2D Video Analysis of the Effects of TheraBand® CLX Neuromuscular Exercises on Overhead Deep Squat: An Observational Cohort Study

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Background: Overhead deep squat (OHDS) is used in both Functional Movement Screen (FMS™) and other systems to examine movement competency during squatting. There is little evidence examining the effectiveness of exercises in improving OHDS performance in individuals with stability dysfunctions.

Purpose: The purpose of this study is to determine the effect of low-level corrective exercises using TheraBand® CLX™ bands on OHDS performance in subjects with identified stability dysfunction during squatting.

Study Design: This is an observational cohort study.

Methods: In total, 59 healthy subjects (age, 18–40 years), participated in this study. Subjects were included if they demonstrated stability dysfunction during squatting and were excluded if they had a history of spinal or lower extremity injury or surgery and/or neurological or balance issues. Two-dimensional (2D) videos were used to record a preintervention (pre) OHDS in the frontal and sagittal views. Corrective exercises using TheraBand CLX were assigned on the basis of OHDS deficits. Subjects performed 3 sets of 15 repetitions of the assigned corrective exercises at a nonfatiguing workload, and postintervention (post) 2D videos were repeated. All videos were analyzed using Dartfish® Software to measure trunk angle, knee separation distance, and squat depth.

Results: Statistically significant differences were observed between pre and post measures of knee separation at 0° of knee flexion (P = 0.013) and 60° of knee flexion (P = 0.039), as well as trunk-to-floor angle at 60° of knee flexion (P = 0.020) and at full depth (P = 0.000). Pre and post measures of full squat depth and knee separation at full depth were not significantly different. The effect sizes of the measured variables were small to medium, ranging from 0.02 to 0.67.

Discussion: Corrective exercises using TheraBand CLX had several positive short-term statistically significant effects on OHDS mechanics. Small effect sizes were associated with knee separation (0° and 60°) and trunk angle at 60°, and a medium effect size was associated with trunk angle at full depth. Thus, movement changes observed in the postintervention squat cannot be fully attributed to the interventions.

Conclusion: Significant short-term changes with small-to-medium effect sizes were found in multiple outcome measures; however, it is questionable whether these changes would be clinically observable in a physical therapy or sports performance setting without the use of video analysis.

Keywords: Corrective exercises; movement System; overhead deep squat; TheraBand

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Key Points: Corrective exercises utilizing elastic resistance improved kinematic parameters in subjects with deficits in overhead deep squat mechanics. However, the differences were small-to-medium effect sizes which may not be clinically relevant or attributable to the intervention.

INTRODUCTION

Treatment of the movement system defines the practice of physical therapy. Many individuals demonstrate movement system dysfunction; yet, it is difficult to detect such dysfunction by simply observing an individual’s daily activities. With the use of simple screening or assessment tools, such as the Functional Movement Screen (FMS™) or the Selective Functional Movement Assessment (SFMA), a trained professional can identify imbalances and dysfunctions within the movement system by observing functional movement patterns that help guide therapeutic intervention.

The FMS can be used to identify movement limitations or asymmetries in uninjured populations through the performance of seven movement patterns. These seven patterns represent fundamental movements that place an individual in positions where weakness and imbalance become observable owing to insufficiency in mobility, stability, or balance. The reliability of the FMS has been widely examined, and it has been established as a reliable movement screening system. Interrater reliability (intra-class correlation coefficient [ICC] = 0.843) and intrarater reliability (ICC = 0.87) for composite scores of the FMS™ range from moderate to good.

The SFMA is an assessment used in those with suspected or identified pathology. It comprises specific movement patterns that provide a professional with the opportunity to identify an impairment that may be seemingly unrelated to the expected problem area, a concept referred to as regional interdependence. When an individual is unable to properly complete a movement pattern, the SFMA provides additional comprehensive algorithmic flow charts (also referred to as breakouts) that allow for further examination regarding whether the individual demonstrates a stability or mobility dysfunction. A mobility dysfunction is an underlying cause of a movement deficit owing to restriction of tissue extensibility or joint limitation(s). Conversely, a stability dysfunction is an underlying cause of a movement deficit owing to limitation of motor control. The SFMA is typically scored categorically, and this scoring system has shown substantial to excellent intrarater reliability among experienced raters ($\kappa = 0.72–0.83$). However, the interrater reliability was poor to substantial ($\kappa = 0.20–0.76$), with the most experienced raters having the highest interrater reliability.

