

EFFECTS OF WHOLE-BODY ELECTROMYOSTIMULATION ON STRENGTH AND BATTING VELOCITY OF FEMALE COLLEGIATE SOFTBALL PLAYERS

Raja Nurul Jannat Raja Hussain^{1*}, Kee Kang Mea¹, Rizal Razman², Shariman Ismadi Ismail¹, Maisarah Shari¹, and Norizzati Mohd Idris¹

¹Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia

²Centre for Sport and Exercise Sciences, University of Malaya, Malaysia

*Email: rajanuruljannat@gmail.com

(Received 9 December 2017; accepted 6 November 2018; published online 17 January 2019)

To cite this article: Raja Hussain, R. N. J., Kee, K. M., Razman, R., Ismail, S. I., Shari, M., & Mohd Idris, N. (2019). Effects of whole-body electromyostimulation on strength and batting velocity of female collegiate softball players. *Malaysian Journal of Movement, Health & Exercise*, 7(2), 175-184. <https://doi.org/10.15282/mohe.v8i1.191>

Link to this article: <https://doi.org/10.15282/mohe.v8i1.191>

Abstract

Batting velocity is an important component for successful hitting. Previous research has shown that batting velocity is influenced by increased muscular strength. Resistance training is broadly applied by strength and conditioning coaches to increase strength. However, recently, Whole-Body Electromyostimulation (WB-EMS) has been proven to be able to increase muscular strength in high performance athletes. This study aimed to examine the effects of eight weeks of dynamic WB-EMS training on muscular strength and batting velocity among female collegiate softball players. Forty softball players were randomly assigned to two groups: DS-EMS (n = 20) and DS (n = 20). Both groups performed 100 basic dry swings per session using a standard bat. Additionally, DS-EMS group performed whole body electromyostimulation after the dry swing training. The training program was conducted three times a week and all participants were tested before (baseline) and after (week-8) the training programs. Both groups showed statistically significant increases in predicted 1RM torso rotational strength ($p \leq 0.01$) and batting velocity ($p \leq 0.01$) after 8 weeks of training. The WB-EMS group showed significant increase in predicted 1RM bench press, and predicted 1RM squat ($p \leq 0.01$). The WB-EMS group showed greater increases ($p \leq 0.01$) in batting velocity compared to control group. These data indicate that an 8-week of dry swing training supplemented by dynamic WB-EMS sessions may significantly increase strength and batting velocity among female collegiate softball players.

Keywords: Swing, electromyostimulation, batting, velocity

Introduction

Batting velocity is an essential component of successful hitting in softball and baseball (Szymanski, DeRenne, & Spaniol, 2009; Wilson et al., 2012). A previous study found that batting velocity can be increased by sport-specific resistance training, which is able to increase muscular strength (Szymanski, Szymanski, Schade, & Bradford, 2008). Furthermore, research also indicates that upper and lower body strength and torso rotational strength (Szymanski, McIntyre, et al., 2007) have a significant relationship with batting velocity. Therefore, based on previous studies, batting velocity may be influenced by changes in strength.

Over the past 30 years, traditional resistance training has been utilised to increase batting velocity among high school, collegiate, amateur, and professional softball and baseball players (Szymanski, Albert, et al., 2008; Szymanski et al., 2009). Such studies have reported significant improvement in muscular strength with a corresponding increase in batting velocity. It is typically reported that traditional resistance training takes up to 60 minutes per session (Fisher, Steele, Bruce-Low, & Smith, 2011; Nybo et al., 2010). However, in recent times, coaches have limited time to train their athletes. Consequently, they usually neglect the conditioning practice and focus more on techniques and tactics of the game. These leads to players having weak strength base and in turn only worsens their sports performance (Sugimoto et al., 2017).

Recently, whole-body electromyostimulation has been used to increase muscular strength in athletes and healthy adults over four to twelve weeks of training (Filipovic et al., 2016; Filipovic, Kleinöder, Dörmann, & Mester, 2011, 2012). Previous meta-analysis of EMS methods revealed that this training method works effectively as an alternative to the traditional resistance training for developing maximal strength performance in athletes (Filipovic et al., 2012). Several studies reported a significant change in strength (Billot, Martin, Paizis, Cometti, & Babault, 2010; Girolid et al., 2012). Moreover, EMS has also shown positive effects on sports performance such as swimming (Girolid et al., 2012), kicking soccer ball (Billot et al., 2010) and rugby (Babault, Cometti, Bernardin, Pousson, & Chatard, 2007). All of these studies applied single electrodes EMS to specific muscles. However, with the new generation of EMS devices, several muscle groups can be trained simultaneously through electrode belt and vest system.

