Differences in Abdominal Muscle Thickness, Strength, and Endurance in Persons Who Are Runners, Active, and Inactive

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Background: Core musculature is important for efficiency during activities including running. Both abdominal muscle strength and endurance contribute to this efficiency. The purpose of this study is to determine what differences and relationships exist in abdominal muscle thickness, strength, and endurance among persons who are runners, active, and inactive.

Hypothesis: Persons in the running group would show significantly greater abdominal muscle thickness, muscle strength, and muscle endurance compared with those in the nonrunning groups.

Study Design: Quantitative cohort design.

Level of Evidence: Level 2b.

Methods: A total of 78 subjects aged 18 to 27 years were divided into 3 groups: runners, active, and inactive. Assessment included abdominal muscle thickness via diagnostic ultrasound (Mindray North America), strength using a static Isotrack dynamometer (JTech Medical), and abdominal muscle endurance using a side plank. Statistical analysis using analysis of variance, *t* tests, and Pearson's correlation coefficients and partial correlations was performed using SPSS Version 26 with a significance level of $P < 0.05$.

Results: Significantly greater muscle thickness of internal obliques (IOs) at rest and during contraction was found in the running group compared with the active group, the active group compared with the inactive group, and the running group compared with the inactive group. There were no statistically significant differences in overall strength measured by dynamometry among the 3 groups. Plank time was significantly greater for the running group compared with the other 2 groups. Male participants were greater in all areas: strength, plank time as a measure of muscle endurance, and muscle thickness. Body mass index was significantly correlated with resting thickness, muscle endurance, and muscle strength.

Conclusion: Persons who run, are active, and are inactive use their abdominal muscles differently. Runners have thicker IOs and better abdominal muscle endurance than the other 2 groups. Focusing on endurance training of the obliques may be beneficial for persons who run.

Clinical Relevance: This research could contribute to developing core training programs to ensure runners target the correct abdominal muscles with the best type of training.

Keywords: conditioning; core; diagnostic imaging; obliques; running

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The common expression "You must have a good core to perform well," has been used for decades. Good core strength is, in fact, important for efficiency in movement as well as peak performance for many activities.[21] Core strength not only enhances performance but can also help prevent injury.[2,21] It optimizes energy transfer from the torso to the extremities for functional limb movement as needed in athletic and nonprofessional athletes (ie, amateur runners),[2,27] but also for the general population. A good core can prevent injury in persons who do not specifically workout.[21] The core musculature is comprised primarily of the abdominal muscles (transverse abdominis [TA], rectus abdominis, internal oblique [IO], and external oblique [EO]) on the anterior trunk, and the erector spinae and multifidi on the posterior trunk.[12] These muscle groups are well positioned on the body and make up the junction of the lower extremities with the rest of the body. The core not only helps control the trunk but also assists with movement performed throughout the entire body.[2] To achieve more efficient movements, athletes need good abdominal muscle strength as well as abdominal muscle endurance as both contribute to the efficiency in activity.[19] According to Medha et al,[19] better core stability leads to improved running performance.

Categorizing activity level is a challenge in many studies because of the broad spectrum of activities. For this study, the 3 categories include a running group (persons who specifically run >20 miles per week, which may or may not also including other activities), an active group (persons who participate in any kind of workout like weightlifting, group exercise, sports activity ≥30 minutes during a session, 3 times per week but do not run >20 miles per week), and an inactive group (persons who workout <30 minutes at a time or <3 times per week). All 3 groups have different levels of activity, and thus may show a difference in abdominal strength and muscle endurance. Bade et al[3] investigated foot posture in experienced runners, whom they defined as persons who run 18 miles per week. Schmitz et al[23] studied experienced and novice runners and grouped experienced runners with subjects running an average of 20.2 miles per week. Active persons are not defined as consistently, with definitions varying among research studies.[13,26,27] They have been defined broadly in studies as persons who train 4 to 5 times a week in running or nonrunning activity and recreation,[4] and engaging in moderate activity 30 minutes, or vigorous activity ≥20 minutes a day 3 times a week.[15] LeBlanc et al[16] established their guidelines for physical activity as 150 minutes of physical activity per week; they followed-up with defining inactivity as not meeting established physical activity guidelines. While the World Health Organization (WHO) does not have a category for runners, it does differentiate between adequate and inadequate levels of physical activity.[30] Persons who are physically active are those who do ≥150 to 300 minutes of moderate-intensity aerobic physical activity or ≥75 to 150 minutes of vigorous intensity aerobic physical activity, or an equivalent combination of moderate and vigorous intensity activity. Persons who do not meet these requirements are not considered adequately physically active.[30] Because no clear categorizations encompassing all 3 groups (runners, active, and inactive) exist, this study used a compilation of WHO information and that used in previous studies on running and activity.