The overhead deep squat (OHDS) is commonly used to assess function. The OHDS is performed when the individual stands with the feet approximately shoulder width apart with the toes pointing forward, roughly parallel. The individual holds a dowel overhead, grasped in both hands, with shoulders flexed and slightly abducted, and elbows fully extended. The individual descends into a squat position as far as he or she can while attempting to keep the dowel in position overhead, maintaining an upright torso and keeping the heels on the floor (Figure 1).

Patients and athletes participating in movement screens and assessments often demonstrate some form of dysfunction during OHDS movement, as it challenges range of motion, strength, and neuromuscular control of the extremities and trunk. In a study by Clifton et al., scores on OHDS had a moderate, positive correlation with composite FMS™ scores in NCAA Division I athletes ($r = 0.50, P < 0.001$). The results of their study show the utility of OHDS for predicting FMS™ performance overall. Moreover, Moran et al. reported acceptable (defined in the study as ICC ≥ 0.6) interrater reliability when scoring OHDS in real time. Because OHDS is reliable and may have predictive validity for the FMS™ as a whole, it is a useful and time-efficient test for movement competency.

There is limited research examining exercises used to address identified movement dysfunctions. Many health professionals have suggested various interventions to address dysfunctions observed during OHDS; however, many of these proposed interventions have not been studied to examine their effectiveness. Authors of prior studies have assessed the
effect of core stability and muscular imbalances on injury in various populations, but no interventions are proposed to mitigate those instabilities or imbalances, and none of these studies assessed the effect of low-level, nonfatiguing corrective exercises (i.e., those that target motor control) to address movement dysfunctions discovered during FMS and SFMA.\textsuperscript{13–15}

One manner of achieving low-level, nonfatiguing resistance exercise addressing the neuromuscular control system is through the use of TheraBand\textsuperscript{\textregistered} CLX\textsuperscript{\textsuperscript{TM}} bands (Performance Health, Akron, OH). The TheraBand CLX resistance bands (CLX) are beneficial in comparison with typical flat elastic resistance bands owing to the consecutive loops embedded into the CLX bands that allow for novel methods of attaching the bands to the body. Tyler et al. reported that physical therapy patients preferred CLX resistance bands over traditional bands 96\% of the time because of increased versatility and usability of the CLX elastic bands.\textsuperscript{16}

**PURPOSE/HYPOTHESIS**

The purpose of this study was to determine the effect of low-level corrective exercises using TheraBand CLX bands on the performance of OHDS in subjects with identified stability dysfunction during squatting. The authors hypothesized that the performance of a standardized TheraBand CLX resistance band squatting exercise regimen would improve short-term OHDS performance in individuals presenting with stability dysfunction during OHDS movement pattern.

**METHODS**

**Participants**

An \textit{a priori} power analysis was completed (effect size = 0.35, alpha = 0.05, power = 0.80), which suggested that 88 subjects were needed to be protected against a Type II error.

Normal, uninjured volunteers between the age of 18 and 40 years were recruited and included if they were able to perform a squat independently, if they were determined dysfunctional during OHDS portion of the FMS, and if they were determined to have stability dysfunction by OHDS breakout of the SFMA. Volunteers were excluded from the current study if they had a history of surgery or injury to the lower back, hips, knees, ankles, or feet in the 6 months before the study. Those with a disorder that affected balance, such as a history of vertigo from Meniere’s disease, a neurological disease, or peripheral neuropathy related to diabetes, were also excluded. Volunteers were excluded if they were determined to be limited in their ability to perform OHDS owing to mobility dysfunction or pain. Finally, they were excluded if they passed OHDS with a score of 3, indicating movement competency. The study was approved by Grand Valley State University Human Subjects Review Committee.

