MUSCLE ACTIVITY DURING FUNCTIONAL COORDINATION TRAINING: IMPLICATIONS FOR STRENGTH GAIN AND REHABILITATION

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ABSTRACT

Jørgensen, MB, Andersen, LL, Kirk, N, Pedersen, MT, Søgaard, K, and Holtermann, A. Muscle activity during functional coordination training: implications for strength gain and rehabilitation. *J Strength Cond Res* 24(7): 1732–1739, 2010—The purpose of this study was to evaluate if different types, body positions, and levels of progression of functional coordination exercises can provide sufficiently high levels of muscle activity to improve strength of the neck, shoulder, and trunk muscles. Nine untrained women were familiarized with 7 functional coordination exercises 12 times during 4 weeks before testing. Surface electromyographic (EMG) activity was obtained from rectus abdominus, erector spinae, obliquus externus, and trapezius during the exercises with 2–4 levels of progression. Electromyography was normalized to the maximal EMG activity during maximal voluntary contractions, and a p value < 0.05 was considered significant. All recorded muscles reached sufficiently high levels of activity during the coordination exercises for strength gain ($>$60% of maximal EMG activity). Type of exercise played a significant role for the attained muscle activity. Body position during the exercises was important for the activity of the erector spinae, and level of progression was important for the activity of the trapezius. The findings indicate that depending on type, body position, and level of progression, functional coordination training can be performed with a muscle activity sufficient for strength gain. Functional coordination training may therefore be a good choice for prevention or rehabilitation of musculoskeletal pain or injury in the neck, shoulder, or trunk muscles.

KEY WORDS functional coordination training, muscle strength, electromyography, rehabilitation

INTRODUCTION

Muscle strength is important for the longevity of life without pain (13). Furthermore, strength training can be effective as treatment and prevention of musculoskeletal pain (2,6). Besides muscular strength, improved coordination skills may be critical for prevention of musculoskeletal pain. Persons with musculoskeletal pain are observed to have an impaired coordination compared with healthy controls (8,10,17,18). Therefore, coordination exercises are generally recommended for preventing and reducing musculoskeletal pain (11). The main advantage of functional coordination exercises is that several muscle groups are simultaneously activated, reflecting the muscle activity pattern during daily work tasks, and might therefore function as a preventive strategy toward work-related pain. Moreover, the high muscle activation with less stress on joints and muscles during functional instable exercises is generally considered beneficial for general musculoskeletal health and rehabilitation (5). However, a limitation of functional coordination training is a lack of increase in muscular strength (1,15). If coordination training can be performed with sufficient intensity to also induce a strength gain, this may further enhance its value compared to other types of prevention and rehabilitation exercises for musculoskeletal pain and injury.

A muscle activity level of 60% of maximal voluntary activity is generally considered necessary for gaining strength (3,16). Although a high level of muscle activity can be easily attained during traditional strength training by enhancing the external load, it is not so easily achieved during complex functional coordination exercises and conventional therapeutic exercises (4). This may explain the lack of strength gain from functional coordination training in previous studies.

The muscle activity during functional coordination training can mainly be modulated by voluntarily activating the muscles more intensely, by changing body positions or by applying higher levels of difficulty (progression) in each exercise. However, activity of the neck, shoulder, and trunk muscles remains to be studied during different types, body

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positions, and levels of progression of functional coordination exercises.

The aim of this study was to evaluate if different types, body positions, and levels of progression of functional coordination exercises can provide sufficiently high levels of muscle activity to improve strength of the neck, shoulder, and trunk muscles. The hypotheses of the study were that (a) the type of functional coordination exercise is important for the attained level of activity in the neck, shoulder, and trunk muscles where some exercises evoke sufficient levels of muscle activity for strength gain and (b) the body position and level of progression of the functional coordination exercises are important for the level of activity in trunk, neck, and shoulder muscles.

METHODS

Experimental Approach to the Problem

For testing the hypotheses of the study, the activity in the neck, shoulder, and trunk muscles was recorded by surface electromyography (EMG) during functional coordination exercises of different types, body positions, and levels of progression in women with musculoskeletal symptoms familiarized to these exercises.