There are numerous ways to assess the abdominal muscles. It is important to look at muscle strength as well as endurance. A clinical and practical way to measure strength is dynamometry - the gold standard.[24] Dynamometers range from static, like an Isotrack, to hand-held, like Lafayette. Recently, diagnostic ultrasound has been used to evaluate strength by observing muscle thickness both at rest and during contraction.[14] In addition to measuring the abdominal strength, looking at a person's core endurance may be as important for longer distance training. Maeo et al[18] found that performing a side plank was a quick and effective way to measure abdominal endurance.

Understanding which abdominal muscles are used the most during running would be beneficial in training runners to prioritize specific core muscles for strengthening and muscle endurance improvement for optimal speed, less energy output, and to decrease strain and stress on other parts of the body. Knowing which muscles are utilized the most during workouts can allow a person to be more concise in their workouts and have better and safer movements during their activity. This is important for persons wanting to improve their running for competition as well as those who want to improve their running to enhance their health and quality of life. According to the study by Trowell et al[28] on the biomechanics of long distance runners, faster runners exhibit a smaller sagittal-plane hip motion during swing, less thorax flexion at toe-off, a smaller ankle plantarflexion angle at contact, a greater knee flexion at initial swing, smaller total range of sagittal-plane knee motion during swing, slower peak knee flexion velocity during swing, larger vertical oscillation of the center of mass during stance, and larger peak vertical ground reactive force. Abdominal strength and/or endurance may play a role in these factors, particularly sagittal hip motion, thoracic trunk flex, and vertical oscillation of the center of mass. The question remains, how does the abdominal strength and muscle endurance in runners compare with those who participate in other activities or little to no activity? Further, is there a difference in muscle thickness of the different abdominal muscles (TA, IO, or EO) at rest and during contraction among those who run, those who are active, and those who are inactive?

The purpose of this study is to determine whether differences exist in abdominal muscle thickness, strength, and muscle endurance among runners, persons who are active, and persons who are inactive. In addition, relationships between muscle thickness and strength and endurance are explored. It was hypothesized that runners would show significantly greater abdominal muscle thickness, strength, and muscle endurance compared with those who are active and those who are inactive. Results from this study could potentially be helpful in determining what specific core training exercises runners as well as persons who work out using activities other than running should incorporate into training.

METHODS

Experimental Approach to the Problem

This study used a quantitative cohort design to investigate the relationships and differences of activity level, abdominal strength, abdominal endurance, and muscle thickness. Participants were grouped by their weekly level of activity: a running group reported dedicated running >20 miles a week, an active group were those who worked out in any activity for ≥30 minutes at a time ≥3 times a week but did not engage in dedicated running >20 miles, and inactive group participants who did not meet either criteria. Similar categories have been used in previous studies and reflect minimal training standards for endurance training like cross country and track.[3,15,16] A convenience sample was used to expedite the research.

Subjects

This study was approved by the Institutional Review Board (No. 202110) and included 78 subjects who provided informed consent after a written and verbal explanation of the benefits and risks of the study, the purpose, their voluntary participation, and the process for withdrawal from the study at any time. A convenience sample was recruited from the Abilene area, and persons were included if they were between 18 and 50 years of age, had a body mass index (BMI) of ≤30 kg/m^2 or lower, resting blood pressure (BP) of ≤160/90 mm Hg, and no previous abdominal or back surgery, abdominal hernias, shoulder or elbow instability or injury, or pregnancy in the last 2 years. Persons of all fitness levels were invited. Subjects were classified into 1 of 3 groups: runners, those who have a specific activity of running for >20 miles per week (n = 23); active, those who work out ≥3 times a week for 30 minutes at a time but do not run >20 miles per week (n = 32); or inactive, those who work out <3 times per week and do not run >20 miles a week (n = 23). Subjects included 22 male and 56 female participants ranging in age from 18 to 27 years with mean of 21.7 ± 2.0 years. Height ranged from 59.5 to 76.0 inches with an average of 66.5 ± 0.5 inches and weight ranged from 89.4 to 220.8 pounds with an average of 145.0 ± 0.5 pounds. Average BMI was 23.1 ± 0.4 kg/m^2 (range, 17.8-30.0 kg/m^2) (Table 1).

Procedures

All testing was performed during the day. Subjects were asked not to have performed any strenuous activity on the day of testing. Before testing began, subjects signed a consent form and completed the demographics form. While sitting, the subjects' blood pressure was recorded. Their height and weight were measured and BMI was calculated (kg/m^2). The BMI criteria for this study were taken from Callahan,[6] who reported that normal BMI is 18.5 to 24.9 kg/m^2. Any values higher than that would place someone in the overweight, obese, or extremely obese category. If the subject met all the criteria, they were able to start testing.

