

TRUNK AND SHOULDER EMG AND LUMBAR KINEMATICS OF MEDICINE-BALL SIDE THROW AND SIDE CATCH AND THROW

Francisco J. Vera-Garcia ¹; Iñaki Ruiz-Pérez ¹; David Barbado ¹;
Casto Juan-Recio ¹; Stuart M. McGill ²

1. Sport Research Center. Miguel Hernández University of Elche, Spain.
2. Spine Biomechanics Laboratory, Department of Kinesiology, University of Waterloo, Canada.

ABSTRACT

The objective of this study was to analyze trunk and shoulder muscle activation and lumbar spine kinematics of backward and forward phases during both isolated medicine-ball side throws, and medicine-ball side catch and throw sequences. Thirteen recreationally trained men performed three isolated medicine-ball side throws with 1 min rest between repetitions, and three medicine-ball side catch and throw sequences. Surface electromyography signals were collected bilaterally in seven trunk muscles and in the right side for anterior deltoid and pectoralis major. Spine kinematics were measured using an electromagnetic tracking instrument. The results showed that left external oblique and right anterior deltoid activations reached peak levels above 100% MVC during the forward phase highlighting their important role during side medicine-ball throwing. When both exercises were compared, the amplitude of the lumbar motion and the muscle activation in the backward phase were higher during the medicine-ball side catch and throw than in the medicine-ball side throw. According to these results, the medicine-ball side catch and throw is a high demanding plyometric exercise, which seems more appropriate for high performance throwing and striking athletes than for recreationally trained individuals. Suggestions to reduce back injury risk were provided.

Key Words: trunk exercises, plyometric training, muscle function, spine biomechanics

RESUMEN

El objetivo del estudio fue analizar la actividad electromiográfica de músculos del tronco y del hombro y la cinemática del raquis lumbar durante las fases de preparación y aceleración de lanzamientos laterales de balón-medicinal autorregulados (Th) y secuencias de recepción y lanzamiento lateral de balón-medicinal (Ca-Th). Trece participantes realizaron tres Th, con 1 min de descanso entre repeticiones, y tres secuencias de Ca-Th. Mediante electromiografía de superficie se registró la activación mioeléctrica de dieciséis músculos del tronco y del hombro. La cinemática del raquis fue medida utilizando un sistema electromagnético. Los resultados mostraron que el oblicuo externo izquierdo y la sección anterior del deltoides derecho alcanzaron picos de activación superiores al 100% MVC durante la fase de aceleración en ambos ejercicios, subrayando su importancia durante este tipo de lanzamientos. Al comparar ambos ejercicios, la amplitud del movimiento lumbar y la activación muscular durante la fase de preparación fueron mayores en el ejercicio Ca-Th que en el ejercicio Th. Atendiendo a estos resultados, el Ca-Th es un ejercicio pliométrico de alta intensidad, el cual parece más apropiado para el alto rendimiento que para el entrenamiento recreacional. Finalmente, se proporcionaron algunas sugerencias para reducir el riesgo de lesión lumbar en estos ejercicios.

Palabras clave: ejercicios de tronco, entrenamiento pliométrico, función muscular, biomecánica del raquis

Correspondence:

Francisco José Vera-García
Sport Research Center. Miguel Hernández University of Elche. Spain
Avda. de la Universidad s/n. 03202 - Elche (Alicante).
fvera@umh.es

Submitted: 15/11/2014

Accepted: 16/12/2014

INTRODUCTION

In the sport performance field, besides conventional trunk muscles conditioning through exercises in supine, prone or lateral positions (McGill, 2002; Monfort-Pañego, Vera-Garcia, Sanchez-Zuriaga & Sarti-Martínez, 2009; Santana Vera-Garcia & McGill, 2007), trunk muscular power and speed strength is mainly trained through global actions in standing, for example, cable pulley exercises (press standing cable chop wood, overhead wire pulls, etc.), free weight exercises (squat one-armed kettlebell, kettlebell swing, etc.) or medicine-ball throw exercises (mainly overhead, side and chest medicine-ball throws) (McGill, 2006; Monfort-Pañego, Vera-Garcia, Sanchez-Zuriaga & Sarti-Martínez, 2009). In these actions, the core is central to the kinetic chains and an important structure in the transmission of forces between upper and lower limbs (Borghuis, Hof & Lemmink, 2008; Kibler, Press & Sciacia, 2006).

Between the abovementioned exercises, medicine-ball side throws are broadly used as a way of plyometric training for improving performance in throwing and striking sports, such as tennis, baseball or martial arts (Fernandez-Fernandez, Ellenbecker, Sanz-Rivas, Ulbricht & Ferrauti, 2013; Genevois, Frican, Creveaux, Hautier & Rogowski, 2013; Ouergui et al., 2014; Stodden, Campbell & Moyer, 2008; Szymanski, Szymanski, Bradford, Schade & Pascoe, 2007). These exercises are characterized by an explosive trunk rotation action, first in opposite direction to the ball trajectory (negative work or backward phase) and later in the ball trajectory (positive work or forward phase) (Ikeda, Miyatsuji, Kawabata, Fuchimoto & Ito, 2009). Trunk rotator muscles are activated throughout a stretch-shortening cycle, storing elastic energy during the backward phase and reusing part of it in the forward phase (Cavagna, Mazzanti, Heglund & Citterio, 1985; Henchoz, Malatesta, Gremion & Belli, 2006).

