Journal of Athletic Training 2012;47(3):314–319
doi: 10.4085/1062-6050-47.3.03

http://www.nata.org/journal-of-athletic-training

original research

Muscle Imbalance Among Elite Australian Rules Football Players: A Longitudinal Study of Changes in Trunk Muscle Size

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Context: Trunk muscles, such as the transversus abdominis (TrA) and multifidus, play a key role in lumbopelvic stability, which is important in athletic performance. Asymmetry or imbalance in these and other trunk muscles could result from the specific requirements of the game of Australian rules football.

Objective: To determine whether seasonal variations in the sizes of key trunk muscles associated with lumbopelvic stability occur in Australian Football League players.

Design: Cross-sectional study.

Setting: Hospital.

Patients or Other Participants: The number of players eligible to participate at each of the 4 time points was 36 at the start of preseason 1 (T1), 31 at end of season 1 (T2), 43 at the end of preseason 2 (T3), and 41 at the start of preseason 3 (T4). The group with data at all 4 time points ($n = 20$) was used in the analyses and was shown to be representative of the total sample.

Intervention(s): Magnetic resonance imaging was used to determine the cross-sectional areas (CSAs) of the multifidus (vertebral levels L2 to L5) and lumbar erector spinae (LES) muscles (L3), as well as the thickness of the TrA and internal oblique (IO) muscles at L3.

Main Outcome Measure(s): Cross-sectional areas of the multifidus and LES muscles and thickness of the TrA and IO muscles.

Results: By the end of the playing season, results showed 11.1% atrophy for multifidus CSA at L3 and 21% atrophy for TrA thickness at rest. In comparison, the CSA of the LES muscles increased by 3.6%, and the thickness of the IO muscle increased by 11.8% compared with the start of the preseason.

Conclusions: The results indicated an imbalance of the key muscles associated with lumbopelvic stability.

Key Words: Australian Football League, magnetic resonance imaging, multifidus muscle, transversus abdominis muscle

Key Points

- The size of trunk muscles with a proposed role in torque production, such as the lumbar erector spinae and internal oblique increased over the playing season and decreased by the start of the next season.
- The size of local muscles, such as the multifidus and transverse abdominis, decreased over the playing season and recovered by the start of the next season.
- Seasonal variations in trunk muscles associated with lumbopelvic stability might have serious implications for susceptibility to injury.

The specific physical characteristics of the elite athlete reflect both inherited features and the conditioning effects of high-level, sport-specific training. Thus, the expectation might be that the athlete's body composition and anthropometry will not remain static but might change according to the quantity, intensity, and type of activity undertaken. This effect is best observed in sports that are played in seasons. Researchers have examined changes in the physical profiles of athletes at different stages of the year, such as preseason and postseason and peak season and off-season.[1–3] Most investigators have shown an improvement in desirable characteristics (ie, reduction in body fat, increase in fat-free mass) after a period of training or competition.[1–3] Whereas training for and playing football can lead to an increase in muscle mass, the specific requirements of the game could affect individual muscles differently, creating muscle imbalance.

In many ways, Australian rules football is similar to soccer[4,5] and Gaelic football[5,6] and involves a combination of repetitive, high-intensity activities such as kicking,[7,8] sprinting, and jumping. These activities not only are physically demanding on players but carry a potential bias toward the use of trunk and hip flexor muscles. For example, Stewart et al[9] reported that Australian Football League (AFL) players have large psoas muscles, which have been reported in sprinters[10] and athletes who undertake sports such as gymnastics, ballet, and figure skating.[11] Therefore, whereas some muscles involved primarily in torque generation might hypertrophy in response to training for and playing football, other muscles might decrease in size, in line with the concept of muscle imbalance.