Abdominal muscle thickness of bilateral IO, EO, and TA at rest was tested first in all subjects using diagnostic ultrasound (Mindray North America). Diagnostic ultrasound is a noninvasive, reliable method of assessing muscle thickness. According to Miyachi et al,[20] muscle thickness has an independent relationship with muscle strength. A greater abdominal muscle thickness may drive the increase in muscle strength as well as endurance.[11] Each subject lay in a relaxed, supine position. A mark was placed on both the right and left sides at the midpoint between the anterior superior iliac spine and inferior border of the rib cage, 10 cm lateral the midline. Ultrasound gel was placed over the midpoint mark, then the ultrasound head was placed. Once a clear image of the IO, EO, and TA was produced, the image was captured and muscle thickness of each of the 3 muscles was measured (Figure 1).

A coin toss determined whether subjects performed strength or endurance testing first. For abdominal strength testing, an Isotrack dynamometer (JTech Medical) was used. This static dynamometer was chosen because it provides a valid and reliable method for assessing muscle strength in most muscles of the body including abdominals.[29] A maximal voluntary contraction of the abdominal muscles was used for consistency and was confirmed via the Isotrack dynamometer.

The subject was belted in the Isotrack machine with their back and posterior hip against the seat, hands in lap, and legs dangling to help minimize accessory muscle use. The dynamometer head was placed below the clavicle on the pectoralis major, at the midpoint between the acromion process and the sternoclavicular joint. The subject started on the right or left side, depending on the flip of a coin. The subject rotated the trunk toward the opposite knee pushing into the dynamometer head, replicating an oblique crunch using maximum force for 3 seconds until told to relax. Subjects were given a practice trial. This motion was repeated for 3 trials on each side with 30 seconds rest between trials. During the first 2 trials of muscle testing on each side, diagnostic ultrasound was placed on the right and the left side as described above to determine muscle thickness at maximal contraction (Figure 2). On the first contraction, the transducer head was placed on the ipsilateral side, and on the second contraction, it was placed on the contralateral side. This allowed ipsilateral and contralateral capture of the thickness of the IO and EO during maximal contraction of the same movement.

Muscle endurance may be defined as "the time period a constant (nonfatiguing) force output can be maintained."[5] There is no standard for testing abdominal muscle endurance.[8] In the recent studies by Luedke et al[17] and Maeo et al,[18] side planks were used to assess abdominal muscle endurance as they are commonly used in the clinic as a quick, reliable way to determine abdominal muscle endurance. This current study chose to follow the study of Luedke et al[17] study and set the ceiling time for the side plank as 2 minutes (120 seconds). According to a study by Strand et al,[25] the average plank time for

Table 1. Subject demographics and data by group[a]

	All Subjects (n = 78)	Active (n = 32)	Inactive (n = 23)	Runners (n = 23)
Age, y	21.74 (2.00)	22.31 (2.00)	22.52 (1.28)	20.17 (1.72)
Height, inches	66.46 (3.41)	66.23 (3.36)	66.37 (3.42)	66.88 (3.59)
Weight, pounds	144.98 (21.01)	148.54 (25.94)	146.49 (18.18)	138.53 (14.21)
BMI, kg/m^2	23.06 (2.74)	23.67 (2.74)	23.45 (3.04)	21.81 (2.05)
R TA resting thickness, cm	0.59 (0.20)	0.55 (0.21)	0.58 (0.20)	0.66 (0.18)
R TA contraction thickness, cm	0.88 (0.32)	0.86 (0.33)	0.83 (0.32)	0.97 (0.29)
L TA resting thickness, cm	0.54 (0.18)	0.54 (0.19)	0.54 (0.21)	0.55 (0.10)
L TA contraction thickness, cm	0.85 (0.32)	0.85 (0.29)	0.72 (0.29)	00.95 (0.35)
R EO resting thickness, cm	0.68 (0.22)	0.65 (0.22)	0.72 (0.28)	0.70 (0.12)
R EO contraction thickness, cm	0.80 (0.25)	0.73 (0.26)	0.80 (0.27)	0.90 (0.20)
L EO resting thickness, cm	0.61 (0.20)	0.61 (0.23)	0.62 (0.22)	0.61 (0.15)
L EO contraction thickness, cm	0.81 (0.25)	0.81 (0.33)	0.77 (0.19)	0.86 (0.17)
R IO resting thickness, cm	0.98 (0.34)	0.93 (0.32)	0.88 (0.34)	1.14 (0.33)
R IO contraction thickness, cm	1.22 (0.41)	1.19 (0.39)	1.11 (0.45)	1.38 (0.35)
L IO resting thickness, cm	0.92 (0.30)	0.92 (0.32)	0.79 (0.23)	1.05 (0.29)
L IO contraction thickness, cm	1.28 (0.38)	1.23 (0.32)	1.12 (0.43)	1.49 (0.33)
R abdominal strength, pounds	40.24 (17.58)	42.75 (19.16)	39.17 (17.42)	37.83 (15.63)
L abdominal strength, pounds	51.49 (19.01)	54.60 (19.47)	47.64 (14.74)	51.04 (21.99)
R plank time, seconds	79.90 (29.50)	78.53 (27.20)	67.87 (28.97)	98.39 (30.95)
L plank time, seconds	81.24 (30.92)	75.78 (25.90)	65.00 (24.96)	100.52 (27.84)