During power and speed strength training programs, the medicine-ball side throw exercise progresses generally from isolated side throws to medicine ball side tosses, i.e. cyclic quick medicine-ball side catch and throw sequences (using for example a partner, a wall or a mini-tramp to return the ball), which increase the demands of the elastic energy storage and recovery system of the abdominal wall (McGill, 2006). However, to the best of our knowledge, no biomechanical studies have analyzed the trunk muscle recruitment or the kinetic chains during medicine-ball side catching and throwing exercises and only one has analyzed the trunk muscle activity during isolated medicine-ball side throws (Ikeda et al. 2009). In this study, Ikeda et al. compared the best and worse five side medicine-ball throwers of a sample of 30 competitive throwers and found that external oblique activation was the major difference between both groups and an important factor for fast side medicine-ball throwing.

Nevertheless, only four muscles were bilaterally recorded by Ikeda et al. (pectoralis major, latissimus dorsi, rectus abdominis and external oblique). Further research is needed to analyze the trunk muscle recruitment during several variations of side medicine-ball throwing. This information may be useful for the prescription of trunk plyometric exercises in throwing and striking sports. In addition, taking into account that medicine-ball throws have been used as field test to assess the physical fitness and performance (Falk, Cohen, Lustig, Lander, Yaaron & Ayalon, 2001; Salonia, Chu, Cheifetz & Freidhoff, 2004), knowing the role of the trunk muscles during these actions could help to understand better the meaning of the test scores.

Considering the lack of information on the trunk musculature response in medicine-ball throw exercises, an electromyographic and kinematic study of the backward and forward phases of two side medicine-ball throw exercises was performed: medicine-ball side throw and medicine-ball side catch and throw. The aim of this study was to compare trunk and shoulder muscle activation and lumbar spine kinematics between these exercises in a sample of recreationally trained individuals.

METHOD

Participants

Thirteen recreationally trained men voluntarily took part in the study (age: 27.85 ± 8.59 years; mass: 77.84 ± 10.83 kg; height: 1.78 ± 0.05 m). All of them were right-handed, healthy and familiar with the practice of trunk muscle exercises. Individuals with known medical problems, histories of spinal or abdominal surgery, or episodes of back or shoulder pain requiring treatment twelve months before this study were excluded.

Participants were informed of the characteristics of the research and they signed a written informed consent document which was approved by the Ethics Committee of the Institution.

Instrumentation and Data Collection

Exercises

Participants performed three isolated medicine-ball side throws (Figure 1), with 1 min rest between repetitions, and three medicine-ball side catch and throw sequences with a 4 kg and 21.5 cm diameter medicine-ball. Before throwing, each participant stood in a staggered stance with the left leg forward and knees slightly bent. In order to help the participant to perform the exercises, a researcher with a great experience in this type of plyometric exercises was located 5 m in front of him, with a similar staggered stance. For the medicine-ball side throws, participants were instructed to throw the ball as

hard as possible toward the researcher. For the medicine-ball catches and throws, participants received the ball from the aforementioned researcher and threw the medicine-ball back to the researcher as hard and as fast as possible in a cyclic and plyometric catching and throwing sequence. In both exercises, the medicine-ball was thrown directed toward the right hip of the partner and both feet were in contact with the ground throughout whole trial. Participants were encouraged to generate a sequential activation of body segments (lower limbs, pelvis, thorax and upper limbs) during the forward phase of each throw, emphasizing the horizontal rotation and anterior translation of the pelvis to face the target before the upper body motion. The abovementioned researcher and another one visually evaluated each trial and selected the throw performed with the best technique.

A familiarization period consisting of five repetitions of each exercise was performed prior to data collection. Participants were verbally instructed by the researchers on correct throwing technique. A 3 min rest period between exercises was given to avoid muscular fatigue. The order of the exercises was randomized between participants.

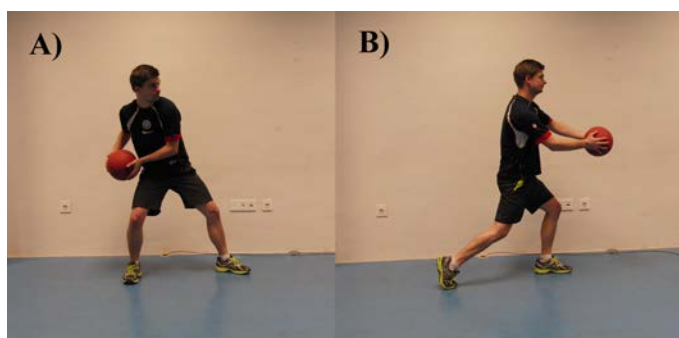


FIGURE 1: Lateral view of the backward (A) and forward phase (B) of the medicine-ball side throw.

Electromyography

Surface electromyography (EMG) signals were collected on each participant (AMT-8, Bortec Biomedical, Calgary, Canada, with a CMRR of 115 dB at 60 Hz, and input impedance of 10 G Ω), amplified to produce approximately ± 2.5 V, and then A/D converted (12 bit resolution) at 1024 Hz.