Subjects

Nine sedentary untrained female workers (mean [*SE*] age: 46 [±2.4] years, height 167 [±1.5] cm, weight 68 [±3] kg) were recruited from a day care office. Neither of the subjects had a higher level of training background of any significance. They reported pain in the neck, shoulder, upper back, or lower back during the past year on a 10-cm Visual Analog Scale. All subjects reported pain in one or more of the following body parts: neck, shoulders, and lower back corresponding to an average pain reporting of 2.3 (±1.0). The project was carried out in spring (March–April).

Appropriate informed consent has been gained from the subjects. The study was performed in accordance with the declaration of Helsinki and approved by the local ethics committee H-C-2007-0033.

Procedures

To attain valid and reliable information about level of muscle activity during different types and levels of functional coordination training, the subjects need to be well familiarized with the exercises (12). Therefore, the subjects received instructions and practiced on the functional coordination exercises for 4 weeks before the muscle activity recordings were performed. The practice of the exercises consisted of 3 sessions of 20-minute duration per week. In Figures 1 A–G, the 7 functional coordination exercises with 2–4 levels of progression are illustrated. Level 1 is the most complex level of progression with decreasing progression level with numbers 2–4, that is, the highest level of muscle activity

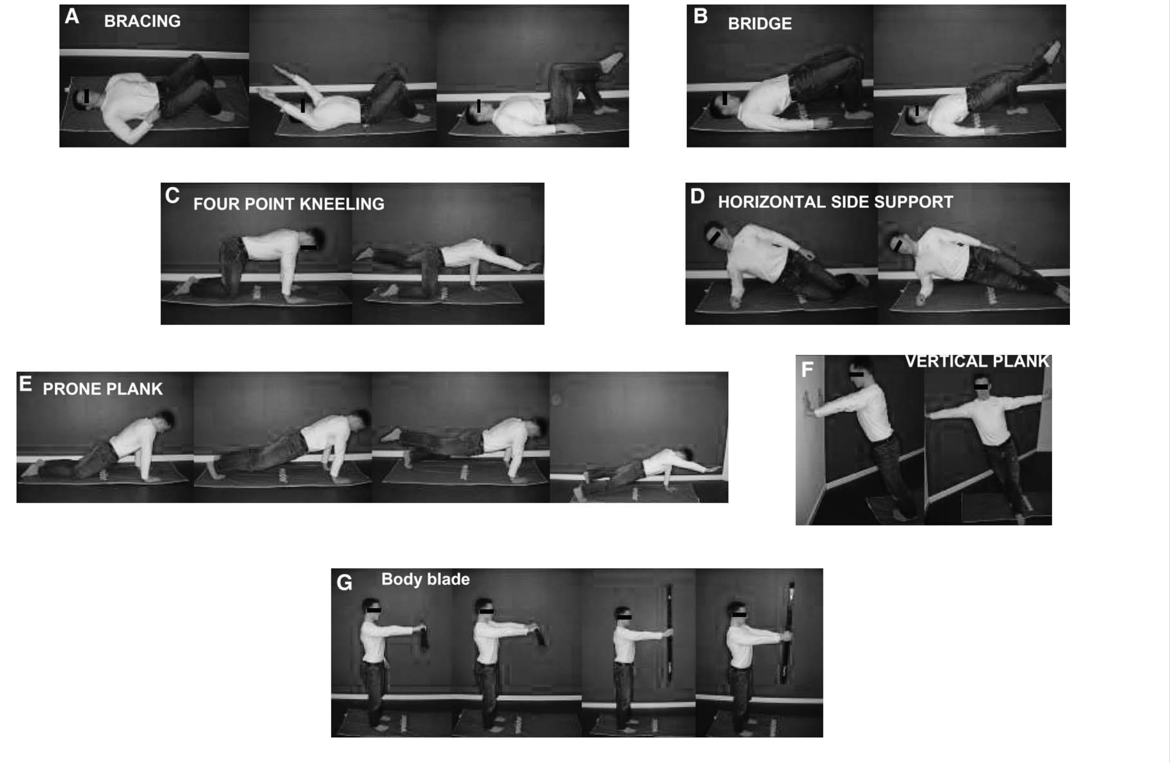

Figure 1. Illustration of the functional coordination exercises: A) bracing, B) bridge, C) 4-point kneeling, D) horizontal side support, E) prone plank, F) vertical plank, and G) bodyblade. The subject has given permission for the use of this figure.