This new technology will be handy to all coaches who have limited time for physical conditioning. In comparison with the single electrode EMS, there are very few studies that apply WB-EMS methods on athletes (Filipovic et al., 2016). Whole Body-EMS has been used in training to improve muscle mass and decrease abdominal fat (Kemmler & von Stengel, 2013), improve energy expenditure (Kemmler, Von Stengel, Schwarz, & Mayhew, 2012), improve resting metabolic rate, body composition and maximum strength (Kemmler, Schliffka, Mayhew, & von Stengel, 2010) among sedentary and older female adults. However, to date, there is only one applied study measuring the effect of WB-EMS on strength, sprinting, jumping, and kicking capacity in elite soccer players. There is an obvious lack of studies conducted on the effects of WB-EMS on applied sports performance. In light of his knowledge gap, this study aimed to quantify the effects of WB-EMS program on maximal strength as well as batting velocity among female collegiate softball players.

Table 1: Training protocols

| | Week 1 – 4 | | | Week 5 - 8 | | |
|---------------------|------------|-------|-------|------------|------|-------|
| | Sets | Reps | Hz | Sets | Reps | Hz |
| Warm-up | 2 | 10 | 50-60 | 2 | 10 | 50-60 |
| Parallel squat | 3 | 6-8 | 65-80 | 3 | 2-4 | 85-90 |
| Stiff leg deadlift | 3 | 6-8 | 65-80 | 3 | 2-4 | 85-90 |
| Bench press | 3 | 6-8 | 65-80 | 3 | 2-4 | 85-90 |
| Triceps kickback | 2 | 10-12 | 50-65 | 2 | 8-10 | 70-75 |
| Biceps curl | 2 | 10-12 | 50-65 | 2 | 8-10 | 70-75 |
| Seated Row | 2 | 10-12 | 50-65 | 2 | 8-10 | 70-75 |
| Ball exercise | Sets | Reps | Hz | Sets | Reps | Hz |
| Hitters throw | 2 | 6 | 80 | 2 | 8 | 70 |
| Standing figure 8 | 2 | 6 | 80 | 2 | 8 | 70 |
| Speed rotation | 2 | 6 | 80 | 2 | 8 | 70 |
| Standing side throw | 2 | 6 | 80 | 2 | 8 | 70 |
| Squat and throw | 2 | 6 | 80 | 2 | 8 | 70 |

Testing procedures

Estimations of One Repetition Maximum (1RM) for upper body, lower body, and torso rotation strength were made by performing 3RM tests (the most amount of weight lifted 3 times) on the bench press, squat, and torso rotational test. Multiple RM prediction models are considered valid ($r = 0.84 - 0.92$), safe, and reliable methods to predict 1RM (Ruivo, Carita, & Pesarat-Correia, 2016). The procedure of conducting multiple RM test for bench press and squat were as per suggested by Baechle et al. (2004). For torso rotational strength test, procedures were conducted as suggested by Szymanski, Szymanski, et al. (2007). The estimated 1RM was subsequently predicted by using Bryzcki’s equation (Ruivo et al., 2016). The predicted 1RM measured at baseline (week-0) and after week - 4 (to ensure that appropriate % were used during training), and after week-8 of training.

Batting velocity was measured the day after the 3RM test. Before the bat swing was measured, a 5-minute full-body and dynamic warm-up exercise was performed. This consisted of five dry-swings, with the same bat they used for testing. An aluminium softball bat, measuring 84 cm long and weighing 0.68 kg, was used. The bat swing velocity was measured by a portable swing analyser device (ZEPP., USA) with has reliability of $r = 0.822-0.988$ (Bailey, McInnis, & Batcher, 2016). Each participant performed 5 swings with a rest period of 30-s between swings. Each participant was instructed to swing as fast as possible, while keeping the same stance and same mechanics. Encouragement to focus on the external environment, rather than movements of the body, was given in an attempt to elicit optimal performance (Gray, 2009). The velocity of each of the five swings was manually recorded for analysis.