The following trunk muscles and locations (bilaterally: R = right, L = left) were used: rectus abdominis (RA), 3 cm lateral to the umbilicus; external oblique (EO), 15 cm lateral to the umbilicus; internal oblique (IO), the geometric center of the triangle formed by the inguinal ligament, the outer edge

of the rectus sheath and the imaginary line joining the anterior superior iliac spine and the umbilicus (García-Vaquero, Moreside, Brontons-Gil, Peco-González & Vera-García, 2012; Vera-García, Barbado & Moya, 2014); latissimus dorsi (LD), lateral to T9 over the muscle belly; and erector spinae at T9, L3 and L5 (ET9, EL3 and EL5, respectively), located 5, 3 and 1 cm lateral to each spinous process. In addition, EMG signals were also recorded from the right anterior deltoid (RAD; approximately 5 cm distal and anterior to the acromion) and the sternal portion of right pectoralis major (RPM).

A topographic marking of the different anatomical points was carried out to facilitate the placement of the electrodes (Delagi, Perotto, Lazzeti & Morrison, 1981). Skin zones for electrode locations were shaved and cleaned with an alcohol swab in order to reduce impedance. Pregelled disposable bipolar Ag-AgCl disc surface electrodes (Blue Sensor, Ambu A/S, Denmark) were placed parallel to the muscle fibers with an inter-electrode distance of 3 cm. After placing the electrodes participants were asked to perform different movements to ensure the precise placement of the electrodes and to test the EMG signal quality.

Prior to perform the medicine ball throws, two series of maximal voluntary isometric contractions (MVCs) were executed to obtain reference values to normalize the EMG signals. For the abdominal muscles, each participant was seated in a sit-up position and manually restrained by a research assistant (after Vera-García, Moreside & McGill, 2010). The subject produced a sequence of maximal isometric exertions in trunk flexion, right lateral bend, left lateral bend, right twist and left twist directions. For the erector spinae, maximal isometric trunk efforts against manual resistance were performed in the Biering-Sorensen position (prone, with the torso horizontally cantilevered over the end of a padded test bench). For the RAD and RPM, participants were positioned supine on the test bench. The MVC for RAD was performed by resisting maximal isometric shoulder flexion at 90° in the sagittal plane. For RPM, a research assistant resisted maximal isometric efforts of shoulder horizontal adduction, extension and internal rotation. Each maximal exertion was maintained during 3-4 s and 5 min rest was allowed between each MVC series to avoid muscular fatigue.

Three-dimensional kinematics

Spine kinematics were measured using an electromagnetic tracking instrument (3Space ISOTRAK, Polhemus Inc., Colchester, VT), collected at a sampling frequency of 32 Hz and synchronized to the EMG signals. An electromagnetic transmitter and one small receiver were strapped in place (via elastic/Velcro® straps) over the sacrum and the T12 spinous process

respectively, to measure relative lumbar motion about the flexion-extension, lateral bend and twist axes. All lumbar angular data were made relative to the standing anatomical position. Consequently, at any time during the medicine ball throws, the instantaneous spine position was determined in 3 planes of motion, relative to upright standing.

Data Processing

EMG and kinematic signals were visually inspected. Data marred with artifacts and other technical problems were excluded from further analyses. Raw EMG signals were full wave rectified and low pass filtered (second order single pass Butterworth) with a cutoff frequency of 2.5 Hz, and then normalized to MVC amplitudes (% MVC).

Based on the lumbar twist displacement time-history, the EMG signals of each throw were divided into 2 phases: backward phase and forward phase. As shown in Figure 2, during the backward phase of both medicine-ball throw exercises participants twisted the thorax to the right while right bent and sagittal flexed the lumbar spine. During the forward phase, the opposite motion was observed in the lumbar spine. The peak normalized EMG amplitude of each phase was calculated in order to evaluate the muscle recruitment during the medicine-ball side throw and side catch and throw. In addition, the duration and amplitude of the extension-flexion, lateral bend and twist spine motions were calculated for the backward and forward phases of each throw attending to each plane of motion.