In elite sport and everyday function, the trunk muscles can contribute to lumbopelvic stability. In a biomechanical study, Bergmark[12] categorized the trunk muscles into local and global muscles based on architectural properties. The local muscles included deep muscles and deep portions of some muscles that have their attachments to the lumbar vertebrae. An example of a local muscle is the multifidus, which provides segmental support and control of vertebral segments,[13] controls the lumbar lordosis, and probably has a proprioceptive role because it is dense with muscle spindles.[14] Of the abdominal muscles, the transversus abdominis (TrA) also has been considered a local muscle because it has direct attachments to the lumbar vertebrae via the thoracolumbar fascia. Proposed mechanisms for the TrA muscle's contribution to lumbopelvic stability include generation of intra-abdominal pressure,[15] tension in the thoracolumbar fascia,[16,17] and compression of the sacroiliac joints.[18,19] The global muscles consist of large, superficial muscles spanning the lumbar region that control spinal orientation, balance external loads applied to the trunk, and transfer load from the thorax to the pelvis.[12] Examples include the external oblique, rectus abdominis, and erector spinae muscles. For normal function, integration or adequate neuromuscular control of local and global muscles is needed. Deficits in neuromuscular control of the lumbopelvic region have been suggested to affect the dynamic stability of the knee because they might contribute to instability throughout the entire segment of the kinetic chain.[20–22] In longitudinal studies of female athletes, researchers have shown that inadequate neuromuscular control of the trunk was associated with an increased incidence of knee injury.[20,21]

In studies of trunk muscles in nonathletic populations, investigators have shown evidence of muscle imbalance, as indicated by differential changes in muscle size. Some muscles, such as the psoas, increased in size, whereas other muscles, such as the multifidus, decreased in size.[23–26] Given that muscle imbalance and deficits in muscles associated with lumbopelvic stability have been nominated as problems in a qualitative study of elite AFL players,[27] the purpose of our study was to measure the size of key trunk muscles over 3 playing seasons to determine whether playing Australian rules football is associated with seasonal changes in these muscles.

METHODS

Participants

All players from a professional AFL club who were training or playing during the period of investigation (November 2005–November 2007) ($n = 63$) were eligible for participation in the study. At entry to the study, this eligible sample had a mean age of 22.2 ± 3.9 years, height of 187.8 ± 6.6 cm, and mass of 87.5 ± 7.1 kg. Variability in the number of participants occurred across the 4 assessment points because of player recruitment and retirement. The number of eligible participants at each time point was 36 for time point 1 (T1; start of preseason 1), 31 for time point 2 (T2; end of season 1), 43 for time point 3 (T3; end of preseason 2), and 41 for time point 4 (T4; start of preseason 3). We instructed participants to nominate their leg preference for kicking, which was considered the *dominant leg*. Among the total number of eligible players assessed, 17.7% were left-leg dominant, 80.7% were right-leg dominant, and 1.6% (assessed only at T1) reported no leg dominance. Participants were excluded from the investigation if they were deemed to be unsuitable for magnetic resonance imaging (MRI; eg, presence of metal implants, claustrophobia). We did not collect MRI data for 1 participant with a history of claustrophobia. All participants provided written informed consent, and the study was approved by the University of Queensland Medical Ethics Committee.

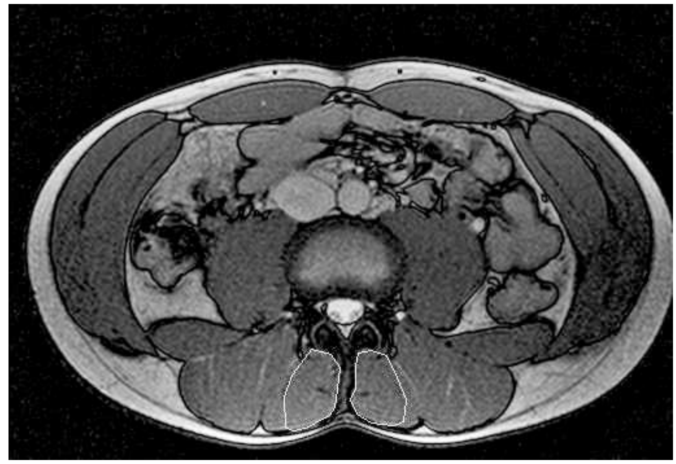

Figure 1. Cross-sectional areas of the multifidus muscle were measured by tracing around the muscle borders. They were measured in square centimeters at the L2, L3, L4, and L5 vertebral levels using the vertebral lamina as a landmark.