was expected at level 1. Four exercises (4-point kneeling, prone plank, bracing, and bridge) were performed in prone or supine-lying body positions, and horizontal side support was performed in sideways-lying positions, whereas bodyblade exercises and vertical plank were performed standing. The spine and neck were held in an anatomically neutral position with shoulder blades neutrally protracted during all exercises. Participants were instructed to activate relevant muscles all-out for 20 seconds during static exercises and for 8 repetitions during dynamic exercises. The dynamic exercises were performed in an even and controlled manner, with a pace of approximately 2 seconds per movement and in the following order: Four-point kneeling levels 3, 2, 1, prone plank levels 4, 3, 2, 1, bracing levels 3, 2, 1, bodyblade levels 4, 3, bridge levels 2, 1, vertical plank levels 2, 1, horizontal side support levels 2, 1, bodyblade levels 2 and 1. The subjects rested approximately 1 minute between exercises.

Bracing. Bracing was performed with subjects supine on the floor with hips and knees flexed at a 90° angle and feet on the floor and at 3 levels of progression (Figure1A). At level 3, subjects focused on stabilizing the trunk by activating the abdominal muscles. At level 2, subjects dynamically extended their arms to almost 180° extension. At level 1, subjects dynamically flexed the hip to 90° flexion, so the foot was lifted from the floor.

Bridge. The subjects were supine on the floor with hips and knees flexed at a 90° angle and feet on the floor. The exercise was performed at 2 levels of progression as shown in Figure 1B. At level 2, the hip was dynamically extended to 0° while the subjects focused on stabilizing the trunk. At level 1, the hip and knee were statically extended to 0°, lifting the foot from the floor.

Four-Point Kneeling. The subjects were prone in a 4-point stand with knees hip width apart and hands shoulder width apart and hip and knees 90° flexed (Figure 1C). The exercise was performed at 2 levels of progression. Level 2 was performed with no dynamic movement, only focusing on stability of the trunk and shoulders, while one shoulder and the contralateral hip/knee were simultaneously extended in level 1, so the arm and the leg were horizontally stretched.

Horizontal Side Support. Horizontal side support was performed at 2 different levels of progression as shown in Figure 1D. At level 2, subjects were in side-lying position with only knee and elbow resting on the floor. At level 1, subjects were in a side-lying position with only one foot and elbow resting on the floor.

Prone Plank. Prone plank was performed at 4 levels of progression as shown in Figure 1E. At level 4, the subjects were prone with their knees and hands on the floor shoulder width apart. At level 3, subjects were prone on their feet and hands. At level 2, subjects dynamically extended one hip to lift the foot from the floor. At level 1, subjects dynamically extended their shoulder to lift the hand from the floor.

Vertical Plank. Subjects leaned forward with their hands resting on the wall shoulder width apart and their body approximately 70° to the floor (Figure 1F). Shoulders were 90° extended. The exercise was performed in 2 levels of progression. At level 2, subjects stood statically in this position, focusing on stabilizing the trunk and shoulders. At level 1, subjects rotated their feet 90° in relation to the floor and performed a bilateral shoulder abduction at the horizontal level, so only one arm supported the body against the wall.