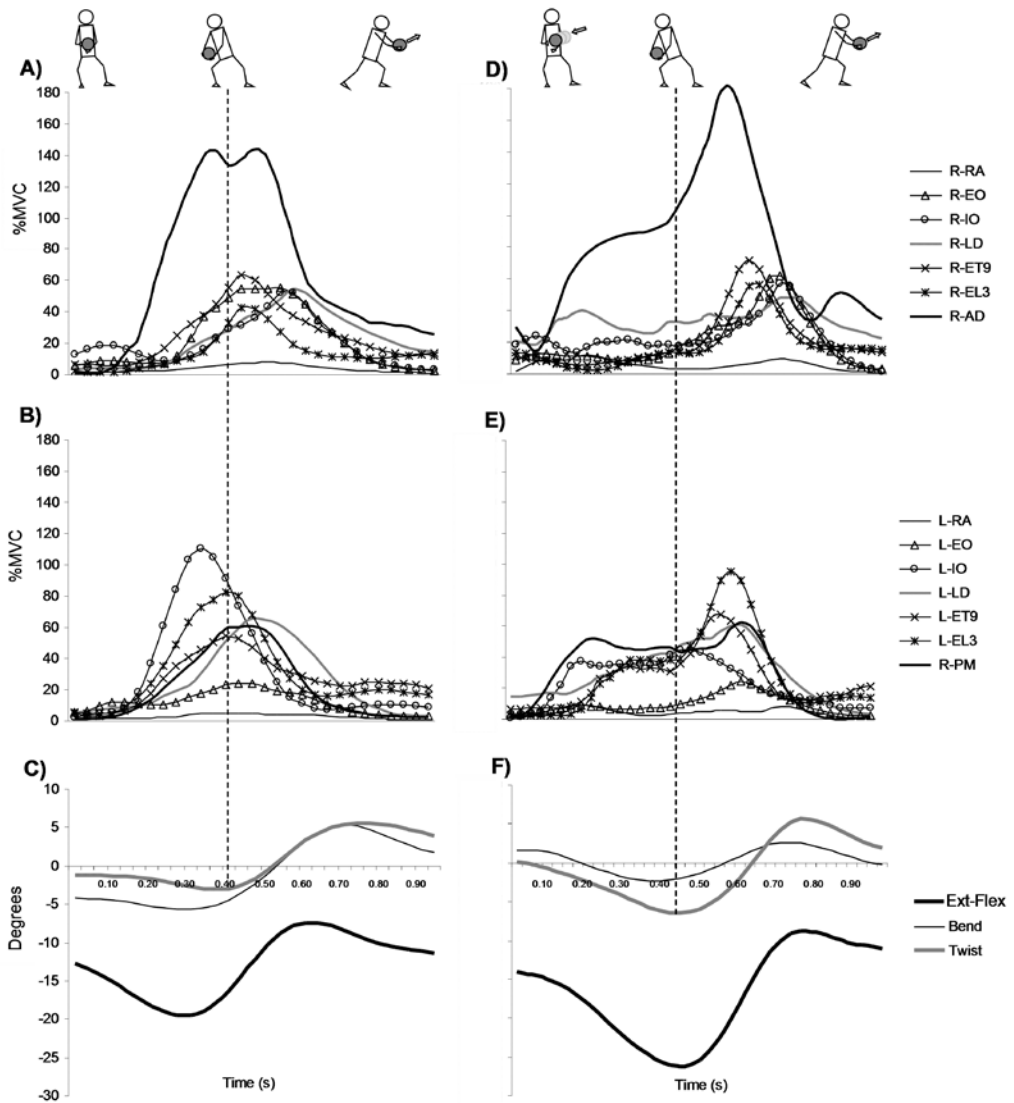


FIGURE 2: EMG and lumbar displacement time-histories of subject number 11 for medicine-ball side throw (graphs on the left) and side catch and throw (graphs on the right). A) & D) EMG amplitudes of the right trunk muscles and anterior deltoid. B) & E) EMG amplitudes of the left trunk muscles and pectoralis major. C) & F) Lumbar spine extension-flexion, lateral bend and twist.

Statistical Analysis

Descriptive statistics (mean and standard deviation) were calculated for all variables. Data normality was examined using the Kolmogorov-Smirnov statistic with a Lilliefors correction. Three-ways repeated-measures ANOVA with exercise (throw and catch-throw), phase (backward and forward) and lumbar motion direction (extension-flexion, lateral bend and twist) as within-subjects factors were performed to investigate the differences in lumbar angular motion duration and amplitude. In addition, three way repeated measured ANOVA with exercise (throw and catch-throw), phase (backward and forward) and muscle (RRA, LRA, REO, LEO, RIO, LIO, DLD, LLD, RET9, LET9, REL3, LEL3, REL5, LEL5, RAD, RPM) as within-subjects factors were performed to investigate the differences in peak of muscle activation. Partial eta squared (η^2_p) was calculated as a measure of effect size. The following scale of thresholds was used to analyse the magnitudes of effect size: ≥ 0.64 strong; 0.25–0.64 moderate; and ≤ 0.04 small. Post hoc analysis with Bonferroni adjustment was used for multiple comparisons. All analyses were performed using the SPSS package (version 18, SPSS Inc., Chicago, IL, USA) with a significance level chosen at $p < 0.05$.

RESULTS

Table 1 shows the lumbar motion duration and amplitude during both phases of medicine-ball throw and medicine-ball catch and throw. For the lumbar angular motion duration, ANOVA did not show significant differences between exercises ($p = 0.316$; $\eta^2_p = 0.083$) or phases ($p = 0.147$; $\eta^2_p = 0.167$), nor significant interactions between exercises, phases and directions. In addition, although significant differences between directions were found ($p = 0.027$; $\eta^2_p = 0.344$), post hoc analyses did not show significant pairwise differences for this variable.

On the other hand, for the lumbar motion amplitude, ANOVA showed significant main effects for exercise ($p = 0.010$; $\eta^2_p = 0.441$), phase ($p < 0.001$; $\eta^2_p = 0.809$) and direction ($p < 0.001$; $\eta^2_p = 0.729$) and for exercise*phase ($p = 0.014$; $\eta^2_p = 0.408$) and phase*direction interactions ($p < 0.001$; $\eta^2_p = 0.525$). Specifically, during the backward phase, medicine-ball side catch and throw showed significantly higher amplitudes of lumbar spine motion than medicine-ball side throw, being significant for twist and extension-flexion directions (Table 1). Moreover, when backward and forward phases were compared, the lumbar motion amplitudes were higher during the forward phase for all directions and exercises.