Statistical analysis

The Kolmogorov-Smirnov test of normality was conducted before the analysis and all parameters were found to be normally distributed. Baseline and after week-8 differences of predicted 1RM and batting velocity between groups were investigated using the independent t-test. Assumption of homogenous variances was tested using Levene’s test. To determine the effect of the training interventions, a paired sample t-test was conducted and partial eta-

square (η^2) values are reported as estimated effect size. For all inferential statistical analyses, significance was defined as p-value less than 0.05. All descriptive and inferential statistical analyses were conducted using SPSS 20 (IBM®, Armonk, NY, USA).

Results

Group comparison

After eight weeks of training, the DS-EMS showed significantly ($p \leq .01$) higher predicted 1RM bench press, squat, and torso rotational strength as well as batting velocity compared to DS group (Table 3). The DS group showed no significant improvement in predicted 1RM bench press and squat ($p > .05$).

Table 3: Mean (SD) DS and DS-EMS for pre-test, post-test and percent (%) change

| Variable | Pre-test | Post-test | % change | p value | η^2 |
|-------------------------|--------------|--------------|----------|---------|----------|
| Bench Press | | | | | |
| DS | 25.10 (3.02) | 25.33 (2.88) | 0.92 | .163 | 0.4 |
| DS-EMS | 24.08 (3.50) | 26.46 (3.07) | 9.88†‡ | .000 | |
| Squat | | | | | |
| DS | 42.71 (2.15) | 42.83 (1.93) | 0.28 | .582 | 1.5 |
| DS-EMS | 42.04 (2.53) | 46.01 (2.36) | 9.44†‡ | .000 | |
| Torso Rotational | | | | | |
| DS | 28.29 (5.16) | 30.95 (5.03) | 9.40† | .001 | 0.5 |
| DS-EMS | 27.70 (5.57) | 33.31 (4.06) | 20.25†‡ | .000 | |
| Batting Velocity | | | | | |
| DS | 54.20 (3.65) | 55.00 (3.48) | 1.48† | .002 | 0.4 |
| DS-EMS | 54.30 (3.64) | 56.25 (3.21) | 3.59†‡ | .000 | |

* DS = Dry Swing, DS-EMS = Dry Swing and EMS

† Significant difference within groups at $p \leq 0.05$.

‡ Significant difference between groups at $p \leq 0.05$

Discussion

The main findings of this study were that three WB-EMS sessions in addition to 100 normal swing training sessions per week over eight weeks (for a total of 24 sessions) was sufficient to enhance strength and batting velocity in collegiate level female softball players.

For predicted maximal strength, the DS-EMS group showed significant increases in mean predicted 1RM bench press, squat, and torso rotational after eight weeks of training. To date, gains in predicted upper body strength have not been discovered by any study using WB-EMS. However, there was one study that was able to show gains in predicted 1RM for lower body strength after 14 sessions of WB-EMS training (Filipovic et al., 2016). Filipovic’s study found a significant increase in 1RM leg strength of 13.06% after seven weeks of dynamic WB-EMS. While, in other parameters such as speed strength and power, a study by Kreuzer, Kleinoeder, and Mester (2006) only showed low gains in maximal strength after four weeks (eight sessions) of isometric and dynamic WB-EMS. One of the possible reasons why this current study able to show gains in predicted maximal strength could be the

relatively longer study duration of eight weeks (24 sessions) compared to four weeks (eight sessions) in Kreuzer et al. (2006). It is highly likely that strength parameters might need more than eight sessions to be developed.