Bodyblade. The bodyblade exercise was performed in 4 levels of progression. Subjects stood on both feet hip width apart. As shown in Figure 1G, subjects stood with the dominant shoulder at 90° flexed position holding a bodyblade (Bodyblade Classic, NMK import, Bringevej 1B DK-3500 Værløse, Denmark) horizontally in their hand at level 4. Small extensions and flexions of the shoulder were performed to make the bodyblade oscillate. Level 3 was similar to level 4 with both hands holding the bodyblade. At level 2, the bodyblade was held by one arm in a vertical position. Small abductions and adductions of the shoulder at the horizontal level were performed to make the bodyblade oscillate. Level 1 was similar to level 2 with both hands holding the bodyblade.

Maximal Voluntary Contraction

To attain maximal levels of EMG activity for each muscle, isometric maximal voluntary contractions (MVCs) were performed in backward extension and forward flexion of the trunk and shoulder elevation in accordance to validated standard procedures (9). The subject was verbally instructed (and encouraged) to slowly increase force, maintain a maximal level for ~2 seconds and then slowly reduce the force. Each measurement of muscle strength was repeated 3 times with 30-second rest between and if the force increased more than 5% an additional MVC was performed up to maximum 5. Because of elevated blood pressure (>100/140 mm Hg), 3 subjects were excluded from the MVCs.

Electromyography

Bipolar surface EMG electrodes (6-mm diameter, Neuroline 725-01-k, Medicotest A/S, Rugmarken 10, DK-3630 Ølstykke, Denmark) were placed on the skin with an interelectrode distance of 2 cm of the dominant side according to standard procedures above the rectus abdominus (3 cm lateral to the umbilicus), external oblique (15 cm lateral to the umbilicus), erector spinae (3 cm lateral to the spine at the level of crista iliaca), and trapezius (2 cm medial to the midpoint between acromion and the spinous process of C7). The reference electrode was placed on the spinous process of C7.

The EMG signals were sampled at 1,000 Hz (Datalogger, Logger teknologi HB, Sweden), amplified, analog band-pass filtered (10–400 Hz, eighth order, Butterworth), AD converted at 1 kHz, and recorded on computer via a laboratory interface (CED 1401, Spike2 software, Cambridge Electronic Devices, Cambridge, United Kingdom). The EMG amplitude was calculated by root-mean-square (RMS) with nonoverlapping windows of 500 milliseconds. Start and end of each repetition of all exercises were marked with a trigger. For the dynamic functional coordination exercises, peak RMS EMG amplitude of each repetition was averaged from the first 4 repetitions of each exercise. The average of the first 4 repetitions of each exercise was done to get representative information of the maximal activity in each exercise. For static functional exercises, peak RMS EMG amplitude was averaged during the first half of the exercise minus the first 2 seconds. The first half of the exercise minus the very first 2 seconds was used because of a very stable performance of the exercises in this part. During the MVCs, the peak RMS EMG amplitude with a time window of 500 milliseconds was calculated (peak EMG [mean (*SE*)]): trapezius = 567.44 (±177.62) mV, erector spinae = 103.63 (±25.9) mV, obliquus externus = 95.20 (±11.43) mV, rectus abdominus = 83.29 (±15.20) mV. The RMS EMG activity from each muscle during the functional coordination training were normalized to the peak RMS EMG activity from each respective muscle from each respective subject during the MVCs. This was performed to attain the relative activity of each respective muscle during the functional coordination exercises. All tests were performed in the midday or afternoon, and the subjects were informed to eat and drink appropriately before the testing. The subjects were offered water during the testing.

Statistical Analyses

Analysis of variance for each muscle and Tukey–Kramer's post hoc tests was used to test differences in muscle activity between the different exercises. From each type of exercise only the progression level with highest muscle activity was applied in the test. General Linear Model was used to test the effect of level of progression, and Tukey–Kramer's post hoc tests were used to specify differences. An adjusted p value ≤ 0.05 was used as level of significance. Results are presented as mean ± *SE*. Statistical analyses were conducted with SAS version 9 (SAS institute Inc., 100 SAS Campus Dr., Cary NC 27513-2414). Because 3 subjects were excluded from the MVCs, the descriptive statistics on the normalized EMG activity were based on 6 subjects. However, all statistical tests were performed on absolute EMG values of the 9 participating subjects with within-subject comparison only.