TABLE 1
Descriptive statistics of lumbar angular motion duration and amplitude during medicine-ball throw and medicine-ball catch and throw.

Phase	Direction	Duration (s)		Amplitude (°)	
		Catch-Throw	Throw	Catch-Throw	Throw
Backward	Twist	0.42 ± 0.15	0.42 ± 0.19	8.93 ± 2.98 ^{AB}	3.98 ± 3.22 ^A
	Ext-Flex	0.47 ± 0.16	0.43 ± 0.15	13.38 ± 5.81 ^{AB}	8.55 ± 3.79 ^A
	Bend	0.38 ± 0.19	0.33 ± 0.22	4.44 ± 2.53 ^A	3.03 ± 1.87 ^A
Forward	Twist	0.36 ± 0.09	0.37 ± 0.05	17.63 ± 3.35	17.28 ± 3.91
	Ext-Flex	0.34 ± 0.14	0.35 ± 0.15	19.02 ± 7.91	16.33 ± 5.17
	Bend	0.35 ± 0.15	0.27 ± 0.11	8.25 ± 5.58	7.51 ± 3.75

Post hoc analyses with Bonferroni adjustment were used for multiple comparisons: ^ASignificantly different from "Forward phase"; ^BSignificantly different from "Throw".

Figure 3 shows the peak normalized EMG amplitudes of trunk and shoulder muscles during both phases of medicine-ball throw and medicine-ball catch and throw. ANOVA showed significant main effects for exercise ($p = 0.009$; $\eta^2_p = 0.448$), phase ($p < 0.001$; $\eta^2_p = 0.922$) and muscle ($p < 0.001$; $\eta^2_p = 0.531$) and for exercise*phase ($p = 0.041$; $\eta^2_p = 0.305$), exercise*muscle ($p < 0.001$; $\eta^2_p = 0.241$), phase*muscle ($p < 0.001$; $\eta^2_p = 0.368$) and exercise*phase*muscle interactions ($p = 0.001$; $\eta^2_p = 0.185$). Specifically, the muscle activation levels were higher during the forward phase than during the backward phase in both exercises. Regarding to the comparison between exercises, no differences were found for the forward phase. However, for the backward phase, the peak activation of RRA, REO, RLD, REL3, RAD, RPM, LIO and LEL5 during the medicine-ball side catch and throw was significantly higher than during the medicine-ball side throw (Figure 3).

As shown in Tables 2 and 3, more significant pairwise differences between muscles were found during the forward phase than during the backward phase in both exercises. Overall, LEO and RAD peak activations were higher than those of many of the other muscles, reaching activity levels above 100% MVC in the forward phase (Figure 3). The RIO, LIO and most sites for the erector muscles (mainly in the left side) produced activation levels above 50% MVC in the aforementioned phase (Figure 3), which in some cases were significantly higher than those of RPM, RRA and LRA (Table 3). In general, the latter three muscles produced the lowest activation levels across exercises and phases.