Previous studies showed that the improvement of neural adaptation was the likely reason why muscular strength increased with electrical stimulation (Gondin, Guette, Ballay, & Martin, 2006; Maffiuletti et al., 2000). Strength improvement was usually associated with changes occurring in the central nervous system (increased in neural drive) and/or at the muscle level (hypertrophy). Although no EMG or muscle cross-sectional area were measured in this study to investigate muscle level strength improvement, it was assumed that whole-body electromyostimulation training had produced neural adaptation compared to muscular adaptation. This is due to the fact that during the first few weeks (three to five) of resistance training and electrical stimulation training, there is limited adaptation at the muscle level (Aldayel, 2010; Bhambhani, 2004). Furthermore, electrical stimulation mechanism resulted in excitation of intramuscular branches of the nerve and not directly the muscle fiber (Aldayel, 2010). It has been said that muscle contraction that is stimulated by electrical stimulation occur when the depolarization of motor axons directly evoked through a peripheral mechanism to the electrodes that placed on the skin. As fast twitch muscle fibers are located near the skin where the electrodes are placed, this probably leads to greater fast twitch muscle fibers recruitment compared to slow twitch muscle fibers (Aldayel, 2010).

DS-EMS training group also showed greater improvement in batting velocity compared to DS group. This was most likely because the training regime was specifically designed to stimulate the group of muscles that are involved during softball swing. Reilly, Morris, and Whyte (2009) suggested that sport performance can be optimized by training specific muscle groups, joint angle, range of motion and type of contraction such as concentric, eccentric or isometric. In addition, the training program given to DS-EMS group involved with progressive overload. Progressive overload is one of the most important factors in increasing sports performance. It has also been shown that altering the training load does affects acute metabolic (Ratamess et al., 2009; Ratamess et al., 2007) and neural (Ratamess et al., 2009), hormonal (Kraemer & Ratamess, 2005; Kraemer et al., 2006), and cardiovascular (Ratamess et al., 2009) responses towards exercise. The training load (intensity) was started at low intensity and was increased weekly up to 90% of 1RMM at the end of the training period.

Increasing the load imposed on skeletal muscle elicits adaptations that result in increased muscle size and changes in contractile characteristics (Bird, Tarpenning, & Marino, 2005). It can be concluded that the principle of overload leads to muscular strength adaptation and this adaptation leads to the increment of dynamic strength. This statement supports the significant improvement in dynamic strength shown in previous studies which applied the principle of progressive overload in their training program (Szymanski et al., 2009; Szymanski, McIntyre, et al., 2007; Szymanski, Szymanski, et al., 2007).

Various studies have examined the relationship between strength and batting velocity and most researchers suggest that softball or baseball players who have greater upper body strength (Szymanski et al., 2009), lower body strength (Basile, Otto, & Wygand, 2007) and torso rotational strength (Szymanski, McIntyre, et al., 2007) demonstrated greater batting velocity. This is because players use their three body segments (hips, torso and upper body) as a kinetic link when performing the swing (Szymanski et al., 2009). Past studies indicate

that a softball swing in an optimal kinetic energy system is transferred from the large basement (legs and hips) to the torso and upper extremities, and finally to the bat (DeRenne, 2007; Szymanski, McIntyre, et al., 2007). While Szymanski, McIntyre, et al. (2007) added that when the players increased the strength of muscles that are involved in swing movement and execute the movement properly, they are able to produce optimal rotational velocities, resulting in increased batting velocity.

Chu, Keenan, Allison, Lephart & Sell (2015) mentioned that lower-body strength was positively correlated to batting velocity. The rectus femoris muscle of the lead leg was found to be highly activated approaching the instant of ball contact (Nakata, Miura, Yoshie, Kanosue, & Kudo, 2013). Lead knee extension generates a ground reaction force which is transferred up along the leg. Such force stops anterior translation of the pelvis started during strides and braces the pelvis, facilitating pelvic rotation. Such movement is the primary source of angular momentum rotating the body (Yanai, 2007). Stronger lead knee extensors allow more aggressive weight transfer during stride and therefore greater angular momentum generated for bat velocity. In contrast, weak lead knee extensors are not able to stop pelvic anterior translation which allows the body to keep moving forward throughout the swing, resulting in less kinetic energy being transferred toward the end of the kinetic chain - the bat. Findings in this study demonstrate that WB-EMS is able to improve the strength of the three body segments that work as a kinetic energy system in softball swing.

This study has also provided support for the use of whole-body electromyostimulation as an alternative or supplementary training method in improving batting velocity. As a practical recommendation for softball players, it is suggested that additional whole-body electromyostimulation (WB-EMS) be used by coaches in enhancing their players' batting velocities across eight weeks of training.

