The effect of a 12 week core training regimen on electromyographic activation in national-level junior swimmers

Hibbs AE [1], Weston M [2], Thompson KG[3], Spears IR [2], Dixon J[2]

[1] Northumbria University, Newcastle Upon Tyne, UK

[2] Teesside University, Middlesbrough, UK

[3] UCRISE, University of Canberra, Canberra, Australia

Address for correspondence

Dr John Dixon
Health & Social Care Institute
Teesside University
TS1 3BA
UK
Email: john.dixon@tees.ac.uk
Phone: +44 (0)1642 384125
Fax +44 (0)1642 342983

ABSTRACT

Knowledge of muscle activation during core training exercises over the duration of a training program would enhance our understanding of the physiological responses to training. The purpose of this study was to quantify the effect of a 12-week core training regimen on neuromuscular activation in swimmers. Ten national-level junior swimmers performed a core exercise regimen three times a week over a 12-week training period. Surface electromyographic (EMG) measurements from 6 core muscles were taken pre- (0 weeks), mid- (6 weeks) and post-training (12 weeks). Analysis was carried out on the EMG activity during maximal voluntary isometric contractions (MVCs) and on the normalized and non-normalized EMG values during the core exercises. MVC EMG activity increased with the intervention in all muscles. The magnitudes of changes in MVC EMG activity were greater during the initial phase (effect sizes - standardized mean differences 0.32 to 1.01) compared to the second phase (effect sizes -0.20 to 1.04). Substantial reductions were observed in the normalized EMG data, with these effects being greater during the initial phase (effect sizes -1.54 to -0.28) compared to the second phase (effects sizes -1.12 to -0.22). There were also substantial reductions in non-normalized absolute EMG activity in both the initial (effect sizes -2.73 to -0.27) and second (effects sizes -1.27 to -0.20) phases. Over the 12 week training program substantial neuromuscular adaptations occurred in the core muscles; activation during the core exercises reduced, whilst activation during the MVCs increased. These adaptations are indicative of improvements in neuromuscular strength and efficiency. Changes in EMG data provide objective measures of neuromuscular adaptation which can inform future iterations of training regimens for athletic populations.

Keywords: Core training, core exercise, muscle activity, electromyography, training response

INTRODUCTION

The core refers to the musculature of the shoulder stabilisers, trunk and the upper leg muscles (1). A major role of the core musculature is to provide dynamic stiffness for the central joints of the body and in particular the spinal joints. The tension created by coordinated core muscular actions induces controllable stiffness of the spine via axial compression (2) and the ability to perform this function is often referred to as core stability (3). It is commonly held that a stable core will increase the efficiency of movement (e.g. 1). Accordingly, there is often an assumption in the sports sciences that core exercises lead to performance improvements. Consequently, core muscles exercises are integrated into many strength and conditioning regimens (4, 5).

The goal of any muscular training regimen is to overload the muscle to elicit a consistent physiological training response over the time course of the regimen. There are several mechanisms by which the muscles respond to this loading which include changes in size, structure and neural drive (6,7). Although attention has recently been placed on the harmful/beneficial effects of core training programs (3), importantly little is actually known about muscle activity whilst performing these core exercises during the time course of the regimen.

Surface electromyography (EMG) is a standard technique for the objective quantification of muscular activity (8). A number of studies have used EMG to quantify muscle activity during a range of functional exercises which include components of core training (9-12). Collectively, these studies have contributed to a better understanding of muscle activity during a range of core exercises. In addition, based on the relationship between normalized EMG values and predetermined threshold levels (13), these studies were able to quantify muscle overload and thus predict whether a training response is likely. However, these aforementioned studies were all cross-sectional in design and thus it is not possible to quantify the magnitude of response over a typical core training regimen.

Any observed training response could be due to increases in strength, an increased ability to maximally activate motor units which produces an increase in maximal EMG activity (14), or changes in the muscular strategy for performing these movements (15, 16). So the prediction of the neuromuscular response to training is not straightforward. However, changes in EMG over the time course of a training regimen have been recorded to quantify changes in neural drive in untrained participants and patients with musculoskeletal disorders (7, 17-21). Specifically, these changes are suggested to reflect the changes in efferent neural output from the central nervous system to muscles which, particularly in the absence of noticeable hypertrophy, are the major training response to a short-term training regimen (15). However, it has been highlighted that most of the research in this area has focussed on untrained rehabilitating populations and very little is known about the magnitude of neuromuscular changes during athletic training regimens (22). To the best of our knowledge, this is still the case.

In athletic research there is a key need to develop objectively determined training regimens relevant to the sport. Efficient swimming is believed to require a core musculature that is able to stabilise the spine (23) and a high-level swimmer will elicit activity in the core musculature to levels greater than 40% of maximal voluntary isometric contraction (MVC) when performing a stroke (24,25). Consequently, swimmers undergo dry-land training which often involves a substantial component of core training. However, at present these core training regimens are subjectively determined using "good judgement, experience and educational training" (26, p.374). In order to develop an objectively determined core training regimen for swimmers it is vital to have a better understanding of neuromuscular adaptations and the likely time course of the training response. To the authors' knowledge, there are currently no studies providing evidence regarding this.