**Procedures**

Each participant completed an informed consent process and a medical screening form to identify any exclusion criteria. They then performed a warm-up of 5 min on an exercise bicycle at a self-selected speed. Three attempts on OHDS were performed and scored according to FMS procedures, using a standard directional script taken directly from the FMS instructions.\textsuperscript{1,2} Subjects who demonstrated impaired movement competency (scored 1 or a 2) on OHDS continued to the performance of the OHDS SFMA breakout algorithm. Those whose movement dysfunctions were caused by mobility limitations were excluded from the study. Those who had dysfunction related to stability/motor control dysfunction were included. Participants completed the remaining FMS screening tests and their height, weight, and anthropometric measurements were recorded; a self-report of the exercise level was recorded as descriptive information.

Latissimus dorsi length was measured by having the subject stand one foot length away from the wall with the body and back of the head held against the wall. Subjects actively flexed their shoulders while keeping...
their elbows extended until they were unable to maintain the starting position. A standard goniometer was used to measure the degree of shoulder flexion achieved.

Weight-bearing dorsiflexion was measured by placing an inclinometer on the anterior midpoint of the tibia while the subject shifted their weight as far over the foot as possible while maintaining heel contact with the ground (Figure 3).

Video recording

Bright pieces or strips of TheraBand kinesiology tape were used to mark bony landmarks on the hips, pelvis, trunk, knees, and ankles for 2D motion analysis. Participants’ movements were recorded using two laboratory-based digital video cameras (Sony DCR-TRV70 Mini DV, Sony Corporation, Tokyo, Japan) and a digital video mixer (Videonomics MXPro, VMA Media, Dana Point, CA). The cameras were placed on tripods (~15 feet from the subject), and the distance between the cameras and each subject remained constant during recordings. Videos were captured synchronously using standard frontal and sagittal views during the performance of a single repetition of OHDS per FMS protocol instructions.\(^1,2\) Depth of squat (full depth) during squat performance was chosen by each subject on the basis of individual ability and comfort, although subjects were cued to squat as far as they were able. Before video recording, participants were instructed to assume FMS-suggested foot placement positions for performance of OHDS, which was traced on paper, to standardize foot placement between pre- and postintervention performances.

After intervention, OHDS was repeated and video-recorded using the same protocol as the preintervention OHDS to assess acute, short-term effects of the intervention.

 Intervention

For resistance exercise to be considered low-level and non-fatiguing (or targeting the neuromuscular system), it needs to be dosed appropriately. Researchers have suggested that exercise that achieves muscle activation (as measured by electromyography [EMG]) of ≥60% of an individual’s 1-repetition maximum typically induces an effect that leads to strength gains and hypertrophy.\(^17,18\) Then, as resistance is lessened, interventions target lower threshold responses such as neuromuscular control.\(^3,17,18\) Intraset rest is also an important component of minimizing fatigue and targeting the neuromuscular system. When compared with traditional resistance training with no rest between sets, adding intraset rest has been shown to induce lower fatigue centrally and peripherally, as well as decrease cardiovascular stress.\(^19\) The TheraBand Resistance Intensity Scale for Exercise (RISE) (Figure 4) has been examined for its use in monitoring exercise during resistance exercise; it has been reported as an appropriate and valid tool for monitoring elastic band exercise intensity\(^20\) and was used to monitor exertion during exercise interventions in this study to ensure that it remained low.

On the basis of the stability deficits identified in the prescreen through the use of FMS and SFMA, one of four pre-established neuromuscular corrective exercises using TheraBand CLX was assigned (Figure 5). Subjects performed 3 sets of 15 overhead deep squats using the TheraBand CLX band in the assigned exercise condition, chosen on the basis of identified dysfunction(s). The CLX band color (resistance) was chosen on the basis of the degree of identified deficits,
and band length was chosen on the basis of subject height to maintain a nonfatiguing intervention. Each OHDS was performed to a self-selected half-depth squat in an attempt to keep the intervention at a non-fatiguing level. Following the first set of squats, the participant reported his or her fatigue level using the RISE scale. If the individual reported “moderate,” “hard,” or “maximal” fatigue level, a change was made in the CLX band by decreasing tension (changing hands in loops) on the same band or by moving to a band with lighter resistance. If the individual reported “easy” or “minimal,” he or she continued the intervention as performed in the previous set. Further, 60 s of rest was given between each set, and the fatigue level was assessed using the RISE scale following each set; 2 min of rest was given following the final set of the intervention before performing the post-intervention OHDS with video recording.