Procedures

The MRI assessments and questionnaires were performed in a hospital setting. The MRI assessments were conducted at the 4 time points. Screening for MRI contraindications and measurement of height and mass were performed by a medical practitioner. A questionnaire was used to determine history of low back pain (LBP) and location of symptoms if applicable. We instructed participants to void their bladders and bowels before imaging to avoid tension on the anterior abdominal wall. Participants were positioned in supine, lying with their knees and hips resting on a foam wedge for comfort. Transverse magnetic resonance images at rest (a breath hold at midexpiration) were acquired using a 1.5-T Magnetom Sonata magnetic resonance system (Siemens Corp, Washington, DC). Image slices were oriented perpendicular to the anterior abdominal wall and consisted of 10 slices at a thickness of 8 mm with an interslice distance of 0.5 mm. A fast-gradient recalled echo sequence was used with a repetition time of 4.8 milliseconds, echo time of 2.3 milliseconds, flip angle of 70°, and number of averages of 2. The resulting matrix for all images was 128×128 interpolated to 256×256. Total scanning time was 23 seconds, which was within the breath-hold tolerance of all participants.

The magnetic resonance images were stored offline under an allocated number for the purposes of participant deidentification. Measurements were completed with the ImageJ image-processing package (version 1.37; http://rsb.info.nih.gov/ij/). Cross-sectional areas (CSAs) of the multifidus and lumbar erector spinae (LES) muscles were measured by tracing around the muscle borders (Figures 1 and 2). For the multifidus muscle, we measured CSAs in square centimeters at L2, L3, L4, and L5 vertebral levels using the vertebral lamina as a landmark. Multilevel measurements of the multifidus muscle were conducted because researchers have shown a segmental response of this muscle to LBP in line with its anatomy and segmental

Figure 2. Cross-sectional areas of the lumbar erector spinae muscle were measured by tracing around the muscle borders. They were measured in square centimeters at the L3 vertebral level.

innervation.[28,29] The CSA of the LES muscle was measured at the L3 vertebral level. The thickness of the transversus abdominis (TrA) and internal oblique (IO) muscles was measured using a protocol that has been described.[30] Measurements were conducted by an experienced operator (J.H.) with demonstrated reliability[25] (intraclass correlation coefficient = 0.95) who was blinded to the participants' identities, past histories of LBP, and information such as preferred kicking leg.

Statistical Analysis

Repeated-measures analysis of covariance (ANCOVA) with a type I sums-of-squares model was used to analyze muscle size and asymmetry. A type I model was used because researchers have shown that higher-order interactions involving mass and muscle size are problematic in a type III model.[30] A separate analysis was conducted for each muscle (dependent variable), which included CSA of the multifidus at vertebral levels L2 to L5, LES at L3, and a measure of thickness of TrA and IO at L3. The factors of age, height, and mass were included as covariates in the analyses. The repeated-measures factors were asymmetry relative to the side of the abdomen, which was coded as ipsilateral or contralateral to preferred kicking leg, and season (T1, T2, T3, T4). A priori contrasts adjusted for multiple comparisons were used to test for differences across the levels of season. The between-subjects factor of group was coded as no history of LBP (35%), past history of LBP but not in the past week (30%), or current LBP (35%). All LBP participants in the analysis reported central or bilateral pain. In the case of the multifidus muscle data, a multivariate analysis of covariance (MANCOVA) was used with vertebral level (L2, L3, L4, L5) as a multiple outcome measure. Use of MANCOVA enabled comparison across the vertebral levels by standardizing the measures to z scores. This procedure accommodates the systematic increase in multifidus size that otherwise results in vertebral level being inappropriate as a repeated-measures factor.

The analyses were conducted for 20 participants with data at all 4 time points. To examine the generalizability of the results to the total sample, an attrition analysis using analyses of variance was conducted to compare the muscle size of this group with the muscle size of the remainder of participants at each time point. A nonsignificant finding indicated that the participants included in the analysis were a representative group of the total sample. The α level was set at .05 for all analyses. We used SPSS (SPSS Inc, Chicago, IL) to analyze the statistics.

RESULTS

Results of the attrition analysis showed that the cases included in the longitudinal study (n = 20) were representative of the total sample of players in the squad for all muscles examined ($F_{1,41}$ range, 0.01–4.3, $P > .05$). The mean age, height, and mass (±standard deviation) of 20 participants in the analysis were 22.5 ± 3.3 years, 188.9 ± 6.1 cm, and 88.4 ± 8.1 kg, respectively.