BMI, body mass index; EO, external oblique; IO, internal oblique; L, left; R, right; TA, transverse abdominis.
[a]Data are expressed as mean (SD).

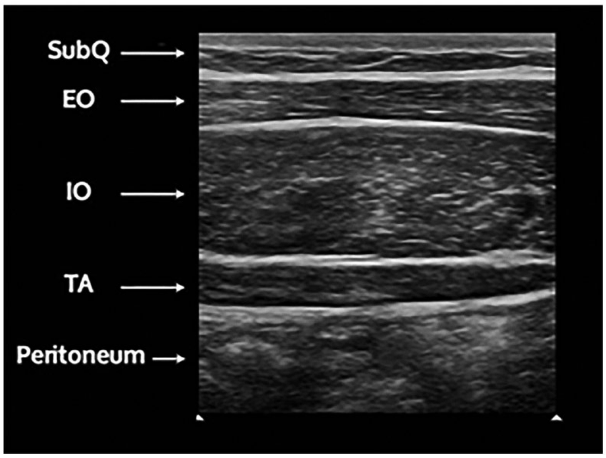

Figure 1. Image of IO, EO, and TA from diagnostic ultrasound.

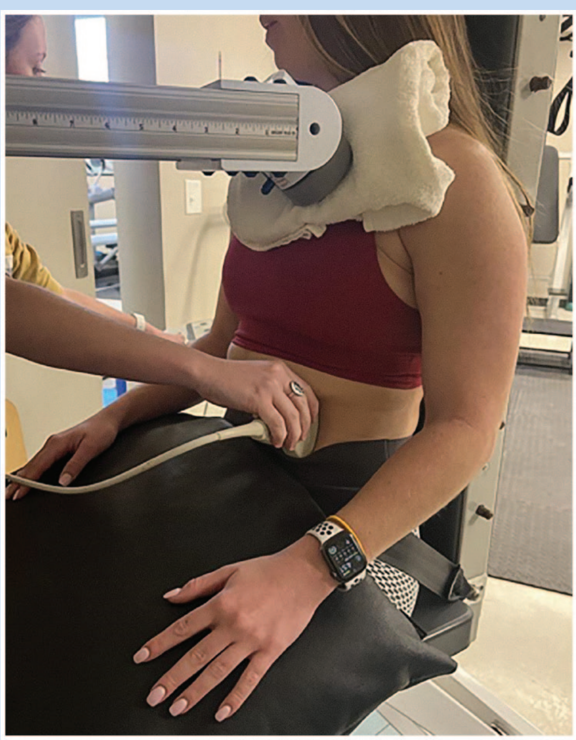

Figure 2. Subject testing position with the use of the static dynamometer.

male and female participants was 123 ± 72 seconds and 83 ± 63 seconds, respectively. Longer times on side plank suggest greater abdominal muscle endurance. The maximum of 2 minutes set for this research should be able to capture plank times to fatigue for most participants before stopping at the cut-off time.

Figure 3. Subject test position for endurance testing (side plank).

To assess abdominal muscle endurance, subjects performed a side plank until fatigue or until 2 minutes had elapsed. Subjects were placed in a side-plank position with legs extended and top foot stacked on the bottom foot. The subjects supported themselves with their elbow directly below the shoulder and forearm flat on the mat, perpendicular to the body. The uninvolved arm rested across the top hip (Figure 3). Time started when subjects lifted their lower hip off the mat, and the test was terminated when the hip height could not be sustained, or the bottom shoulder began to sag. This was determined by placing a meter stick in line with the occiput, spine, and the sacrum. The test was performed on a plinth and timed on both sides with a 30 second rest in between.