A difference of less than 15% between exercises was considered clinically insignificant. This was based on recommendations from general strength training literature (e.g., recommendations on hypertrophy 70–85% of 1 repetition maximum (RM) or muscular power 85–100% of 1RM) (16). Power analysis made before the study showed that 8 subjects in this paired design were sufficient to obtain a statistical power of 80% at a minimal relevant difference of 15%, a type I error probability of 1%, and assuming a standard deviation of 10% based on previous research in our laboratory (3).

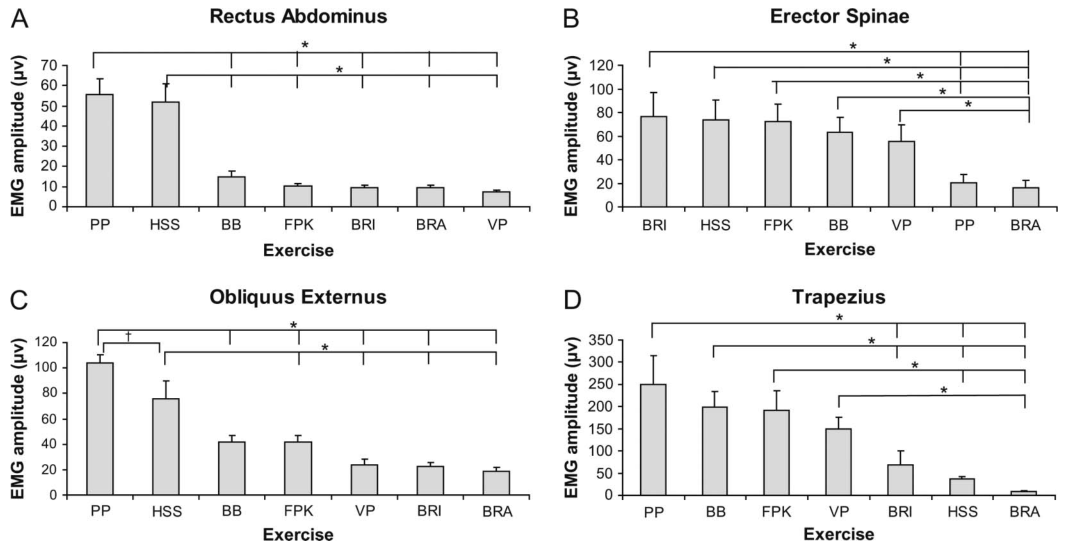

Figure 2. Muscle activity during the 7 functional coordination exercises for A) Rectus abdominus, B) Erector spinae, C) Obliquus externus, and D) Trapezius. The muscle activity is presented in absolute values. Level of difference between exercises has been marked. *$p < 0.001$, †$p < 0.01$. Error bars represent *SEM*. HSS = horizontal side support; PP = prone plank; FPK = 4-point kneeling; VP = vertical plank; BRI = bridge; BB = bodyblade; BRA = bracing.