### Outcome measures

Outcome measures for each participant included the angle achieved at full depth squat, knee separation at 0° of knee flexion, knee separation at 60° of knee flexion, knee separation at full squat depth, trunk-to-floor angle at 60° of knee flexion, and trunk-to-floor angle at full squat depth. Each of these outcomes (Table 1) was analyzed during performance of the pre- and post-intervention OHDS. The data were analyzed using a paired t-test.

### Table 1. Description of 2D video analysis procedures for outcome measures

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>Description of Dartfish Measurement Procedure</th>
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<tbody>
<tr>
<td>Full Depth Squat (degrees)</td>
<td>Angle of the tibiofemoral joint at self-selected deepest squat position, measured using the frontal plane view</td>
</tr>
<tr>
<td>Knee Separation at 0° (inches)</td>
<td>Linear distance between markers on the central patellae, in upright stance, measured using the sagittal plane view</td>
</tr>
<tr>
<td>Knee Separation at 60° (inches)</td>
<td>Linear distance between markers on the central patellae at 60° of knee flexion (visualized on the frontal view video), measured using the sagittal plane view</td>
</tr>
<tr>
<td>Knee Separation at Full Depth (inches)</td>
<td>Linear distance between markers on the central patellae at full depth squat (visualized on the frontal view video), measured using the sagittal plane view</td>
</tr>
<tr>
<td>Trunk-to-Floor Angle at 60° (degrees)</td>
<td>Angle formed between the mid-axillary line of the trunk and floor at 60° of knee flexion visualized and measured using the frontal plane view</td>
</tr>
<tr>
<td>Trunk-to-Floor Angle at Full Depth (degrees)</td>
<td>Angle formed between the mid-axillary line of the trunk and floor at full depth squat visualized and measured using the frontal plane view</td>
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</table>
postintervention squats and the objective values were obtained from Dartfish™ 2D video analysis (Pinnacle Studio 16, Corel Corporation, Ottawa, Canada).

Data analysis and statistical procedures

Three researchers were involved in data collection and analyzing data on Dartfish. To assess intrarater reliability of video outcome measurements, each researcher performed data analysis on 10 randomly selected preintervention videos on Dartfish and returned to perform the same measurements on the same 10 videos two weeks later. Intrarater reliability was then determined by calculating ICC_{2,1} for each measurement made by each of the three researchers. ICCs were then averaged to provide a reliability ICC for each researcher. Researcher 1 showed a single-rater ICC of 0.82, while researchers 2 and 3 achieved single-rater ICCs of 0.84 and 0.89, respectively. These values indicate good intrarater reliability regarding video analysis for all researchers; therefore, all researchers participated in data analysis.

Paired t-tests were used to compare each outcome measure, and the associated effect sizes were calculated using Cohen’s d. An a priori alpha value was set at $P \leq 0.05$. Finally, linear regression modeling was used to determine predictors for trunk-to-floor angles while performing OHDS. All data were analyzed using SPSS (Version 20).

RESULTS

In total, 61 participants volunteered in the study; two participants were subsequently excluded owing to a score of 3 on the FMS OHDS. Of the 59 remaining participants, 35 female and 24 male participants were included. Descriptive data are provided in Table 2.

The greatest number of subjects showed a forward trunk dysfunction, knee varus, or a combination of both during squatting (Figure 6). Thus, the most commonly prescribed intervention was CLX attached to the arms and the knees (Figure 7), and this is depicted in Figure 5B.

Most subjects used either red ($n = 30$) or yellow ($n = 28$) CLX, while one subject used green CLX to attain neuromuscular level stimulus (Figure 8).