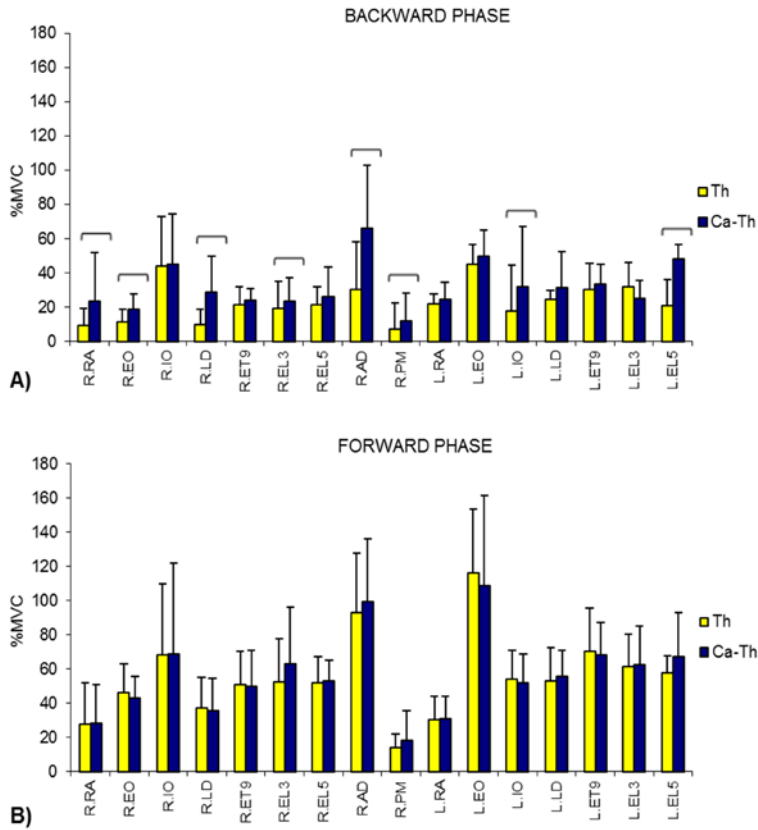


FIGURE 3: Averages and standard deviations of the peak normalized EMG amplitudes for medicine-ball throw (Th) and catch and throw (Ca-Th). A) Backward phase. B) Forward phase. Bracket means significant differences ($p < .05$) in muscle activation between exercises. Abbreviations: RRA = right rectus abdominis; REO = right external oblique; RIO = right internal oblique; RLD = right latissimus dorsi; RET9 = right erector spinae at T9, REL3 = right erector spinae at L3; REL5 = right erector spinae at L5; RAD = right anterior deltoid; RPM = right pectoralis major; LRA = left rectus abdominis; LEO = left external oblique; LIO = left internal oblique; LLD = left latissimus dorsi; LET9 = left erector spinae at T9, LEL3 = left erector spinae at L3; LEL5 = left erector spinae at L5.

TABLE 2
Significant results (p-values) from pairwise comparisons with Bonferroni adjustment between muscles during Backward Phase for medicine-ball catch and throw (upper right) and medicine-ball throw (lower left).

	RRA	REO	RIO	RLD	RET9	REL3	REL5	RAD	RPM	LRA	LEO	LIO	LLD	LET9	LEL3	LEL5
RRA																
REO								.043								.024
RIO																
RLD																
RET9																.049
REL3																
REL5																
RAD										.022						
RPM					.024		.015					.026		.008	.007	.001
LRA									.021							
LEO																
LIO									.048							
LLD																
LET9					.011				.014							
LEL3	.042	.038		.004					.003							
LEL5																

Abbreviations: RRA = right rectus abdominis; REO = right external oblique; RIO = right internal oblique; RLD = right latissimus dorsi; RET9 = right erector spinae at T9; REL3 = right erector spinae at L3; REL5 = right erector spinae at L5; RAD = right anterior deltoid; RPM = right pectoralis major; LRA = left rectus abdominis; LEO = left external oblique; LIO = left internal oblique; LLD = left latissimus dorsi; LET9 = left erector spinae at T9; LEL3 = left erector spinae at L3; LEL5 = left erector spinae at L5.

TABLE 3
Significant results (p-values) from pairwise comparisons with Bonferroni adjustment between muscles during Forward Phase for medicine-ball catch and throw (upper right) and medicine-ball throw (lower left).

	RRA	REO	RIO	RLD	RET9	REL3	REL5	RAD	RPM	LRA	LEO	LIO	LLD	LET9	LEL3	LEL5
RRA								.007			.019					
REO								.003	.011							
RIO																
RLD							.009									
RET9																
REL3																
REL5										.018						
RAD	.006	.010		.002					.001	.003						
RPM		.001	.038		.013	.028		.001			.004	.027	.031	.013	.015	.009
LRA		.041						.001			.012			.024		.027
LEO	.001	.047		.003	.010	.002	.016		.001	.001						
LIO									.001							
LLD									.002		.043					
LET9	.036			.019					.001	.011	.042					
LEL3	.037			.011					.001	.028	.009					
LEL5				.043					.001	.001	.007					

Abbreviations: RRA = right rectus abdominis; REO = right external oblique; RIO = right internal oblique; RLD = right latissimus dorsi; RET9 = right erector spinae at T9; REL3 = right erector spinae at L3; REL5 = right erector spinae at L5; RAD = right anterior deltoid; RPM = right pectoralis major; LRA = left rectus abdominis; LEO = left external oblique; LIO = left internal oblique; LLD = left latissimus dorsi; LET9 = left erector spinae at T9; LEL3 = left erector spinae at L3; LEL5 = left erector spinae at L5.

DISCUSSION

Although medicine-ball side throws are frequently used as a way of plyometric training in throwing and striking sports (Fernandez-Fernandez et al., 2013; Genevois et al., 2013; Ouergui et al., 2014; Stodden et al., 2007), electromyographic and kinematic studies on several variations of this exercise are lacking. In this study, we have analyzed trunk and shoulder muscle activation and lumbar spine kinematics of backward and forward phases during both, isolated medicine-ball side throws and medicine-ball side catch and throw sequences. The main findings were that the amplitude of the lumbar motion and the muscle activation in the backward phase were higher during the medicine-ball side catch and throw than in the medicine-ball side throw; conversely, no differences between exercises were found in the forward phase. The lumbar motion and the muscle activation were higher during the forward phase than during the backward phase in both exercises, finding peak activation levels above 50% MVC for most muscles, highlighting LEO and RAD, which reached peak activation levels above 100% MVC.

Medicine-ball side throwing are plyometric actions characterized by a backward-forward motion sequence in which the musculature is activated

throughout stretch-shortening cycle. At the end of the backward phase, the eccentric activation of the antagonistic muscles generates forces in the opposite direction of the movement, braking the motion and storing elastic energy which is partially reused during the forward phase (Cavagna et al., 1985; Henchoz et al., 2006). Based on our results (Table 1), both phases had similar lumbar motion durations, but the amplitude of the lumbar motion was higher during the forward phase. Therefore, the lumbar motion was faster during the latter phase, needing higher trunk activation levels (Figure 3) to produce higher trunk speed motions (Vera-Garcia, Flores-Parodi, Elvira & Sarti, 2008).