Statistical Analysis

Statistical analysis was performed using SPSS Version 26. Box plots were used to detect outliers and outliers were removed before data analysis. No outliers were detected for dynamometry or planks. Three outliers were noted for resting abdominal thickness, and 2 outliers were noted for contracted abdominal thickness. Normality was confirmed using the Shapiro-Wilk test, and the Levene Statistic was used as a test of homogeneity of variance among groups. Subject and variable characteristics (means, medians, standard deviations, and ranges) were described. A 1-way analysis of variance (ANOVA) with Tukey post hoc testing was used to compare the differences in abdominal thickness at rest and in a contracted state, as well as compare abdominal muscle strength and endurance among persons who are runners, active, and inactive. Effect size was determined using eta squared with small effect represent by 0.01, medium effect by 0.06, and large effect >0.14.[10] While a 2-way ANOVA using group and sex as factors would have been preferable, the disparity in sample size of male and female participants resulted in a lack of power for this analysis, with observed power <0.50 for all tests and eta squared <0.01 for these tests compared with power of 0.50 to

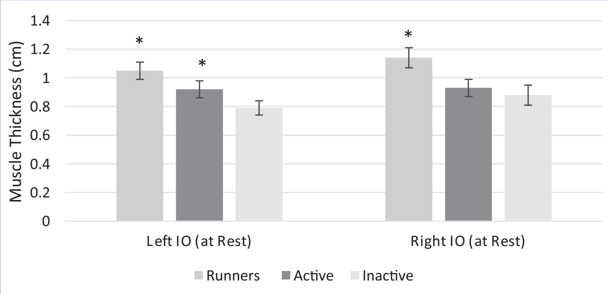

Figure 4. Resting IO muscle thickness (cm) by group. IO, internal oblique.

0.99 and eta squared ranging from 0.01 to 0.23 when using 1-way ANOVA. Unpaired *t* tests were used to detect gender differences in abdominal muscle thickness at rest and during contraction, abdominal muscle strength, and abdominal muscle endurance. Effect sizes for *t* tests were determined using Cohen *d*, with 0.20 indicating a small effect, 0.50 indicating a medium effect, and ≥0.80 indicting a large effect.[7] Pearson correlations were used to look at the relationship between BMI, abdominal muscle thickness at rest and in a contracted state, abdominal strength, and muscle endurance, with $r = 0.01$ being a small effect, 0.30 a medium effect, and ≥0.50 a large effect.[7] A partial correlation was run to determine the relationships while controlling for sex. Statistical significance was set at $P < 0.05$. Sample size was determined using means and standard deviations from a study by Gong. Calculations determined a needed n of 21 per group. The recruitment goal was 30 per group to allow for potential attrition. In all, 78 subjects participated in this study, with 23 in the running group, 32 in the active group, and 23 in the inactive group.

RESULTS

Statistical analysis using 1-way ANOVA found significant differences in muscle thickness of the IO at rest (Figure 4) and during contraction (Figure 5) (F = 4.088-8.986; P = 0.00-0.02; eta squared = 0.120-0.193) between runners and active, active and inactive, and runners and inactive. There were no statistically significant differences in overall strength among groups. Plank time was significantly different between the runner and active groups and between the runner and inactive groups (Figure 6) (F = 6.669-11.221; P = 0.00 to <0.01; eta squared = 0.150-0.230). Furthermore, through unpaired *t* tests, gender differences were noted showing male participant's values were greater in all areas: strength (t = -17.0850 to -10.0016; P = 0.00-0.04; d = 0.585-0.978), plank time (t = -29.924 to -10.0016; $P < 0.01$; d = 1.070-1.077), resting thickness (t = -4.380 to -3.234; P = 0.00 to < 0.01; d = 0.906-1.102), and contracted thickness (t = -3.158 to -2.051; $P < 0.01$ to 0.04; d = 0.289-0.613). Finally, Pearson's correlation coefficients revealed that BMI was significantly

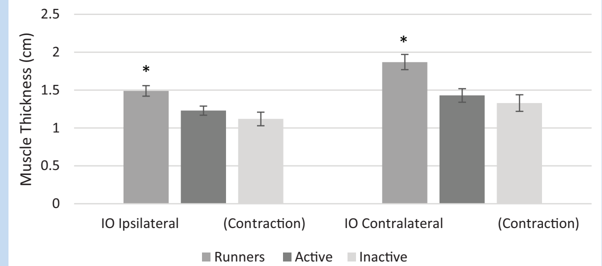

Figure 5. Contracted IO muscle thickness (cm) by group. IO, internal oblique.