The mean change between pre- and postintervention measures for each variable is found in Table 3. A positive mean difference indicates the measure became larger and a negative mean difference indicates that the measure became smaller during the postintervention squat. Mean knee separation at 0° of knee flexion and 60° of knee flexion and at full squat depth became larger postintervention, indicating greater distance between the knees (less valgus), while separation became slightly less at full depth, indicating less distance between the knees (increased valgus). Mean trunk angle at 60° of knee flexion and full squat depth became larger (more upright) postintervention. Full squat depth angle became larger (less squat depth) postintervention.

![Figure 6. Subjects with identified OHDS dysfunctions.](image-url)
Statistically significant differences were found in knee separation at 0° of knee flexion ($P = 0.01$), knee separation at 60° of knee flexion ($P = 0.04$), trunk-to-floor angle at 60° of knee flexion ($P = 0.02$), and trunk-to-floor angle at full depth ($P = 0.00$). Knee flexion angle at full squat depth ($P = 0.13$) and knee separation at full squat depth ($P = 0.89$) were not significantly different between pre- and post-intervention (Table 3).

Effect sizes were calculated for all variables using formulas for Cohen’s $d$ and these ranged from 0.02 to 0.67 (Table 3). Trunk angle at full squat depth showed a medium effect size, while the other variables that were found to be significant showed a range of small effect sizes. Portney and Watkins interpreted effect sizes as small, medium, and large. A medium effect size implies that for the represented variable, the results can be applied clinically, and meaningful results are likely to be observed.

Regression modeling was used to examine the trunk-to-floor angle at 60° of knee flexion as the target (dependent variable), while age, gender, FMS composite score, body mass index (BMI), pelvic width, latissimus dorsi length, ankle dorsiflexion, hamstring length, hip flexor length, knee separation at 0° of flexion, and knee separation at 60° of knee flexion were used as the possible predictors (independent variables).

The linear regression model indicated that transformed data for full depth squat distance, BMI, and latissimus dorsi length were significantly related to the trunk-to-floor angle at 60° of knee flexion, with latissimus dorsi length contributing 50% to the model. The model accuracy was 30% (Table 4).

Table 5 illustrates the results of the linear regression model for the target variable being floor-to-trunk angle at full squat depth and all other possible descriptive data as independent variables. Both trunk lean at 60° and BMI were significantly related to trunk angle at full depth squat, with trunk lean at 60° contributing 43% to the outcome and transformed BMI data contributing 26%. The overall accuracy of this model was 49.8%.

**DISCUSSION**

The purpose of this study was to determine the effect of low-level corrective exercises using TheraBand CLX bands on OHDS performance in individuals with a stability dysfunction, as defined by the SFMA. Although multiple systems exist for identifying movement dysfunctions, no studies have identified and validated the most effective means of treating a movement dysfunction. By describing methods that efficiently address movement dysfunction, patient outcomes and cost of treatment could be positively affected. The results of this study indicate that low-level, nonfatiguing, corrective exercises had an effect on movement. More
specifically, the interventions administered had short-term, positive effects on four of the six biomechanical outcomes of OHDS in healthy, normal subjects.

**Knee separation**

Knee separation distance is a measure that may be affected by numerous aspects of an individual’s body, including bony anatomy, muscular strength, flexibility, and neuromuscular control. Knee separation was used to quantify and observe lower extremity alignment during squatting, because frontal plane projection angles are difficult to observe during OHDS, although reliably and validly assessable with 2D analysis and commonly used in single limb assessment.

<table>
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<tr>
<th>Table 3. Mean and mean change measurements for pre- and postintervention ODHS variables, statistical comparisons (paired t-tests), and effect sizes (Cohen’s d)</th>
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<tr>
<td><strong>Knee Separation</strong></td>
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<tr>
<td>at 0° Knee Flexion</td>
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<tr>
<td><strong>Preintervention mean</strong></td>
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<tr>
<td><strong>Postintervention mean</strong></td>
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<tr>
<td><strong>Mean change</strong></td>
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<tr>
<td><strong>P-value (2-tailed)</strong></td>
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<td><strong>Effect Size</strong></td>
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</table>

Bold values indicate statistically significant differences in pre- to postintervention measures.