The main differences among the medicine-ball side throw and the medicine-ball side catch and throw were found in the backward phase. The amplitude of the spine motion and the eccentric activation of the trunk and shoulder muscles in this phase were higher for the medicine-ball side catch and throw than for the medicine-ball side throw (Table 1 and Figure 3), showing the participants' difficulty to brake the motion after catching the 4 kg medicine-ball. As shown in the EMG time-histories of Figure 2, while the participant reached a single peak activity in most muscles during the isolated medicine-ball side throw, he contracted his musculature over a broader length of time and reached a double peak activity in most muscles during the medicine-ball side catch and throw. This activation pattern was found in all participants for this exercise, and suggests the transition time between muscle stretching and shortening was very long, possibly impairing the mechanical efficiency of this plyometric action (Henchoz et al., 2006). Similarly, a previous study by Freeman et al. (2006) showed that unlike high performance level athletes, less skilled participants contracted trunk and arm musculature over a broad length of time and were not able to synchronize force development during a trunk plyometric exercise (i.e. clapping push up). Based on these results, it seems the 4 kg medicine-ball side catch and throw exercise was too difficult for the recreationally trained participants, which could not always catch the medicine-ball during the EMG recording. Other less demanding variations of this exercise (e.g. using a lighter medicine-ball or throwing it to the participant at a slower speed) could be more appropriate for this recreational level.

During the forward phase, no differences were found between the medicine-ball side throw and the medicine-ball side catch and throw. In both exercises, LEO and RAD reached the highest activations levels, followed by the left erector muscles and internal oblique (Figure 3). The high LEO activation during this exercise could be necessary for pelvis left rotation and anterior translation to face the target at the beginning of the forward phase (Hirashima, Kadota, Sakurai, Kudo & Ohtsuki, 2002). These results support those by Ikeda et al. (2009), who found that external oblique activation was a key factor during

fast side medicine-ball throwing. However, in relation to RPM activation, while Ikeda et al. found high levels of activation for pectoralis major, this muscle contracted at the lowest activation level in our study (Figure 3). Possibly, these differences were caused by the throwing technique, which in our study involved an important shoulder flexion (resulting in high RAD activation levels), while in Ikeda's study it could involve a higher shoulder adduction, i.e. a more lateral throw.

A discussion of injury potential is appropriate given the level of muscle activation and repeated twisting of the spine. Repeated twisting of the lumbar spine has been shown to lead to delamination of the collagenous rings forming the intervertebral disc annulus (Marshall & McGill, 2010). When combined with higher loads, this damage accumulates faster. When throwing the medicine ball laterally the individual has the choice to rotate about the hips and the torso. More rotation about the hips, and less about the spine, will reduce the risk of disc damage when performing this exercise.

A limitation of this study was that the medicine-ball speed was not controlled during the recording session. However, two experienced researchers visually evaluated each throw, selecting the trial performed with the best technique for each participant and exercise. Another limitation of this study was the relatively high variability of muscular activation and lumbar kinematics between participants, which is common in many trunk biomechanical studies (see for example: García-Vaquero et al., 2012; Vera-Garcia et al., 2010). In addition, although two series of MVCs were performed, we cannot exclude the possibility of not having reached the actual maximum value in some muscles, which could affect to some comparison between muscles. Finally, specific technique to focus the twisting rotation about the hips or the spine was not coached. This study documented un-coached behavior to obtain spine motion and muscle activation patterns.

CONCLUSIONS

The medicine-ball side throw and the medicine-ball side catch and throw are plyometric exercises which differ mainly in the backward phase. On the base of our results, the medicine-ball side catch and throw was a more demanding exercise, requiring higher lumbar motion amplitudes and muscle activation levels in the mentioned phase. This exercise seems appropriate for high performance throwing and striking athletes rather than recreationally trained individuals. Given the mechanism of rotational spine disk injury, it is recommended to focus the twisting rotation about the hips rather than the spine.

In both exercises the lumbar motion and the muscle activation were higher during the forward phase than during the backward phase. LEO and RAD activations reached peak levels above 100% MVC during the forward phase and seem crucial during side medicine-ball throwing. Further research is necessary to analyze the contribution of the lower limb muscles to these exercises.

ACKNOWLEDGMENTS

This study was made possible by financial support of the Ministerio de Ciencia e Innovación of Spain (Plan Nacional de I+D+i, Ref.: DEP2010-16493) and the Natural Sciences and Engineering Research Council of Canada. Casto Juan-Recio was supported by a pre-doctoral grant (Val i+d) given by Generalitat of Valencia of Spain.