Therefore, the purpose of this study was to quantify neuromuscular adaptations in a group of national-level junior swimmers during a 12-week core training regimen. It was expected that loading the core muscles would lead to changes in EMG activity of the core muscles and these changes would provide insight into the underlying training response during the regimen. In order to elucidate the specific detail of any adaptations, we also aimed to assess changes in a) EMG amplitude during MVCs, and b) in normalized and non-normalized EMG amplitude, during the core exercises.

MATERIALS AND METHODS

Participants

Ten national-level junior swimmers (five men, age: 16.2 ± 1.3 years, stature: 174.3 ± 5.6 cm, body mass: 63.4 ± 6.4 kg; five women, age: 17.4 ± 1.5 years, stature: 173.2 ± 4.4 cm, body mass: 63.8 ± 4.6 kg) were recruited to the study and completed a 12-week core training regimen in addition to their normal pool-based swimming regimen. This took place during the pre-season training period prior to competitions occurring for the athletes. To be included in the study participants had to compete at national age group level competitions in swimming and be trained to a high standard with 9+ sessions a week. All subjects were highly-trained and familiar with, but not currently practising, core training exercises. We used a mixed gender sample to increase generalizability and help recruitment. A quasi-experimental research design was used in this study which is considered appropriate for the sub-elite athletes (27). The group was exposed to a control (pre) and intervention (mid and post) period where multiple observations of EMG muscle activity were made over time. This study was approved by the

Teesside University Ethics Committee. All subjects signed an informed consent form and completed a medical questionnaire.

Exercises

The core training intervention exercises which were performed in the training regimen are shown in Table 1 and were as follows; forward bridge, side bridge, bird dog, straight leg raise, shoulder press, overhead squat and medicine ball sit-twist (2, 9, 12). This regimen of exercise was chosen to include static, dynamic, low-threshold (no external resistance), high-threshold (with external resistance), symmetrical and asymmetrical movements. In a previous study (12) we found these exercises to induce levels of activity to be greater than threshold levels required for improving core stability (10-25% of MVC) and core strength (>60% of MVC) (13). To minimise learning effects all participants were given a familiarisation exercise session and performed the exercises for two weeks prior to data collection. The repetition rate of the exercise was varied according to the demands of the exercise (Table 2). Each exercise was performed twice for a total of 60 seconds with 60 seconds recovery between sets. The order of exercises was randomised for each subject. The quality of the exercises was monitored by a British Association of Sport and Exercise Sciences accredited sport scientist and a swimming coach, during the test sessions and training regimen, respectively. Over the 12-week training period, the core exercises were performed three times a week. A linear model for functional progression, an important component of core training (28), was incorporated (Table 2).

Data Collection

Surface EMG measurements were collected at 3 testing sessions: pre- (0 weeks), mid- (6 weeks) and post-training (12 weeks). EMG data were recorded from the right side of six muscle sites. These were the upper rectus abdominis (RA), external oblique (EO), gluteus maximus (GM), multifidus (MF), latissimus dorsi (LD) and rectus femoris (RF). The six muscles were selected based on previous research that highlights them as important to core stability and strength (9, 13, 29, 30) and from which activity levels can be accurately and reliably measured (12, 31, 32). Photographs were taken during each data collection period to ensure accurate placement of the electrodes on subsequent sessions. EMG data were collected using a Delsys Wireless Myomonitor III device with surface electrodes, and sampled at 1000 Hz (Delsys DE-2.3 Single Differential Surface Electrode; inter-electrode distance 1 cm, gain 1000, bandwidth 20 – 450 Hz, common mode rejection ratio of −92 dB, pre-amplifier gain 1000 V/V ± 1%, input impedance of >1015 Ω//0.2 pf). EMG data were collected during the core exercises. In addition, at the beginning of each of the 3 testing sessions, 5 MVC exercises were performed three times each for 10 seconds, with one minute rest between each. These MVC exercises, detailed previously and shown to have good reliability (12), were; resisted sit-up (RA), resisted back extension (GM & MF)), resisted trunk rotation (EO), resisted hang (LD) and resisted hip flexion (RF). Whilst performing the exercises, the participants were given verbal encouragement to ensure a maximal and consistent effort. To standardize the effect of the muscle length–tension relationship on the resultant EMG output, these MVC exercises were performed in a similar body position to those of the core training exercises (33, 34).

Data Processing and extraction

The EMG data processing was described in Hibbs et al. (12). The raw EMG signals were processed using Delsys EMGworks software with a Root Mean Square (RMS) moving window of 50 ms. We extracted and analysed data for: normalized EMG amplitude during the core exercises; non-normalized (absolute) EMG amplitude during the core exercises; EMG amplitude during the MVCs. For each of these, following Hibbs et al. (12), both the peak and average EMG values were extracted and analysed. The peak value was taken as the highest EMG value and the average value was taken as the sum of the area under the EMG-time curve divided by the time period (12, 18, 35). The derived EMG variables used in this study are listed in Table 3. For the static exercises and the MVCs we extracted the data for the middle five second period (12). For the dynamic exercises we extracted the data for three repetitions in the middle of each set, determining the EMG onset and cessation points of each visually. To normalize the EMG data during the core exercises, the peak and average values in the exercises were used as the numerators and the MVC peak and average values as the denominators (12). The rationale for analysing both normalized and non-normalized data (20) is that both the exercise EMG and MVC EMG signals could change over time. This could affect interpretation of the normalized data when considered in isolation and potentially mask any neuromuscular responses. In reporting these absolute EMG variables, we are aware that between-day differences (36) due to inaccurate sensor placement could introduce some random noise. Caution was thus adopted when placing and removing the sensors at each testing session (20).