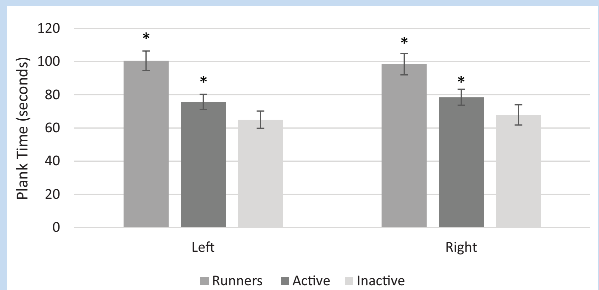

Figure 6. Mean plank time (seconds) by group.

correlated between resting thickness (r = 0.324-0.413; P = 0.00 to <0.01), muscle endurance (the plank) (r = -0.277 to -0.263; P = 0.01-0.02), and strength (r = 0.237; P = 0.04). Plank, as a measure of muscle endurance, was correlated to muscle strength as well as resting and contraction thickness of the IOs (r = 0.223-0.445; P = 0.05 to <0.01). Muscle strength was not correlated significantly with muscle thickness during either resting or contraction. Partial correlation was run to determine the relationships while controlling for sex. When compared with zero-order correlations there was <0.05 difference in all partial correlations, indicating that sex had vey little influence in controlling for the observed relationships.

DISCUSSION

In this study, differences were noted in IO muscle thickness among the 3 groups both at rest and during contraction; however, no statistically significant differences in thickness among the groups were detected for the EO or TA. A study by Adams et al[1] examining runners also found significant differences in the IO muscle thickness with minimal differences in the EO. At walking speeds, the EO, IO, and TA are minimally activated, but when speeds increase to a fast, running pace, there is a distinct activation of the EO and IO muscles in coordination with an increase in trunk motion.[1] Spinal rotation is essential for fast gait. With the IO being a deeper muscle, it aids more in increasing the spinal stability,[1] and allows trunk rotation with arm swing but also controls the deceleration of the spine's rotation, which is important during running. The importance of the TA is to stabilize the pelvis during movements.

As expected, persons who run >20 miles a week were shown to have the greatest IO muscle thickness at rest and during contraction. Out of all the groups, the inactive group showed the least muscle thickness at rest and during contraction. Both at rest and during muscle contraction, there was a significant difference in the IO between the runners and the active group as well as between the runners and inactive group, but no significant difference between the active and inactive groups. This indicates greatest muscle thickness in the runner group but also highlights the 2 groups that were engaged in physical activity (runners and active groups) had greater muscle thickness at rest and during contraction than the inactive group. Physical activity appears to play a role in IO muscle thickness. Further, the type of physical activity may be important. Perhaps running is an activity that uses the IO more than other types of activity. Runners may build more oblique abdominal muscle as a result of the rotational movement of the trunk during running indicating that running is an activity that uses the abdominal IO muscles more specifically that those who are active with other workouts.

This difference in the muscle thickness between runners and active persons compared with the inactive group could be due to the type of training that each group participated in. A possibility may be the running distance. Saunders found that once a runner's speed is above 3 m per second or 6.7 mph, the TA intermittently shuts off, forcing the obliques to activate and elicit more force, causing a greater contraction in those muscles.[22] If the runners group and the active group ran ≥6.7 mph, this may explain why the IOs were significantly thicker than the TAs. Perhaps the significant difference found between the runners and active groups could be due to the increased distance the runners group ran on a weekly basis.

Regarding the strength of the 3 groups, the expectation was that the runners and the active participants would have greater strength than the inactive group.[4] However, in this current study, no significant difference was found between the 3 groups. This could be due to the inability to completely isolate a specific muscle during strength testing with the rotational movement of the trunk; therefore, this is a combination measure of all abdominal muscles during rotation. Perhaps there would have been a significant difference if the strength of each abdominal muscle could be measured individually.

When looking at muscle endurance among the 3 groups, the data showed that runners had significantly greater muscle endurance than the other 2 groups, but there was no significant difference between the active group and the inactive group. This finding could be due to the specific training focus of each group. For the most part, runners consisted of persons who performed primarily muscle endurance type training through running but, for this study, any other activity performed was not documented; the active group may have performed a mixture of strength and muscle endurance-type training, and the inactive group did little-to-no training, but their daily activities could be heavy work. These findings line up with a study done by Degens et al[9] stating higher muscle endurance training is attributed to better oxygen extraction, reflecting a higher muscle oxidative capacity. With greater oxygen extraction and absorption in the muscles, this can cause an increase in muscle mass.