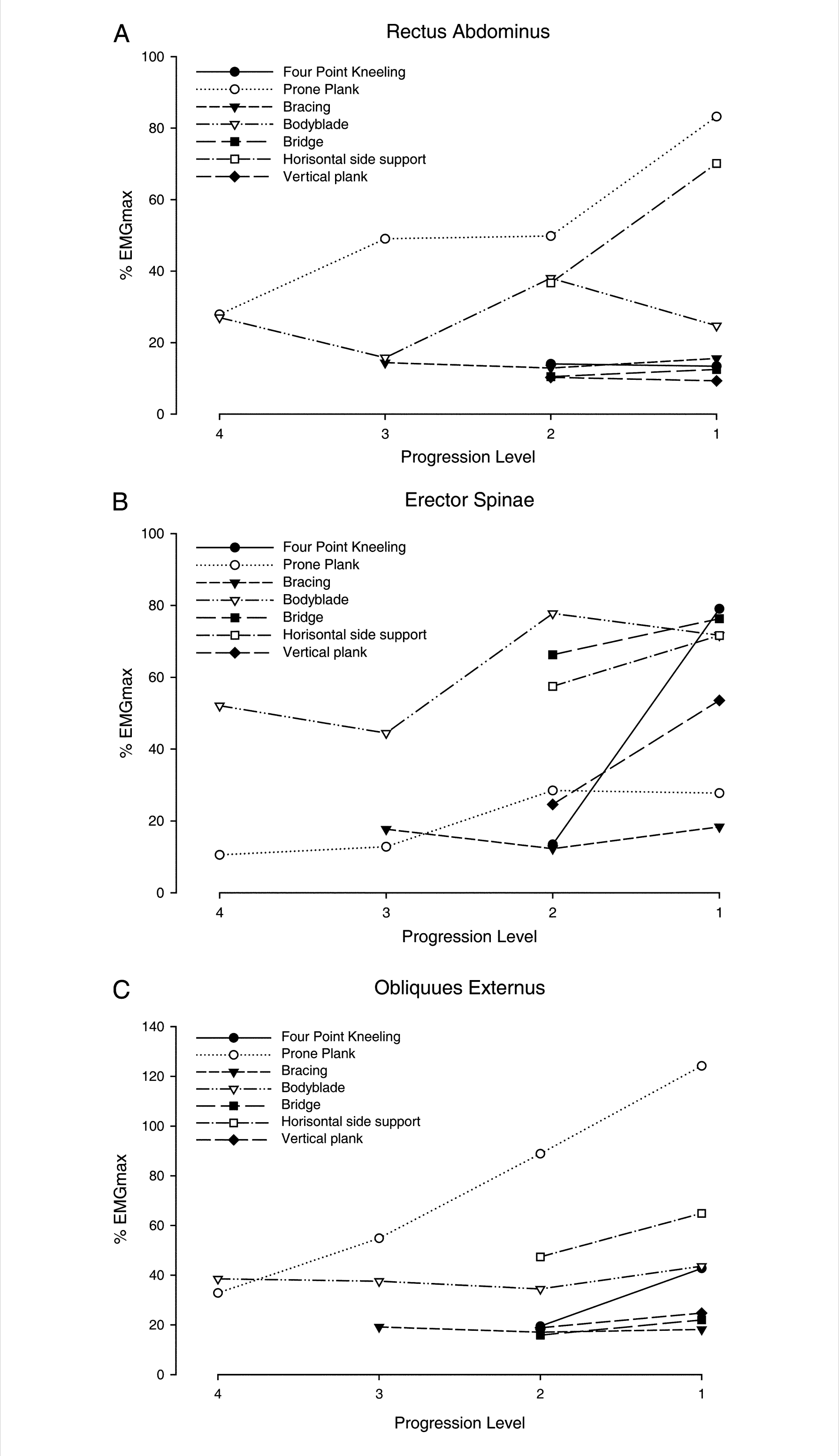

Figure 3. Muscle activity at different levels of progression during the exercises from A) Rectus abdominus, B) Erector spinae, C) Obliquus extremus. The muscle activity during the functional coordination exercises was normalized to the maximal muscle activity during the maximal voluntary contractions.

RESULTS

Exercise Type and Activation above 60% Maximal Voluntary Contractions

As illustrated in Figure 2A–D, the type of exercise had a significant impact on the level of activity of the different muscles ($p < 0.05$).

The average activity of the muscles studied during the different functional coordination exercises is illustrated in Figures 3A–C. As illustrated in the figure, depending on exercise and level of progression, all muscles reached a level of activation above 60% EMGmax.

For the upper trapezius, activity above 60% EMGmax was reached with horizontal unilateral bodyblade (73.9 ± 5.1%) and horizontal bilateral bodyblade exercise (84.9 ± 7.5%). Erector spinae exceeded 60% MVC in 4-point kneeling (79 ± 11.7%), horizontally bilateral bodyblade (77.7 ± 8.1%), bridge (76.3 ± 6.3%), horizontal side support (71.6 ± 10.2%), and vertical bilateral bodyblade (71.7 ± 7.3%). Obliquus externus exceeded 60% MVC in prone plank level 1 (124.2 ± 24%), prone plank level 2 (88.9 ± 22.4%), and horizontal side support (64.9 ± 7.8%). Rectus abdominus reached the 60% MVC level in prone plank level 1 (87.7 ± 10%) and in horizontal side support (70.1 ± 10.1%).