<table>
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<tr>
<th>Table 4. Linear model summary for floor-to-trunk angle at 60° knee flexion</th>
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<tbody>
<tr>
<td><strong>Model Term</strong></td>
</tr>
<tr>
<td>Intercept</td>
</tr>
<tr>
<td>Latissimus Dorsi Length (degrees)</td>
</tr>
<tr>
<td>Full Squat Depth (degrees)</td>
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<tr>
<td>Body Mass Index (transformed)*</td>
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</tbody>
</table>

*Transformed data were used to meet assumptions of distribution normality.

<table>
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<th>Table 5. Linear model summary for floor-to-trunk angle at full squat depth</th>
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<tr>
<td><strong>Model Term</strong></td>
</tr>
<tr>
<td>Intercepts</td>
</tr>
<tr>
<td>Trunk Lean at 60°</td>
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<tr>
<td>Age (transformed)*</td>
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</tbody>
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*Transformed data were used to meet assumptions of distribution normality.
Mean knee separation distance during static standing increased 0.15 inches (1.3 cm) from preintervention to postintervention. Knee separation at 60° of knee flexion increased 0.22 inches (0.55 cm) from preintervention to postintervention (P = 0.04). Owing to foot placement being held constant using the foot tracings, these significant differences were likely due to changes in knee separation only.

One potential cause of the increase in knee separation could be greater neuromuscular recruitment of the hip abductors and external rotators following an intervention targeting the use of these muscles. For subjects presenting with valgus knees during the initial OHDS, the selected intervention included TheraBand CLX placed around the legs proximal to the knees, requiring the hip abductors and external rotators to remain active during squatting to keep tension on the TheraBand CLX. Researchers have shown that an increase in strength/neuromuscular function of the gluteus medius muscle, a hip abductor and external rotator, results in a greater knee varus (knee separation). In the current study, it is possible that the intervention resulted in slightly greater knee varus positioning during static standing and dynamic movement at submaximal range owing to the increased activation of the gluteus medius, hip abductors, and hip external rotator muscles. A more valgus knee position (also known as a greater Q-angle) has been shown to increase the risk of athletes sustaining several knee injuries, including anterior cruciate ligament (ACL) tears, medial collateral ligament (MCL) tears, and meniscus tears. However, muscular activation was not objectively quantified, as EMG was not performed. If increased activation of the aforementioned muscle groups was achieved, the positive short-term effect of this change could prove beneficial, as this change in positioning could contribute to decreasing injury risk, according to the current literature. The duration of this acute effect is unknown, however, and it is uncertain whether 1.3 cm or 0.55 cm changes are sufficient to make a significant difference in injury prevention. Because a positive change was noted, further exploration of the effects and their ramifications is warranted.

Another potential explanation is the increased proprioceptive acuity that may have ensued as a result of the CLX band surrounding the knee during the intervention. Wearing a patellar strap has been shown to improve knee joint proprioception in a healthy population, more markedly in those with lower proprioceptive acuity. A change in proprioceptive acuity may have occurred during the present study owing to similar mechanisms, as wearing a strap because of the placement of the CLX band during the intervention. It is possible that as the knees were being pulled inward by the force of the CLX band during the intervention, the subjects became more aware of their knee joint positioning, and as a result, they may have acquired greater proprioceptive acuity at the knee both during static standing and dynamic movement.

Proprioceptive differences are difficult to empirically test, as there is presently no universally accepted method to measure proprioceptive acuity. It is also uncertain whether this phenomenon would last and, therefore, if it indeed could play a role in knee positioning during activity. It is also important to note that the current study did not have a control group, and changes that occurred in the second trial may also have occurred without an intervention owing to a learning effect. However, statistically significant differences with small effect sizes were achieved after one brief intervention period, and further research should be conducted to assess similar outcomes after numerous neuromuscular training sessions.

In contrast to standing and at 60° of knee flexion, knee separation distance did not significantly change from pre- to postintervention at full squat depth. The mean value decreased an average of 0.02 inches (0.04 cm) for all subjects, which indicates that it essentially remained the same. One plausible explanation for this finding is that the interventions used required the subjects to perform only partial squats. The chosen interventions did not directly target any measures at full squat depth; thus, it is possible that the improvements seen in knee separation at earlier phases of the squat are movement-specific, and did not carry over to full squat depth.