In addition to looking at strength and muscle endurance differences among the runners, active, and inactive groups, there were also correlations with gender and BMI with the 3 groups. Overall, male participants showed increased thickness at rest and during contraction in the IO, were stronger overall, and held a plank longer than female participants. This study found fair but significant correlations among BMI with resting thickness and a negative relationship with muscle endurance. Lack of stronger correlations indicates there may be other factors related to abdominal muscle endurance and thickness other than just BMI alone. Plank time, used as a measure of muscle endurance, was moderately related to IO thickness at both rest and contraction and muscle strength, but muscle strength was not correlated to abdominal muscle thickness. This may indicate a more important role of muscle endurance over muscle strength.

Limitations

There are limitations to this study. Most importantly, this study did not take into account the different body types of each subject. Categorizing each subject into ectomorph, endomorph, or mesomorph might show different results when comparing the running, active, and inactive groups. The intake form that was given to the subjects included questions pertaining to how many workouts the subject did per week but did not ask whether subjects included core training in their workouts. Ultimately, this could have been helpful in better understanding the results we found. Also, on the intake form, the subjects self-reported their activity level, which could have been inaccurate and affected into which group they were classified. Another limitation was that the subjects were only asked, but not required, to abstain from workouts ≥24 hours before testing, which could have resulted in a falsely large muscle thickness measurement due to increased blood flow and hypertrophy from a recent workout if any participants did not abstain. The subjects also were not asked about their nutritional intake for the day of testing. If the subjects had not eaten, that could have affected their testing results.

As predicted, runners have thicker muscles at rest and during contraction when looking at the right and left IO. Despite our hypothesis of runners having the strongest abdominal muscles, no significant difference was found among the groups. However, there was a significant difference found between plank times (abdominal muscle endurance), with runners being able to hold a plank longer compared with the active and inactive groups, potentially pointing to a larger role of muscle endurance versus muscle strength. Further, there was a significantly positive correlation between BMI and resting muscle thickness, and there was a negative correlation between BMI and plank time but no significant difference between BMI and strength. This information taken together may indicate that persons who run, are active, and are inactive use their abdominal muscles differently. Focusing more on muscle endurance training may be beneficial for persons who run.

CLINICAL RECOMMENDATIONS

Training someone to run more efficiently and faster can be a challenging job. Whether the person is self-training or utilizing assistance from a coach or a personal trainer, the knowledge of specific muscles to focus on has been lacking. Training with proper type of exercise (strengthening and/or muscle endurance) to maximize a runner's potential may be the key to decreasing a runner's time, minimizing injury risk, and increasing enjoyment of running.

The findings in this research could contribute to developing proper core training programs to ensure runners are targeting the correct abdominal muscles. It was found that runners' IO were larger at rest and during contraction and that their muscle endurance times for side planks were better than those of nonrunners (Strength of Recommendation Taxonomy rating Level 2). This suggests that runners would benefit by incorporating abdominal muscle endurance training, namely IOs, to their workout regimen to potentially produce a better outcome. To maximize training with runners, increasing the muscle endurance of IOs may potentially improve a runner's time. Incorporating side planks into a runner's program may help prevent running-related injuries and improve performance.[17] For runners, muscle endurance training for the abdominals would be more efficient than just strengthening.