Data Analysis

Data are presented as the mean ± SD. Prior to all analyses plots of the residuals versus the predicted values revealed no evidence of non-uniformity of error. In athletic research, it has been argued that it is not whether an effect exists but how big the effect is that matters and that the use of the P value alone provides no information about the direction or size of the effect or the range of feasible values (37). Therefore, we elected to use effect sizes, with uncertainty of the estimates shown as 90% confidence intervals, to quantify the magnitude of any changes in EMG activity levels across the duration of the study (0, 6, and 12 weeks). Effect sizes were classified as trivial (<0.2), small (0.2 to 0.6), moderate

(0.6 to 1.2), large (1.2 to 2.0), very large (2.0 to 4.0) and extremely large (>4.0) (38). Also, a threshold value of 0.2 between-subject standard deviations was set as the smallest worthwhile change. Inference was then based on the disposition of the confidence interval for the mean difference to this smallest worthwhile effect; the probability (percent chances) that the true population difference between tests is substantial (beneficial / detrimental) or trivial was calculated as per the magnitude-based inference approach (39). These percent chances were then qualified via probabilistic terms and assigned using the following scale: <0.5%, most unlikely; 0.5-5%, very unlikely; 5-25%, unlikely; 25-75%, possibly; 75-95%, likely; 95-99.5%, very likely; >99.5%, most likely (37). The effect sizes, confidence intervals and magnitude-based inferences were determined using a custom-made spreadsheet (38).

RESULTS

The effects of the initial 6 weeks of the core training regimen were clear, substantial increases in MVC EMG for all six muscles (Figure 1; Figure 2). These increases were observed for both peak MVC (PMVC) and average MVC (AMVC) measures, with the magnitude of effects being small to moderate. For the second phase of the exercise intervention (weeks 6-12) there were further substantial increases in MVC EMG (small to moderate effects), with the exception of MF, LD, and RF peak values where the differences were more likely to be trivial.

The effects of the initial 6 weeks of the core stability exercise intervention were clear, substantial reductions in normalized EMG activity in all muscles (Figure 1; Figure 3). These increases were observed for both peak normalized (PNORM) and average normalized (ANORM) measures, with the magnitude of effects being small to large. Further substantial reductions were evident after weeks 6-12 of the training intervention in all muscles in terms of both PNORM and ANORM measures (small to moderate effects).

The effects of the initial 6-week training intervention on absolute EMG activity were clear with substantial reductions in EMG activity for muscles RA, EO, LD, GM, and RF (Figure 1; Figure 4). The magnitude of the effects was larger for peak absolute (PABS) (moderate to very large) than for average absolute (AABS) (small to moderate). There was also a substantial reduction in MF PABS, with a substantial increase in MF AABS and these effects were similar in magnitude (moderate). For weeks 6-12 further substantial reductions in EMG activity were observed for all muscles (small to large effect sizes), with the exception of AABS for the MF and EO where the differences were more likely to be trivial.

DISCUSSION

Despite core exercises being fundamental to many training regimens, very little is known about their effect on neuromuscular activation, and the adaptations they produce. Our results indicate that due to this training regimen MVC EMG increased, and EMG levels during the core exercises reduced: both indicating functional benefit. This is the first study to quantify the effect of a core training regimen on the neuromuscular response of the core muscles in swimmers, thus addressing the stated aim of this study.

Other studies have used EMG to quantify changes in maximal neuromuscular activation and improvements from these studies have been greater than 10% (e.g. 20). For the group of national-level junior swimmers in the present study we report increases of 5-6% in MVC EMG. Thus, in comparison, the reported increase in the current study is relatively modest. However, given that swimming exerts high demands on the core, it should be noted that the participants in the present study are likely to be highly trained in the core musculature. Thus, when training status is taken into consideration, the gains in maximal neuromuscular activation of 5-6% are probably worthwhile for these swimmers. In addition to these gains in MVC EMG, we also found changes in the levels of EMG activity during the core exercises between testing sessions. This pattern occurred in both the normalized and non-normalized EMG data, indicating that it was not solely due to the normalization process. Specifically we report a decrease in absolute EMG activity between 2-6% when the athletes performed the training exercises in the testing sessions. Unfortunately, there are no previous core exercise studies with which to compare these findings but there are a number of potential mechanisms underpinning these changes. There may have been changes in motor unit firing rates and synchronisation, and potentially changes in muscle morphology (19). There is also evidence to indicate that repeated practice of an exercise will cause the central nervous system to select for a muscle activation pattern which is more efficient in generating movement at the loaded joints (e.g. 40). The mechanism in this adaptive response is thought to be a reduction in antagonistic contraction, thus allowing a greater expression of agonistic activity (15, 41). It is suggested that after a period of adaptation to the core exercises, there is less resistive torque to overcome, and the athletes are able to perform the same exercises but with less muscle activation required which is indicated by the reduction in the EMG activity.