While statistically significant, clinical relevance of the change in the two knee separation measures should be interpreted with caution. The magnitude of the mean change in a subject’s knee separation angle may not be large enough to show visually observable change when not assessed using Dartfish measurements.

Trunk-to-floor angle

The angle of the trunk relative to the floor was obtained using Dartfish measurements, and it was hypothesized to be related to the ability of the subject to control the upper body on the pelvis using the muscles of the hips, core, and spine. A statistically significant difference (P = 0.02) was noted between pre and post trunk-to-floor measures taken when the subject reached 60° of knee flexion. The mean magnitude of difference at 60° knee flexion was 0.97° toward vertical, and a mean 2.33° improvement in trunk angle toward vertical (P = 0.00) was found at full squat depth. Both of these changes represent changes in the direction of a more upright trunk after interventions.

For subjects who demonstrated trunk angle dysfunction, interventions with TheraBand were used to provide resistance to trunk extension with the intent of...
promoting improved activation of hip and lumbar extensors and pelvic/core stabilizers.

Typically, as one descends deeper into the OHDS movement, a less vertical trunk is observed. This is likely because of increased muscle compensation (tightness of posterior structures) and greater demand on stabilizing core musculature as the movement progresses into more extreme positions. Because the trunk-to-floor angle is typically worse at full depth, subjects may have had more room for improvement postintervention. This is a potential explanation for greater magnitude of change in trunk-to-floor angle at full squat depth compared to 60° of knee flexion.

In a study by Saeterbakken et al., surface EMG was assessed while adding elastic resistance to a squat in order to increase activation of the erector spinae, external obliques, and rectus abdominis. Although their results did not show greater surface EMG activity with banded resistance versus traditional resistance, elastic resistance did achieve substantial activation of the aforementioned core-stabilizing muscles in a similar manner to traditional resistance. The results by Saeterbakken et al. may explain the statistically significant improvements seen in trunk-to-floor angle in the current study, as banded resistance does have the potential to increase muscle activation. Increased muscle activation and neuromuscular control of these muscle groups during intervention may contribute to the improved trunk angle measured at 60° and full squat depth.

While statistically significant, the magnitude of the mean change in a subject’s trunk-to-floor angle may not be large enough to show observable and meaningful change when applied outside of the research setting or when using less precise tools for measurement. However, these interventions do have the potential for clinically relevant effects, as a significant difference in the desired direction was achieved. In a typical rehabilitation setting, practitioners might use a goniometer or inclinometer to measure changes after an intervention, as they have both been proven to have good intrarater reliability. However, the dynamic nature of the movement would make measuring these differences very difficult using typical tools. Even if the practitioner were able to quantify the difference between pre and post measures of trunk angle with one of these tools, the change, according to the results of this study, would likely be smaller in magnitude than the standard measurement error of the tool. The interventions used in the current study could be adjusted or carried out for a longer period of time over several sessions to elicit a clinically observable difference in addition to the statistically significant differences that were observed.

Full depth squat

Full depth squat was one of two measured variables that did not show a statistically significant difference (P = 0.13) between pre- and postintervention measures. This indicates that subjects essentially squatted to the same depth pre and post measures. There are numerous explanations as to why this occurred. First, while the interventions were designed to indirectly affect squat depth by increasing stability during the OHDS movement, they did not directly influence the overall squat depth. The subjects only performed half depth squats during the nonfatiguing and low-level interventions. During both pre and post measures, the subjects were instructed to squat to their maximum achievable depths and then return to standing. Thus, they likely squatted to similar depths, which was perceived as their maximum achievable depths.

Effect sizes

Effect size is an important consideration when applying the results of the current study to clinical practice. Although mean changes in variables may be determined statistically significantly different, effect size aids in the determination of whether that change is likely to demonstrate clinical importance. If a change is statistically significant but has a small effect size, it is less likely that the observed change will result in meaningful change when applied clinically. The effect sizes calculated for the observed variables ranged from 0.02 to 0.67.