Body Position

For the erector spinae, the standing and sideways exercises resulted in a higher activity (36.7–90.5 mV) in comparison with the prone and supine exercises (19.2–71.8 mV) ($p < 0.05$). Body position did not have any significant effect on muscles activity for any other muscles.

Exercise Level of Progression

The level of progression generally played a significant role for the level of muscle activity ($p < 0.001$), but based on the post hoc test this was only significantly so for the trapezius muscle. For the trapezius, progression of the prone plank from levels 4 to 1 ($p > 0.001$), and 3 to 1 ($p < 0.001$) significantly elevated the activity. There was a tendency to a difference between levels 2 and 1 ($p = 0.05$). Trapezius activation significantly increased from levels 2–1 of the 4-point kneeling ($p = 0.03$). For the vertical plank, progression from levels 2–1 increased the trapezius activity ($p = 0.01$). For the Bodyblade exercise, the different levels of progression provided different trapezius activity, in which level 4 provided higher activity than level 1 ($p = 0.02$).

The levels of progression of the bridge, horizontal side support, and bracing (illustrated in Figure 3A) did not play a significant role for the trapezius activity.

Rectus Abdominus Muscle Activity

By far the highest activation of rectus abdominus was found during prone plank and horizontal side support (Figure 2A). Prone plank activated the rectus abdominus significantly more than the rest of the muscles except horizontal side support. Horizontal side support resulted in significantly higher rectus abdominus activity than the remaining exercises. Among the remaining exercises, no differences in rectus abdominus activity were found, but vertical plank provided the lowest activation.

Erector Spinae Muscle Activity

Bridge, horizontal side support, and 4-point kneeling resulted in the highest activity of the erector spinae. The activity during these exercises was significantly higher than in prone plank and bracing (Figure 2B). Bodyblade showed a significantly higher activation level than bracing. Moreover, vertical plank showed a significantly higher erector spinae activation than bracing, providing the lowest erector spinae activity.

Obliquus Externus Muscle Activity

As shown in Figure 2C, prone plank resulted in the highest obliquues externus activity, being significantly higher than all other exercises. The level of obliquus externus activity during prone plank was followed by horizontal side support, being significantly higher than the rest of the exercises except bodyblade. Between the remaining 5 exercises, no significant differences in obliquus externus activity were found. Bracing though, resulted in the lowest activity of obliquus externus.

Trapezius Muscle Activity

As seen in Figure 2D, the highest activity of the trapezius was found in prone plank and bodyblade. During those exercises, the trapezius activity was significantly higher than during bridge, horizontal side support, and bracing. Four-point kneeling resulted in higher trapezius activation than horizontal side support and bracing. Vertical plank activated the trapezius significantly more than bracing. The lowest trapezius activity was found during bridge, horizontal side support, and bracing, in between which, no significant difference in level of muscle activity was found.

DISCUSSION

The main findings of this study were that untrained women can attain sufficiently high levels of activity in neck, shoulder, and trunk muscles for strength gain during functional coordination exercises. However, the activity of the respective muscles depended on type, body position, and level of progression of the functional coordination exercises.