This study has important practical applications and clinical relevance, showing the ability to highlight the weaknesses of a training regimen such as this. Notably, there was a decrease in training response over the time course leading to the eventual plateau in the neuromuscular response. This plateau is common to many exercise interventions which are designed to improve performance or muscular strength (42, 43). In the current study, it is suggested that the plateau is due to the muscles becoming both stronger and more efficient during the time course of the regimen, thus making it more difficult to maintain overload. Consequently, it is argued that the simple linear model of progression (Table 1) used in this study was not sufficient to maintain a linear improvement in muscle response. With the benefit of hindsight and with this objective data to hand, it is clear that the model of progression should have been non-linear, incorporating a lower overall load in the early stages when the muscle recruitment strategy was inefficient and the neuromuscular strength was relatively low and a higher load in the latter stages when the muscles were more efficient and relatively stronger. A second weakness of the regimen, again highlighted by the EMG data, was the different levels of adaptation occurring across muscles. Ideally, in the case of the core a harmonious balance should be sought (2), such that the training regimen elicits similar responses in all the muscles groups and working pairs. The gains in neuromuscular strength in the current study although similar in direction were different in magnitude. For example, changes in neuromuscular strength for multifidus were much greater than for the external oblique (9% vs 3%, respectively). Further inspection of our EMG data reveals that multifidus was loaded substantially (>25%) in all but one of the exercises, whereas the external oblique was only loaded substantially in 2 of the 6 exercises. With the benefit of hindsight and again with the availability of this objective data, it is clear that the regimen could have included a greater proportion of coronal plane loading by, for example, increasing the repetitions of the side-bridge. Our results show EMG has potential as a tool for measuring neuromuscular response and for providing objective feedback to inform the delivery of exercise regimens in practice. Future studies can develop a more detailed understanding of the physiological responses.

This study does have some limitations including the small sample size and lack of a control group. There are also many limitations of surface EMG which are well-documented (e.g. 36). Nonetheless, it remains a widely accepted and key tool for the purpose of quantifying the drivers of muscle activity. However, it should also be noted that the use of EMG as a measure of neuromuscular adaptations in a pragmatic athletic setting entails further limitations. For example, it was not possible to measure maximal external torque and thus it is not possible to quantify the overall change in strength of the muscles including gains due to hypertrophy or to structural reorganisation. That said, given the applied nature of the research this compromise between measurement and pragmatism are considered to be justified in this first study. Again, future studies can look to incorporate measures of torque to further enhance our knowledge in this area.

CONCLUSION

Over the time course of this 12 week core training program, substantial neuromuscular adaptations occurred in the core muscles. Levels of muscle activation during the core exercises reduced whilst activation during the MVCs increased. These adaptations are indicative of improvements in neuromuscular strength and efficiency in swimmers from this core training regimen. These results also show that, when using normalised EMG in longitudinal studies, it is important to quantify changes in both the numerator and denominator EMG values for a clear understanding of changes that may have occurred.

Acknowledgements

No funds were received for this work. The authors have no conflict of interest to disclose.

References

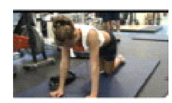
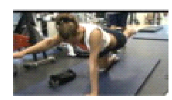
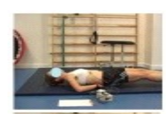
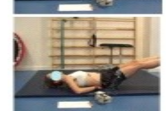
1. Lehman GJ (2006) Resistance training for performance and injury prevention in golf. J Can Chiropr Assoc 50: 27-42
2. McGill SM (1998) Low back exercises: evidence for improving exercise regimens. Phys Ther 78: 754-765
3. Lederman E (2010) The Myth of Core Stability. J Bodyw Mov Ther 14: 84-98
4. Hibbs AE, Thompson KG, French D, Wrigley A, Spears I (2008) Optimizing performance by improving core stability and core strength. Sports Med 38: 995-1008.
5. Reed CA, Ford KR, Myer GD, Hewett TE (2012) The effects of isolated and integrated 'core stability' training on athletic performance measures: a systematic review. Sports Med 42:697-706
6. Kraemer WJ, Duncan ND, Volek JS (1998) Resistance training and elite athletes: adaptations and program considerations. J Orthop Sports Phys Ther 28:110-119
7. Gabriel DA, Kamen G, Frost G (2006) Neural adaptations to resistive exercise: mechanisms and recommendations for training practices. Sports Med 36: 133-149
8. Soderberg GL, Knutson LM (2000) A guide for use and interpretation of kinesiologic electromyographic data. Phys Ther 80: 485-498
9. Axler CT, McGill SM (1997) Low back loads over a variety of abdominal exercises: searching for the safest abdominal challenge. Med Sci Sports Exerc 29: 804-811
10. Ekstrom RA, Donatelli RA, Carp KC (2007) Electromyographic analysis of core trunk, hip, and thigh muscles during 9 rehabilitation exercises. J Orthop Sports Phys Ther 37: 754-762
11. Jørgensen MB, Andersen LL, Kirk N, Pedersen MT, Søgaard K, Holtermann A (2010) Muscle activity during functional coordination training: implications for strength gain and rehabilitation. J Strength Cond Res 24: 1732-1739
12. Hibbs AE, Thompson KG, French DN, Hodgson D, Spears IR (2011) Peak and average rectified EMG measures: which method of data reduction should be used for assessing core training exercises? J Electromyogr Kinesiol 21: 102-111
13. Vezina MJ, Hubley-Kozey CL (2000) Muscle activation in therapeutic exercises to improve trunk stability. Arch Phys Med Rehabil 81: 1370-1379
14. McBride JM, Blaak JB, Triplett-McBride T (2003) Effect of resistance exercise volume and complexity on EMG, strength, and regional body composition. Eur J Appl Physiol 90: 626–632
15. Gabriel DA, Boucher JP (2000) Practicing a maximal performance task: a cooperative strategy for muscle activity. Res Q Exerc Sport 71: 217-228
16. Minetti AE (2004) Passive tools for enhancing muscle-driven motion and locomotion. J Exp Biol 207: 1265-1272
17. Knight C, Kamen G (2001) Adaptations in muscular activation of the knee extensor muscles with strength training in young and older adults. J Electromyogr Kinesiol 11: 405-412
18. Aagaard P, Simonsen EB, Andersen JL, Magnusson P, Dyhre-Poulsen P (2002) Neural adaptation to resistance training: changes in evoked V-wave and H-reflex responses. J Appl Physiol 92: 2309-2318