The effect sizes showed a range of small-to-medium effects. A small effect size is interpreted as having minimal clinical effect, and a medium effect size implies that the results can be applied clinically, as meaningful results are likely to be observed. Thus, clinically meaningful changes in trunk lean in at full depth are likely to be seen after this intervention, while knee separation values would likely show minimal clinical effects due to the intervention.

Regression analyses

Finally, linear regression was used to investigate whether a model existed for predicting the floor-to-trunk angle at 60° knee flexion or full depth squat. Predicting floor-to-trunk angles and identifying if any of the independent variables influence these measurements may be important in identifying contributors to movement pattern deficits and selecting interventions to correct faulty movement patterns and prevent injury. The linear model was determined to be the best predictive model on the basis of model error when compared to other potential models. The model indicated that significant predictors for floor-to-trunk angle at 60° knee flexion included lattissimus dorsi length, full squat depth in degrees, and BMI transformed. The overall model accuracy was 30%. The model accuracy (indicating how often predictions are correct and truly predictive) was low, but it is unknown if this model accuracy is suitable.
for this type of data because there are no other published reports examining predictive modeling for OHDS. The greatest contributor (50%) to the model for trunk lean at 60° was latissimus dorsi length, indicating that this factor should be examined in those who are unable to squat competently. Although all subjects in the current study were not considered to have mobility dysfunction leading to their inability to squat, latissimus length was still a significant contributor to trunk lean.

The second model examined the independent variables and their influence on trunk-to-floor angle at full squat depth. Trunk-to-floor angle at 60° of knee flexion and age transformed were the 2 independent variables that were statistically significant, and the overall model accuracy was 49.8%. However, the use of transformed coefficients in both models add some difficulty in predicting a clinically relevant measurement for the dependent variable of trunk-to-floor angle.

Although both linear models indicate <50% accuracy for overall model accuracy, they may be excellent prediction models and should be considered when evaluating the ability of variables to predict the floor-to-trunk angles during OHDS.

To the authors’ knowledge there is no other published research regarding predictive modeling for the use of corrective exercises with OHDS or any other FMS movement patterns. This area of statistical modeling should be further investigated.

LIMITATIONS

The current study had several limitations. First, the sample population included only healthy normal subjects ranging in age from 18 to 40 years, which therefore limits the generalizability of the findings to a broader population. Also, a control group was not included in the study. Because of this, results cannot be attributed to only the interventions provided, as participants may have improved even without the intervention owing to a potential learning effect from performing the same movement multiple times. Furthermore, the study looked at only the immediate effects the corrective exercises had on OHDS mechanics, and any conclusions gleaned from the study can be applied to only the performance of an OHDS immediately following the intervention. Another limitation includes the fact that the hip rotation profile was not taken into account for each of the participants before performing OHDS. The standardized instructions and procedures used during the study forced the participants to keep his/her feet pointed generally forward, which may have negatively impacted full squat depth for those with greater hip anteversion or retroversion. There are inherent limitations of the computer software and cameras used for the measurement of OHDS, including distortion and pixelation of the recording, potentially influencing the accuracy of the measurements. However, reliability results demonstrate good-to-excellent reliability of the researchers using the software and cameras, so this is likely not a large limitation. Finally, there is a possibility for a Type II error to have occurred, as the study had only 59 participants owing to time constraints during data collection.

CONCLUSIONS

Statistically significant improvements were shown in knee separation at 0° of knee flexion, knee separation at 60° of knee flexion, trunk-to-floor angle at 60° of knee flexion, and trunk-to-floor angle at full depth from pre- to postintervention following a short-term, neuromuscular-targeted intervention using CLX elastic resistance. These improvements could represent improved levels of movement control at the knees and trunk. The effect sizes for the observed variables in the study ranged from small to medium with only trunk angle at full squat depth having a medium effect size, indicating that trunk angle at full depth could likely be clinically influenced by the intervention. Trunk lean at 60 degrees was influenced by the latissimus dorsi length. Caution must be used when interpreting statistically significant results, as they may not be clinically visually observable in a physical therapy or sports performance setting. Further investigation of neuromuscular interventions for movement corrections is warranted.

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