A novel finding of this study was that muscle activity during functional coordination exercises depended on type, body position, and level of progression within each exercise. As we hypothesized, the type of exercise was important for the attained activity of each respective muscle of the neck, shoulder, and trunk. The significantly different activity of the recorded muscles during several of the functional coordination exercises illustrates the need for prescribing specific exercises for specific purposes. Therefore, the results of this study may be useful for designing specific exercise programs based on functional coordination training for populations with need for strengthening neck, shoulder, and trunk muscles in a controlled and functional manner. Because several exercises generate sufficiently high levels of muscle activity for strength gain in most of the recorded muscles, other considerations can be brought into play when deciding which exercise to use in an individualized clinical exercise program. For example, the exercises prone plank and horizontal side support provided very high activity of the abdominal muscles. The bracing exercise, which is also an often applied exercise for the abdominals, generally resulted in low abdominal activity (10–20% of maximal) and cannot be considered a strengthening exercise for untrained subjects. Exercises involving isometric muscle contractions without external resistance are earlier shown to generate insufficient levels of muscle activity for strength gain (4). However, the bracing exercise may still serve a purpose in the early part of a training program, where the goal is to improve the ability to contract the muscles without an external resistance, for example, after Caesarean section or other kinds of open surgery involving the abdominal wall.

The normalized EMG data indicated that functional coordination exercises can activate trunk and shoulder muscles above the level required for strength gain in untrained workers with musculoskeletal symptoms. Although previous studies have shown improved coordination after coordination training (20,21), the present study indicates that this type of training can be used to stimulate gains in maximal strength capacity as well. This finding supports that functional coordination training may be a particular appropriate mean for populations with high incidence of musculoskeletal pain and injuries like workers with high physical demands or an athlete population. For example, the bodyblade exercise activates the often pain-afflicted erector spinae and trapezius muscles to sufficiently high levels for strength gain. Moreover, the high muscle activity of the trunk and shoulder muscles during the controlled functional exercises also indicates that they may be suitable for injury prevention, rehabilitation purposes and strengthening of the trunk and shoulder muscles for an athlete population.

Previous studies evaluating activity of neck, shoulder, and trunk muscles during functional coordination exercises have shown correspondingly high levels of muscle activation as shown in the present study (19). However, these exercises were performed by younger or well-trained nonsymptomatic subjects (7,19), with a lower level of muscle activity (45% of maximal) considered necessary for gaining strength (7). Body position during the functional coordination exercises was of importance for the erector spinae muscle. The erector spinae was activated to a larger extent during standing and sideways exercises than during prone/supine positions. This indicates that functional coordination training for improving strength of the erector spinae muscle may be most appropriate to perform in a standing or sideways position. Moreover, the level of progression during the functional coordination exercise was shown to be of importance for the attained level of activity of the trapezius but not for the other recorded muscles. Traditional increase in levels of progression in prone plank, 4-point kneeling and vertical plank increased the trapezius activity. The level of progression with bodyblade exercise also played a role for the trapezius activity as shown in Figure 2. The unilateral horizontal bodyblade exercise resulted in the highest trapezius activity.

A strength of the study was that the subjects were untrained women with musculoskeletal pain, and they were thoroughly familiarized with the exercises before the evaluation of muscle activity. A limitation of the study was that only sedentary women participated in the study, and the findings may therefore not be representative for a male or athlete population. Although the number of subjects may seem low, power calculations supported, that the number of subjects provided a sufficient power for the analyses. The applied bipolar surface EMG with an interelectrode distance of 2 cm provides only a few centimeters pick-up area of muscle activity (14). This not only avoids significant levels of crosstalk from neighboring muscles but also means that muscle activity from deeper muscles involved in the functional coordination exercises were not recorded.

PRACTICAL APPLICATIONS

Depending of type, body position, and level of progression, functional coordination exercises can generate sufficient levels of activity of neck, shoulder, and trunk muscles for strength gain. When taking the type, body position, and progression into consideration, functional coordination training may be a good choice for prevention or rehabilitation of musculoskeletal pain and injuries and an appropriate means for strengthening the neck, shoulder, and trunk muscles in a controlled and functional manner. The subjects practiced on the functional coordination exercises for 4 weeks for being well familiarized with the exercises before the testing of muscle activity. We would like to mention that the different complexity of the coordination exercises may provide different learning curves, but all subjects learned to correctly perform all exercises within the 4 weeks of practice. Consequently, individually tailored functional coordination exercises may be well suited for both improving strength and coordination and therefore be well suited for several populations with high incidence of musculoskeletal pain and injuries, like workers with high physical work demands or an athlete population.

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