19. Del Balso C, Cafarelli E (1997) Adaptations in the activation of human skeletal muscle induced by short-term isometric training. J Appl Physiol 103: 402-411
20. Fimland MS, Helgerud J, Gruber M, Leivseth G, Hoff J (2010) Enhanced neural drive after maximal strength training in multiple sclerosis patients. Eur J Appl Physiol 110: 435-443
21. Suetta C, Aagaard P, Rosted A, Jakobsen AK, Duus B, Kjaer M, Magnusson SP (2004) Training-induced changes in muscle CSA, muscle strength, EMG, and rate of force development in elderly subjects after long-term unilateral disuse. J Appl Physiol 97: 1954–1961
22. Felici F (2006) Neuromuscular responses to exercise investigated through surface EMG. J Electromyogr Kinesiol 16:578-585
23. Pink M, Jobe F (1996) Biomechanics of Swimming. In: Athletic Injuries and Rehabilitation, edited by Zachazewski J and Magee D. Philadelphia, PA: Saunders p113-140
24. Clarys JP, Cabri J (1993) Electromyography and the study of sports movements: A review. J Sports Sci 11: 379-448
25. Rouard AH, Billat RP, Deschodt V, Clarys JP (1997) Muscular activations during repetitions of sculling movements up to exhaustion in swimming. Arch Physiol Biochem 105: 655-62
26. Kraemer WJ, Adams K, Cafarelli E, Dudley GA, Dooly C, Feigenbaum MS, Fleck SJ, Franklin B, Fry AC, Hoffman JR, Newton RU, Potteiger J, Stone MH, Ratamess NA, Triplett-McBride T (2002) American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. American College of Sports Medicine. Med Sci Sports Exerc 34:364-380
27. Atkinson G, Nevill A (2001) Selected issues in the design and analysis of sport performance research. J Sports Sci 19: 811-827
28. Jeffreys I (2002) Developing a progressive core stability program. Strength Cond J 24: 65-66
29. Garrido, N., Marinho, D.A., Reis, V., van den Tillaar, R., Costa, A., Silva, A., Marques, M. (2010). Does combined dry land strength and aerobic training inhibit performance of young competitive swimmers? Journal of Sports Science and Medicine, 9, 300-310
30. Vera-Garcia F, Grenier S, McGill S (2002) Abdominal muscle response during curl-ups on both stable and unstable surfaces. Phys Ther 80: 564-569
31. Arokoski JP, Kankaanpää M, Valta T, Juvonen I, Partanen J, Taimela S, Lindgren KA, Airaksinen O (1999) Back and hip extensor muscle function during therapeutic exercises. Arch Phys Med Rehabil 80: 842-850
32. Ng JK, Richardson CA, Parnianpour M, Kippers V (2002) Fatigue-related changes in torque output and electromyographic parameters of trunk muscles during isometric axial rotation exertion: an investigation in patients with back pain and in healthy subjects. Spine 27: 637-46
33. Urquhart DM, Hodges PW, Story IH (2005) Postural activity of the abdominal muscles varies between regions of these muscles and between body positions. Gait Posture 22: 295-301
34. Howard J, Enoka R (1991) Maximum bilateral contractions are modified by neurally mediated interlimb effects. J Appl Physiol 70: 306-316
35. Edwards L, Dixon J, Kent JR, Hodgson D, Whittaker VJ (2008) Effect of shoe heel height on vastus medialis and vastus lateralis electromyographic activity during sit to stand. J Orthop Surg Res 3:2
36. Burden A (2010) How should we normalize electromyograms obtained from healthy participants? What we have learned from over 25 years of research. J Electromyogr Kinesiol 20:1023-1035