Multifidus Muscle

Results of analysis of the multifidus muscle CSA showed a change in size across season ($F_{12,123} = 3.6$, $P < .001$). Results of the contrasts across season and the means shown in Table 1 indicated a decrease in CSA at the L3 ($F_{1,14} = 43.2$, $P < .001$), L4 ($F_{1,14} = 6.2$, $P = .03$), and L5 ($F_{1,14} = 32.3$, $P < .001$) vertebral levels of the multifidus muscle by T2. The amount of atrophy differed across vertebral levels, ranging from 11.1% at L3 to 3.8% at L4 and 9.1% at L5. In the case of L5, a decreased CSA also was evident at T3 ($F_{1,14} = 12.1$, $P = .004$). Recovery of muscle size was achieved by T4, which was indicated by a finding of size at T1 that was not different ($F_{1,14}$ range, 0.02–3.6, $P > .05$). We did not find effects involving the factors of LBP history or asymmetry in multifidus muscle size related to preferred kicking leg ($F_{24,168}$ range, 0.6–1.4, $P > .05$).

Table 1. Cross-Sectional Area of the Multifidus Muscle for 4 Vertebral Levels and Lumbar Erector Spinae at L3 at Different Times of 3 Playing Seasons, cm² (Mean ± SE)[a]

	Time Point			
Muscle	Start of Preseason 1	End of Season 1	End of Preseason 2	Start of Preseason 3
Multifidus for L2	4.54 ± 0.19[b]	4.24 ± 0.15	4.34 ± 0.16	4.55 ± 0.20
Multifidus for L3	7.27 ± 0.28[b]	6.46 ± 0.31[c]	7.05 ± 0.22	7.15 ± 0.24
Multifidus for L4	10.39 ± 0.34[b]	10.00 ± 0.27[c]	10.06 ± 0.25	10.19 ± 0.28
Multifidus for L5	11.21 ± 0.32[b]	10.19 ± 0.29[c]	10.56 ± 0.22[c]	10.95 ± 0.31
Erector spinae for L3	23.27 ± 0.88[b]	24.10 ± 0.89[c]	24.38 ± 0.90[c]	23.24 ± 0.82

[a] Means are marginal means adjusted for age, height, and mass.
[b] Indicates reference category for a priori contrasts.
[c] Indicates $P < .05$.

Table 2. Thickness of Abdominal Muscles at L3 at Different Times of 3 Playing Seasons, mm (Mean ± SE)[a]

Muscle	Time Point			
	Start of Preseason 1	End of Season 1	End of Preseason 2	Start of Preseason 3
Relaxed transversus abdominis thickness	7.57 ± 0.29[b]	5.98 ± 0.23[c]	5.94 ± 0.24[c]	7.58 ± 0.25
Relaxed internal oblique thickness	15.26 ± 0.51[b]	17.09 ± 0.45[c]	17.40 ± 0.31[c]	15.21 ± 0.48

[a] Means are marginal means adjusted for age, height, and mass.
[b] Indicates reference category for a priori contrasts.
[c] Indicates $P < .05$.

Lumbar Erector Spinae Muscle

Analysis of CSA for the LES muscle showed an effect across season ($F_{3,42} = 7.7$, $P < .001$). Compared with T1, we found 3.6% hypertrophy at T2 ($F_{1,14} = 10.1$, $P = .007$), 4.8% hypertrophy at T3 ($F_{1,14} = 16.0$, $P = .001$), and recovery by T4 ($F_{1,14}$ range, 0.01–0.96, $P > .05$) (Table 1). We found no effects involving the factors of LBP history or asymmetry in size relative to the preferred kicking leg ($F_{6,42}$ range, 0.02–1.7, $P > .05$).

Transversus Abdominis Muscle

Analysis of the thickness of the TrA muscle indicated an effect across season ($F_{3,42} = 56.1$, $P < .001$). From T1 to T2, the TrA muscle decreased in thickness by 21.0% ($F_{1,14} = 68.0$, $P < .001$). At T3, the muscle also showed a 21.5% atrophy in thickness ($F_{1,14} = 73.3$, $P < .001$). At T4, the muscle had recovered, showing no difference in thickness from T1 (0.001% difference; $F_{1,14} = 0.01$, $P = .93$) (Table 2). We found no effects involving the factors of LBP history or asymmetry in size related to preferred kicking leg ($F_{6,42}$ range, 0.1–0.6, $P > .05$).

Internal Oblique Muscle

We found an effect for season for thickness of the IO muscle ($F_{3,42} = 9.4$, $P < .001$). Compared with T1, 11.8% hypertrophy was evident by T2 ($F_{1,14} = 28.5$, $P < .001$) and 13.8% hypertrophy was evident by T3 ($F_{1,14} = 47.9$, $P < .001$). At T4, the muscle showed a return to baseline value (0.005% difference; $F_{1,14} = 0.001$, $P = .98$). We found no effects for the factors of LBP history or asymmetry ($F_{6,42}$ range, 0.1–0.6, $P > .05$).

