in activities with rotational demands (e.g. volleyball, hockey, shotput).

Funding sources

The authors would like to thank the Royal College of Chiropractic Sports Sciences (Canada) for funding a portion of this investigation.

Acknowledgments

The authors would like to thank Mr. Steven Tran for his help with data collection.

The authors have no conflicts of interests to disclose that are related to this work.

References

Ayash, A., Jones, M.T., 2012. Kettlebell Turkish Get-Up : training tool for injury prevention and performance enhancement. Int. J. Athl. Ther. Train. 17, 8–13.

Bergmark, A., 1989. Stability of the lumbar spine. Acta Orthop. Scand. 60, 1–54.

Brereton, L.C., McGill, S.M., 1998. Frequency response of spine extensors during rapid isometric contractions: effects of muscle length and tension. J. Electromyogr. Kinesiol. 8, 227–232.

Cram, J.R., Kasman, G.S., Holtz, J., 1998. Introduction to Surface Electromyography, first ed. Aspen Publishers, Gaithersburg, MD.

Davids, K., Glazier, P., Araújo, D., Bartlett, R., 2003. Movement systems as dynamical systems: the functional role of variability and its implications for sports medicine. Sports Med. 33, 245–260.

Decker, M.J., Hintermeister, R.A., Faber, K.J., Hawkins, R.J., 1999. Serratus anterior muscle activity during selected rehabilitation exercises. Am. J. Sports Med. 27, 784–791.

Decker, M.J., Tokish, J.M., Ellis, H.B., Torry, M.R., Hawkins, R.J., 2003. Subscapularis muscle activity during selected rehabilitation exercises. Am. J. Sports Med. 31, 126–134.
Dickerson, C.R., Chaffin, D.B., Hughes, R.E., 2007. A mathematical musculoskeletal shoulder model for proactive ergonomic analysis. Comput. Meth. Biomech. Biomed. Eng. 10, 389–400.
Ellenbecker, T.S., Cools, A., 2010. Rehabilitation of shoulder impingement syndrome and rotator cuff injuries: an evidence-based review. Br. J. Sports Med. 44, 319–327.
Escamilla, R.F., Andrews, J.R., 2009. Shoulder muscle recruitment patterns and related biomechanics during upper extremity sports. Sports Med. 39, 569–590.
Escamilla, R.F., Yamashiro, K., Paulos, L., Andrews, J.R., 2009. Shoulder muscle activity and function in common shoulder rehabilitation exercises. Sports Med. 39, 663–685.
Favre, P., Senteler, M., Hipp, J., Scherrer, S., Gerber, C., Snedeker, J.G., 2012. An integrated model of active glenohumeral stability. J. Biomech. 45, 2248–2255.
Hess, S.A., 2000. Functional stability of the glenohumeral joint. Man. Ther. 5, 63–71.
Labriola, J.E., Lee, T.Q., Debski, R.E., McMahon, P.J., 2005. Stability and instability of the glenohumeral joint: the role of shoulder muscles. J. Shoulder Elbow Surg. 14, 32–38.
Lawrence, J.H., De Luca, C.J., 1983. Myoelectric signal versus force relationship in different human muscles. J. Appl. Physiol. Respir. Environ. Exerc. Physiol. 54, 1653–1659.
Leatherwood, M.D., Whittaker, A., Esco, M.R., 2014. Exercise technique: the Turkish get-up with a kettlebell. Strength Condit. J. 36, 107–110.
Lehman, G.J., McGill, S.M., 1999. The importance of normalization in the interpretation of surface electromyography: a proof of principle. J. Manip. Physiol. Ther. 22, 444–446.
Liebenson, C., 2002. Functional exercises. J. Bodyw. Mov. Ther. 6, 108–113.
Liebenson, C., Shaughness, G., 2011. The Turkish get-up. J. Bodyw. Mov. Ther. 15, 125–127.
Myers, J.B., Pasquale, M.R., Laudner, K.G., Sell, T.C., Bradley, J.P., Lephart, S.M., 2005. On-the-field resistance-tubing exercises for throwers: an electromyographic analysis. J. Athl. Train. 40, 15–22.
Potvin, J.R., Brown, S.H.M., 2005. An equation to calculate individual muscle contributions to joint stability. J. Biomech. 38, 973–980.
Reinold, M.M., Gill, T.J., Wilk, K.E., Andrews, J.R., 2010. Current concepts in the evaluation and treatment of the shoulder in overhead throwing athletes, Part 2: injury prevention and treatment. Sport Health 2, 101–115.
Reinold, M.M., Wilk, K.E., Fleisig, G.S., Zheng, N., Barrentine, S.W., Chmielewski, T., Cody, R.C., Jameson, G.G., Andrews, J.R., 2004. Electromyographic analysis of the rotator cuff and deltoid musculature during common shoulder external rotation exercises. J. Orthop. Sports Phys. Ther. 34, 385–394.
Townsend, H., Jobe, F.W., Pink, M., Perry, J., 1991. Electromyographic analysis of the glenohumeral muscles during a baseball rehabilitation program. Am. J. Sports Med. 19, 264–272.