37. Hopkins WG, Marshall SW, Batterham AM, Hanin J (2009) Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc 41: 3-13.
38. Hopkins WG (2006) Spread sheets for analysis of controlled trials, with adjustment for a subject characteristic. Sportsci 10: 46-50
39. Batterham A, Hopkins WG (2006) Making meaningful inferences about magnitudes. Int J Sports Physiol Perform 1: 50-57
40. McGill SM, Chaimberg JD, Frost DM, Fenwick CM (2010) Evidence of a double peak in muscle activation to enhance strike speed and force: an example with elite mixed martial arts fighters. J Strength Cond Res 24: 348-357
41. Carolan B, Cafarelli E (1992) Adaptations after isometric resistance training. J Appl Physiol 73: 911-917
42. Holm, L., Reirelseder, S., Pedersen, T.G., Doessing, S., Petersen, S.G., Flyvbjerg, A., Andersen, J.L., Aagaard, P., Kjaer, M. (2008) Changes in muscle size and MHC composition in response to resistance exercise with heavy and light loading intensity, Journal of Applied Physiology, 105 (5), 1454-1461
43. Kidgell, D.J., Stokes, M.A., Castricum, T.J., Pearce, A.J. (2010) Neurophysiological responses after short-term strength training of the biceps brachii muscle, Journal of Strength and Conditioning Research, 24(11), 3123-3132

Tables

Table 1 Core training exercise descriptions.

Exercise	Description	Repetition rate	Diagram
Forward bridge (static)	Hold a straight body position supported on elbows and toes. Brace the abdominal muscles and hold the back in a neutral position	Hold for 60 s	
Side bridge (static)	Lie on one side, ensuring top hip is positioned above the bottom hip. Push up until there is a straight bodyline through feet, hips and head	Hold for 60 s	
Birddog (asymmetrical)	Position hands below shoulders and knees below hips. Place back in neutral, slowly extend one leg backwards and raise forward the opposite arm until level with back. Ensure back does not extend and shoulders and pelvis do not tilt sideways. Bring leg and arm back to start position and swap sides	2 s change sides–3 s hold in position	 
Straight leg raises (asymmetrical)	Lie on back with knees extended on floor. Place back in neutral position and lift one leg straight up keeping knee extended and other leg held out horizontally off floor. Raise leg till hip at 75degrees, then return to start position and repeat with opposite leg	1 s hip flexion (down) 1 s hip extension (up) continuous, no hold	 

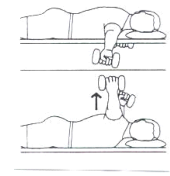
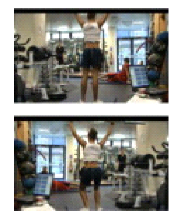
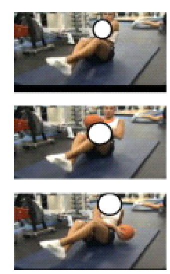
Horizontal Shoulder Press (asymmetrical)	lying horizontal on the floor with both arms extended above head. Using a weighted free dumbbell in each hand, raise one arm upwards extending the shoulder and hold, then return the dumbbell back to the floor and repeat this movement with the other arm	1 s raise up – 1 s hold position – 1 s return to start	
Overhead squat (symmetrical)	Using weighted medicine ball, place hands either side of ball and raise above head with straighten arms. Feet shoulder width apart, squat down as low as possible while maintaining balance, keeping ball, head and back vertical. Straighten legs and repeat	2s hip flexion (down) 2s hip extension (up) continuous, no hold	
Medicine ball, sit-twist (asymmetrical)	Sit up with knees bent and lean back at 45°. Feet off floor, keeping back in neutral, using a 4 kg medicine ball, twist waist and shoulders to one side with ball held out in front of you. Return to forward and repeat to other side	2s move from left to right and return (4s total)	

Table 2. Core exercise progression over the 12 week training regimen.

Exercise	Progression	Week 1-2		Week 3-4		Week 5-6	
		Repetitions	Sets	Repetitions	Sets	Repetitions	Sets
Forward bridge	Volume	30 sec hold	2	60 sec hold	2	90 sec hold	2
Side bridge	Volume	30 sec hold	2	60 sec hold	2	90 sec hold	2
Birddog	Volume	10	3	15	3	20	3
Leg raise	Volume	10	3	15	3	20	3
Shoulder press	Volume	10	3	10	4	15	4
Overhead squat	Load	10 (3kg)	3	10 (4kg)	3	15 (5kg)	3
Sit twist	Load	15 (3kg)	3	15 (4kg)	3	15 (5kg)	3
Exercise	**Progression**	**Week 7-8**		**Week 9-10**		**Week 11-12**	
		Repetitions	**Sets**	**Repetitions**	**Sets**	**Repetitions**	**Sets**
Forward bridge	Volume	90 sec hold	3	120 sec hold	2	120 sec hold	3
Side bridge	Volume	90 sec hold	3	120 sec hold	2	120 sec hold	3
Birddog	Volume	25	3	25	4	30	3
Leg raise	Volume	25	3	25	4	30	3
Shoulder press	Volume	20	3	20	4	25	3
Overhead squat	Load	20 (6kg)	3	20 (7kg)	4	25 (7kg)	3
Sit twist	Load	20 (6kg)	3	20 (7kg)	4	25 (7kg)	3

Table 3. The EMG variables used in this study

Variable	Description (units)
PMVC	Peak EMG activity whilst performing a maximum voluntary isometric contraction (mV).
AMVC	Average EMG activity whilst performing a maximum voluntary isometric contraction (mV).
PABS	Peak absolute (non-normalized) EMG activity whilst performing the core exercise (mV).
AABS	Average absolute (non-normalized) EMG activity whilst performing the core exercise (mV).
PNORM	Peak normalized EMG activity where PABS is the numerator and PMVC is the denominator (%).
ANORM	Average normalized EMG activity where AABS is the numerator and AMVC is the denominator (%).