REFERENCES

- Borghuis, J., Hof, A. L., & Lemmink, K. A. (2008). The importance of sensory-motor control in providing core stability: implications for measurement and training. *Sports Med*, 38(11), 893-916. doi: 10.2165/00007256-200838110-00002.
- Cavagna, G. A., Mazzanti, M., Heglund, N. C., & Citterio, G. (1985). Storage and release of mechanical energy by active muscle: a non-elastic mechanism. *J Exp Biol*, 115, 79-87.
- Delagi, E. F., Perotto, A., Lazzeti, J., & Morrison, D. (1981). *Anatomic Guide for the Electromyographer*. Springfield, USA: Charles C. Thomas Publisher.
- Falk, B., Cohen, Y., Lustig, G., Lander, Y., Yaaron, M., & Ayalon, J. (2001). Tracking of physical fitness components in boys and girls from the second to sixth grades. *Am J Hum Biol*, 13, 65-70.
- Fernandez-Fernandez, J., Ellenbecker, T., Sanz-Rivas, D., Ulbricht, A., & Ferrauti, A. (2013). Effects of a 6-Week junior tennis conditioning program on service velocity. *J Sports Sci Med*, 12, 232-239.
- Freeman, S., Karpowicz, A., Gray, J., & McGill, S. (2006). Quantifying muscle patterns and spine load during various forms of the push-up. *Med Sci Sport Exer*, 38(3), 570-577.
- García-Vaquero, M. P., Moreside, J. M., Brontons-Gil, E., Peco-González, N., & Vera-Garcia, F. J. (2012). Trunk muscle activation during stabilization exercises with single and double leg support. *J Electromyogr Kinesiol*, 22(3), 398-406. doi: 10.1016/j.jelekin.2012.02.017.
- Genevois, C., Fracan, B., Creveaux, T., Hautier, C., & Rogowski, I. (2013). Effects of two training protocols on the forehand drive performance in tennis. *J Strength Cond Res*, 27(3), 677-682. doi: 10.1519/JSC.0b013e31825c3290.

- Henchoz, Y., Malatesta, D., Gremion, G., & Belli, A. (2006). Effects of the transition time between muscle-tendon stretch and shortening on mechanical efficiency. *Eur J Appl Physiol*, 96(6), 665-671.
- Hirashima, M., Kadota, H., Sakurai, S., Kudo, K., & Ohtsuki, T. (2002). Sequential muscle activity and its functional role in the upper extremity and trunk during overarm throwing. *J Sports Sci*, 20(4), 301-310.
- Ikeda, Y., Miyatsuji, K., Kawabata, K., Fuchimoto, T., & Ito, A. (2009). Analysis of trunk muscle activity in the side medicine-ball throw. *J Strength Cond Res*, 23(8), 2231-2240. doi: 10.1519/JSC.0b013e3181b8676f.
- Kibler, W. B., Press, J., & Sciascia, A. (2006). The role of core stability in athletic function. *Sports Med*, 36(3), 189-198.
- Marshall, L., & McGill, S. M. (2010). The role of axial torque/twist in disc herniation. *Clin Biomech*, 25(1), 6-9. doi: 10.1016/j.clinbiomech.2009.09.003.
- McGill, S. M. (2002). *Low back disorders. Evidence-based prevention and rehabilitation*. Champaign, Illinois: Human Kinetics.
- McGill, S. M. (2006). *Ultimate back fitness and performance*. 2^a ed. Waterloo, Canada: Wabuno Publishers.
- Monfort-Pañego, M., Vera-Garcia, F. J., Sánchez-Zuriaga, D., & Sarti-Martínez, M. A. (2009). Electromyographic studies in abdominal exercises: a literature synthesis. *J Manip Physiol Ther*, 32(3), 232-244. doi: 10.1016/j.jmpt.2009.02.007.
- Ouergui, I., Hssin, N., Haddad, M., Padulo, J., Franchini, E., Gmada, N., & Bouhlel, E. (2014). The effects of five weeks of kickboxing training on physical fitness. *Muscles Ligaments Tendons J*, 14:4(2), 106-113.
- Salonia, M. A., Chu, D. A., Cheifetz, P. M., & Freidhoff, G. C. (2004). Upper-body power as measured by medicine ball throw distance and its relationship to class level among 10- and 11-year-old female participants in club gymnastics. *J Strength Cond Res*, 18(4), 695-702.
- Santana, J. C., Vera-Garcia, F. J., & McGill, S. M. (2007). A kinetic and electromyographic comparison of the standing cable press and bench press. *J Strength Cond Res*, 21(4), 1271-1279.
- Stodden, D. F., Campbell, B. M., & Moyer, T. M. (2008). Comparison of trunk kinematics in trunk training exercises and throwing. *J Strength Cond Res*, 22(1), 112-118. doi: 10.1519/JSC.0b013e31815f2a1e.
- Szymanski, D. J., Szymanski, J. M., Bradford, T. J., Schade, R. L., & Pascoe, D. D. (2007). Effect of twelve weeks of medicine ball training on high school baseball players. *J Strength Cond Res*, 21(3), 894-901.

- Vera-Garcia, F. J., Barbado, D., & Moya, M. (2014). Trunk stabilization exercises for healthy individuals. *Rev Bras Cineantropom Desempenho Hum*, 16(2), 200-211.
- Vera-Garcia, F. J., Flores-Parodi, B., Elvira, J. L., & Sarti, M. A. (2008). Influence of trunk curl-up speed on muscular recruitment. *J Strength Cond Res*, 22(3), 684-690. doi: 10.1519/JSC.0b013e31816d5578.
- Vera-Garcia, F. J., Moreside, J. M., & McGill, S. M. (2010). MVC techniques to normalize trunk muscle EMG in healthy women. *J Electromyogr Kinesiol*, 20(1), 10-16. doi: 10.1016/j.jelekin.2009.03.010.