REFERENCES

1. Adams L, Pace N, Heo A, Hunter I, Johnson AW, Mitchell UH. Internal and external oblique muscle asymmetry in sprint hurdlers and sprinters: a cross-sectional study. *J Sports Sci Med*. 2022;21:120-126.
2. Akuthota V, Ferreiro A, Moore T, Fredericson M. Core stability exercise principles. *Curr Sports Med Rep*. 2008;7(1):39-44.
3. Bade MB, Chi TL, Farrell KC, et al. The use of a static measure to predict foot posture at midsupport during running. *Int J Sports Phys Ther*. 2016;11(1):64-71.
4. Behm D, Cappa D, Power G. Trunk muscle activation during moderate- and high-intensity running. *Appl Physiol Nutr Metab*. 2009;34:1008-1016.
5. Bigland-Ritchie B, Woods JJ. Changes in muscle contractile properties and neural control during human muscular fatigue. *Muscle Nerve*. 1984;7:691-699.
6. Callahan A. Is BMI good for your health? The Irish Times. https://www.irishtimes.com/life-and-style/health-family/fitness/is-bmi-good-for-your-health-1.4576824. Accessed February 15, 2022.
7. Cohen J. *Statistical Power Analysis for the Social Sciences*. 2nd ed. Hillsdale, NJ: Lawrence Erlbaum Associates; 1988.
8. Crowther A, McGregor AH, Strutton PH. Testing isometric fatigue in the trunk muscles. *Isokinet Exerc Sci*. 2007;15(2):91-97.
9. Degens H, Stasiulis A, Skurvydas A, Statkeviciene B, Venckunas T. Physiological comparison between non-athletes, endurance, power and team athletes. *Eur J Appl Physiol*. 2019;119(6):1377-1386.
10. Field A. *Discovering Statistics with IBM SPSS Statistics*. Newbury Park, CA: Sage; 2013.
11. Friesenbichler B, Item-Glatthorn JF, Neunstöcklin F, Casartelli NC, Gaël Guilhem G, Maffiuletti NA. Differences in trunk and thigh muscle strength, endurance and thickness between elite sailors and non-sailors. *Sports Biomechanics*. 2018;17(2):216-226.
12. Gilroy A, MacPherson B, Wikenheiser J. *Atlas of Anatomy*. 4th ed. New York: Thieme Publishers; 2020:32.
13. Hamstra-Wright KL, Huxel Bliven KC, Bay RC, Aydemir B. Risk factors for plantar fasciitis in physically active individuals: a systematic review and meta-analysis. *Sports Health*. 2021;13(3):296-303.
14. Kang KW, Kwon YH, Son SM. Ultrasound measurement of the transverse abdominis, internal oblique, and external oblique muscles associated with forward head posture and reduced cranio-vertebral angle. *Med Sci Monit*. 2021;27:e928987-1-e928987-6.
15. Latorre-Román PA, Izquierdo-Sánchez JM, Salas-Sánchez J, García-Pinillos F. Comparative analysis between two models of active aging and its influence on body composition, strength levels and quality of life: long-distance runners versus bodybuilders practitioners. *Nutr Hosp*. 2015;31(4):1717-1725.
16. LeBlanc AG, Gunnell KE, Prince SA, Saunders TJ, Barnes JD, Chaput JP. The ubiquity of the screen: an overview of the risks and benefits of screen time in our modern world. *Transl J Am Coll Sports Med*. 2017;2:104-113.
17. Luedke LE, Rauh MJ. Plank times and lower extremity overuse injury in collegiate track-and-field and cross country athletes. *Sports (Basel)*. 2022;10(3):45-52.
18. Maeo S, Tafakahashi T, Takai Y, Kanehisa H. Trunk muscle activities during abdominal bracing: comparison among muscles and exercises. *J Sports Sci Med*. 2013;12(3):467-474.
19. Mehda P, Zutshi K, Juneja H, Zafar R. Effect of core stabilization exercises in addition to conventional training on core stability and running performance. *Med Sport*. 2019;15(1):3052-3060.
20. Miyachi R, Koike N, Kodama S, Miyazaki J. Relationship between trunk muscle strength and trunk muscle mass and thickness using bioelectrical impedance analysis and ultrasound imaging. *Biomed Mater Eng*. 2022;33(1):31-40.
21. Oliver GD, Adams-Blair HR. Improving core strength to prevent injury. *J Phys Educ Recreat Dance*. 2010;81(7):15-19.
22. Saunders SW, Rath D, Hodges PW. Postural and respiratory activation of the trunk muscles changes with mode and speed of locomotion. *Gait Posture* 2004;20:280-290.
23. Schmitz A, Russo K, Edwards L, Noehren B. Do novice runners have weak hips and bad running form? *Gait Posture*. 2014;40:82-86.
24. Sinacore JA, Evans AM, Lynch BN, Joreitz RE, Irrgang JJ, Lynch AD. Diagnostic accuracy of handheld dynamometry and 1-repetition-maximum tests for identifying meaningful quadriceps strength asymmetries. *J Orthop Sports Phys Ther*. 2017;47(2):97-107.
25. Strand SL, Hjelm J, Shoepe TC, Fajardo MA. Norms for an isometric muscle endurance test. *J Hum Kinet*. 2014;40:93-102.
26. Teixeira da Silva DV, Conte CA Jr. Hormonal response to L-arginine supplementation in physically active individuals. *Food Nutr Res*. 2014;58:22569.
27. Tong TK, Shing W, Nie J, Baker JS, Lin H. The Occurrence of core muscle fatigue during high-intensity running exercise and its limitation to performance: the role of respiratory work. *J Sports Sci Med*. 2014;13:244-251.
28. Trowell D, Phillips E, Saunders P, Bonacci J. The relationship between performance and biomechanics in middle-distance runners. *Sports Biomech*. 2021;20(8):974-984.
29. Verbrugghe J, Agten A, Eijnde BO, et al. Reliability and agreement of isometric functional trunk and isolated lumbar strength assessment in healthy persons and persons with chronic nonspecific low back pain. *Phys Ther Sport*. 2019;38:1-7.
30. World Health Organization. *WHO Guidelines on Physical Activity and Sedentary Behaviour: At a Glance*. Geneva: World Health Organization; 2020.