Figure Legends

Figure 1. Means and standard deviations for EMG variables for each testing session (0, 6 and 12 weeks).

A) The data for each testing session are grouped by muscle and presented as peak EMG variables. PMVC, PNORM and PABS (see Table2 for definitions) are shown as dashed grey, solid black and solid grey lines respectively.
B) The data for each testing session are grouped by muscle and presented as average EMG variables. AMVC, ANORM and AABS (see Table2 for definitions) are shown as dashed grey, solid black and solid grey lines respectively.

Figure 2. Changes in peak and average EMG variables during MVCs. PMVC and AMVC are defined in Table 2. The effects and confidence intervals (90%) for weeks 0-6 and 6-12 are shown in black and grey respectively.

Figure 3. Changes in peak and average normalized EMG variables during the core exercises. PNORM and ANORM are defined in Table 2. The effects and confidence intervals (90%) for weeks 0-6 and 6-12 are shown in black and grey respectively.

Figure 4. Changes in peak and average absolute EMG variables during the core exercises. PABS and AABS are defined in Table 2. The effects and confidence intervals (90%) for weeks 0-6 and 6-12 are shown in black and grey respectively.

Figure 1a and 1b

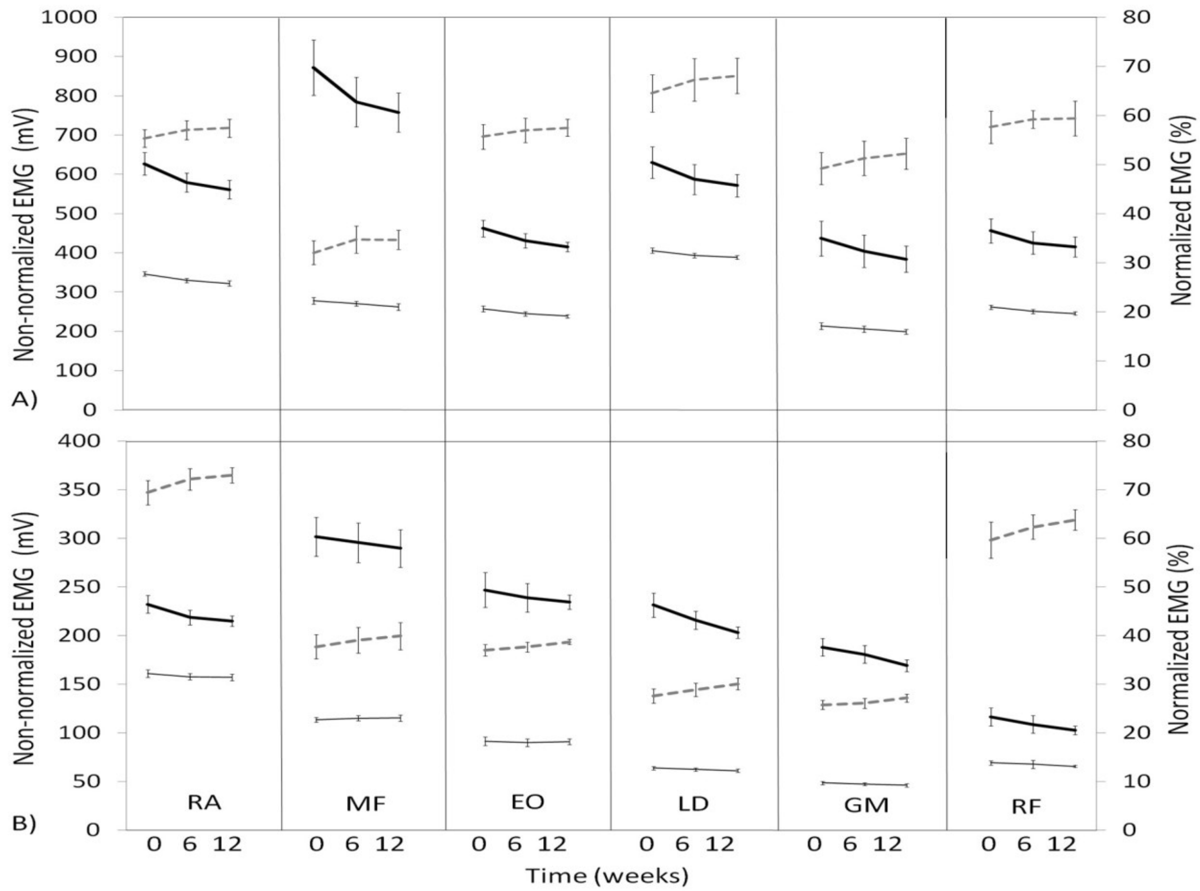


Figure 2

Muscle	EMG Variable	Mean at Pre (mV±SD)	Practical Inference (Post-Pre)
RA	PMVC	691 ± 21	Very likely beneficial
	AMVC	347 ± 12	Most likely beneficial
MF	PMVC	401 ± 29	Most likely beneficial
	AMVC	188 ± 12	Most likely beneficial
EO	PMVC	696 ± 30	Very likely beneficial
	AMVC	185 ± 6	Most likely beneficial
LD	PMVC	807 ± 45	Most likely beneficial
	AMVC	138 ± 7	Most likely beneficial
GM	PMVC	615±39	Most likely beneficial
	AMVC	129 ± 5	Most likely beneficial
RF	PMVC	720 ± 39	Very likely beneficial
	AMVC	298 ± 18	Most likely beneficial