DISCUSSION

Overall, our results indicated that the size of the trunk muscles with a proposed role in torque production, such as IO and LES,[12] increased over the playing season and decreased by the start of the next season. The recovery to baseline values by the start of the next season can be attributed largely to rest and recreation during the off-season. The increase in size during the season could be expected due to larger loads associated with training for and playing football. However, the results also indicated that the size of local muscles, such as the multifidus and TrA, decreased over the playing season and recovered by the start of the next season. This pattern of imbalance during the playing season might be problematic because torque-producing muscles of the trunk generate large forces on the spine.[31] In this situation, a biomechanical in vivo model suggested that these forces might induce instability of the lumbar spine if deeper muscles, such as the multifidus and TrA, were not activated.[31] Atrophy of the multifidus muscles is considered an adverse event among people with LBP[32] and those who experience prolonged bed rest.[24,25] Therefore, this pattern of imbalance seems to be an undesirable outcome for athletes.

The proposed role of the multifidus muscle is segmental support, control of vertebral segments,[13] and control of the lumbar lordosis. It also has been proposed to have a proprioceptive role because it is dense with muscle spindles.[14] The CSA of the multifidus muscle decreased by 9.1% over the playing season at the lumbosacral junction. This could have potentially detrimental effects on the control and protection of the lumbar spine and sacroiliac joints. Assessing LBP status of the players was important in our study because LBP has been associated with a decrease in CSA of the multifidus muscle in athletes[33] and alterations in the recruitment of the anterolateral abdominal muscles in AFL players.[34] We found no relationship between LBP and the changes in the form of the muscles. This suggests that our study results are related primarily to training for and playing football.

Seasonal variations in trunk muscles associated with lumbopelvic stability might have serious implications for susceptibility to injury. Given that Australian rules football is a high-intensity, physically demanding sport, a sport-related effect on the potential ability of these muscles to protect the spine might be worth investigating further. Deficits in neuromuscular control of the lumbopelvic region have been suggested to affect the dynamic stability of the knee because they might contribute to instability throughout the segment of the kinetic chain.[20–22] Given that stability of the lumbopelvic region involves dynamic trunk control to allow production, transfer, and control of forces and motion to the distal segments of the kinetic chain,[35] good control of the lumbopelvic area probably is needed to meet the high demands imposed on the body in a sport such as Australian rules football. Furthermore, Cowan et al[36] showed an association between a delay in activation of the TrA muscle and long-standing groin pain.

The concept of muscle imbalance is that hypertrophy or overrecruitment of one group of muscles might be associated with a corresponding decrease in size or recruitment of opposing muscles (eg, flexor muscles versus extensor muscles). However, muscle imbalance is also possible within a synergy of muscles. For example, one flexor muscle in a group of flexors could increase, whereas another in the group could decrease. This is important for both screening and targeted rehabilitation. For example, if one flexor muscle decreases in size but another compensates by increasing in size, overall measures such as strength might be unchanged. To be effective in this scenario, exercise programs might have to be tailored to focus on recruiting and training individual muscles.

Our study had some limitations. Typically, a high turnover of football players occurs in clubs across seasons. Therefore, fewer players were available for inclusion in the longitudinal study. However, the attrition analysis comparing muscle size of those in or out of the analysis at each time point indicated that the results were representative of the total sample. This suggests that the findings can be generalized to our sample and other populations of football players. However, all players with LBP experienced bilateral pain, and caution is needed in generalizing the findings to cases of unilateral back pain. The clinical importance of changes in muscle size among elite athletes should be examined. Based on the high percentage change in scores across time, our results have clinical implications. In future studies, investigators could study functional differences and injury rates caused by, for example, a reduced size of the multifidus muscle and the effect of intervention to ameliorate atrophy or hypertrophy of muscle mass.

ACKNOWLEDGMENTS

We thank the Centre for Advanced Imaging, University of Queensland, Stephen Wilson, Mark Strudwick, Matt Meredith, Andrew Smith, Marcus Ashcroft, Peter Stanton, Victor Popov, Lachlan Penfold, Nathan Cross, and the Brisbane Lions AFL players. This study was funded by a sports medicine research grant provided by the Brisbane Lions Australian Rules Football Club.

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