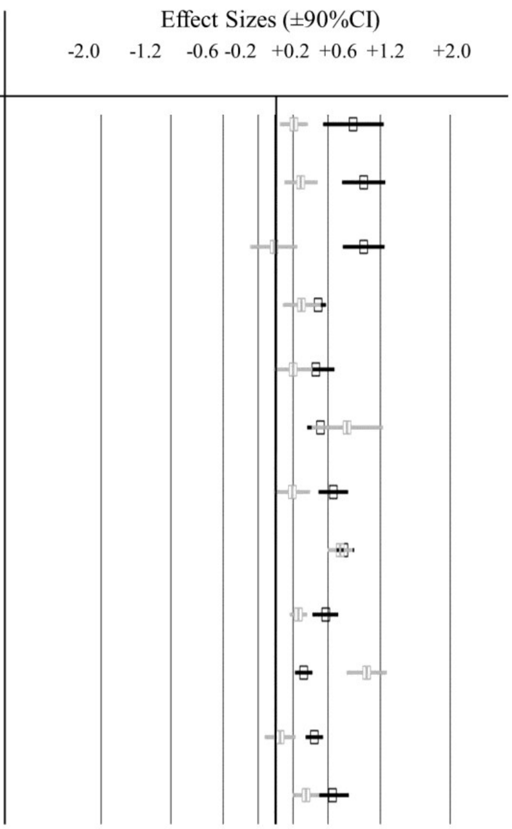


Figure 3

Muscle	EMG Variable	Mean at Pre (%±SD)	Practical Inference (Post-Pre)
RA	PNORM	51±10	Most likely beneficial
	ANORM	45 ± 4	Most likely beneficial
MF	PNORM	67 ± 6	Most likely beneficial
	ANORM	55 ± 4	Most likely beneficial
EO	PNORM	37 ± 8	Most likely beneficial
	ANORM	49 ± 5	Most likely beneficial
LD	PNORM	46 ± 6	Most likely beneficial
	ANORM	46 ± 5	Most likely beneficial
GM	PNORM	37 ± 8	Most likely beneficial
	ANORM	38 ± 6	Most likely beneficial
RF	PNORM	39 ± 8	Most likely beneficial
	ANORM	35 ± 7	Most likely beneficial

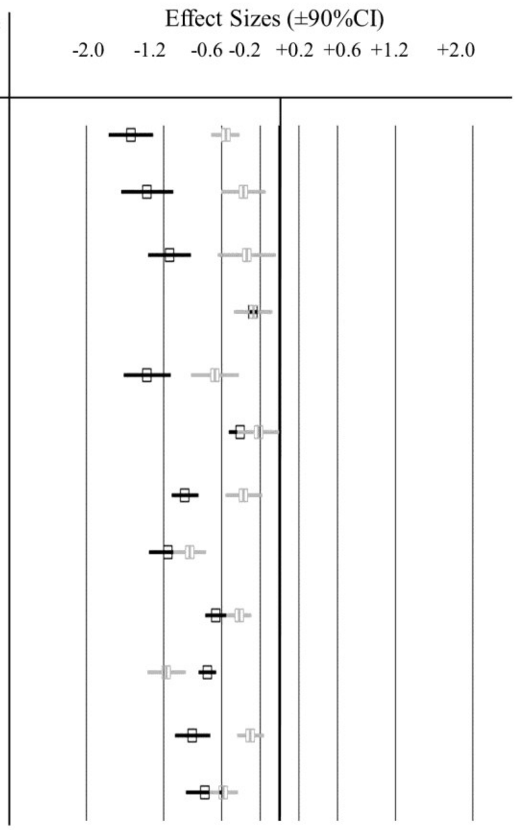


Figure 4

Muscle	EMG Variable	Mean at Pre (mV±SD)	Practical Inference (Post-Pre)
RA	PABS	346 ± 27	Most likely beneficial
	AABS	161 ± 9	Most likely beneficial
MF	PABS	278 ± 16	Most likely beneficial
	AABS	113 ± 6	Most likely beneficial
EO	PABS	257 ± 20	Most likely beneficial
	AABS	91 ± 7	Likely trivial
LD	PABS	405 ± 18	Most likely beneficial
	AABS	64 ± 4	Most likely beneficial
GM	PABS	213 ± 20	Most likely beneficial
	AABS	48 ± 4	Most likely beneficial
RF	PABS	262 ± 19	Most likely beneficial
	AABS	69 ± 5	Most likely beneficial