Conclusion

Three dynamic WB-EMS sessions in combination with normal 300 swings per week is more effective than swing training alone in enhancing the maximal strength and batting velocity of female collegiate softball players. This study found that stimulation using WB-EMS training is able to enhance a softball player's performance and complement a training regime.

Acknowledgement

We gratefully acknowledge the support of United Lifestyle for the use of Miha Bodytec and Universiti Teknologi MARA's Research Management Institute (RMI) for the grant 600-RMI/MyRA 5/3/LESTARI (32/2016). None of the authors have any conflict of interest in relation to this study.

References

- Aldayel, A. A. (2010). *Comparison of acute physiological effects between alternating current and pulsed current electrical muscle stimulation*. Edith Cowan University. Retrieved from <https://ro.ecu.edu.au/theses/131/>
- Babault, N., Cometti, G., Bernardin, M., Pousson, M., & Chatard, J.-C. (2007). Effects of electromyostimulation training on muscle strength and power of elite rugby players. *Journal of Strength and Conditioning Research*, 21(2), 431.
- Earle, R. W., & Baechle, T. R. (2004). *NSCA's Essentials of Personal Training*. United States of America: Human Kinetics.
- Bailey, C. A., McInnis, T. C., & Batcher, J. J. (2016). Bat swing mechanical analysis with an inertial measurement unit: reliability and implications for athlete monitoring. *Journal of Trainology*, 5(2), 43-45.
- Basile, R., Otto, R. M., & Wygand, J. W. (2007). The Relationship Between Physical and Physiological Performance Measures and Baseball Performance Measures: 1448: Board# 211 May 30 9: 30 AM-11: 00 AM. *Medicine & Science in Sports & Exercise*, 39(5), S214.
- Bhambhani, Y. N. (2004). Muscle oxygenation trends during dynamic exercise measured by near infrared spectroscopy. *Canadian Journal of Applied Physiology*, 29(4), 504-523.
- Billot, M., Martin, A., Paizis, C., Cometti, C., & Babault, N. (2010). Effects of an electrostimulation training program on strength, jumping, and kicking capacities in soccer players. *The Journal of Strength & Conditioning Research*, 24(5), 1407-1413.
- Bird, S. P., Tarpennig, K. M., & Marino, F. E. (2005). Designing resistance training programmes to enhance muscular fitness. *Sports Medicine*, 35(10), 841-851.
- Chu, Y., Keenan, K., Allison, K., Lephart, S., & Sell, T. (2015). The positive correlation between trunk, leg, and shoulder strength and linear bat velocity at different ball locations during the baseball swing in adult baseball hitters. *Isokinetics and exercise science*, 23(4), 237-244.
- DeRenne, C. (2007). *The Scientific Approach to Hitting*. San Diego: University Readers Custom Publishing.
- Filipovic, A., Grau, M., Kleinöder, H., Zimmer, P., Hollmann, W., & Bloch, W. (2016). Effects of a whole-body electrostimulation program on strength, sprinting, jumping, and kicking capacity in elite soccer players. *Journal of sports science & medicine*, 15(4), 639.
- Filipovic, A., Kleinöder, H., Dörmann, U., & Mester, J. (2011). Electromyostimulation—a systematic review of the influence of training regimens and stimulation parameters on effectiveness in electromyostimulation training of selected strength parameters. *The Journal of Strength & Conditioning Research*, 25(11), 3218-3238.

- Filipovic, A., Kleinöder, H., Dörmann, U., & Mester, J. (2012). Electromyostimulation—a systematic review of the effects of different electromyostimulation methods on selected strength parameters in trained and elite athletes. *The Journal of Strength & Conditioning Research*, 26(9), 2600-2614.
- Fisher, J., Steele, J., Bruce-Low, S., & Smith, D. (2011). Evidence-based resistance training recommendations. *Med Sport*, 15(3), 147-162.
- Flyger, N., Button, C., & Rishiraj, N. (2006). The science of softball. *Sports Medicine*, 36(9), 797-816.
- Giroid, S., Jalab, C., Bernard, O., Carette, P., Kemoun, G., & Dugué, B. (2012). Dry-land strength training vs. electrical stimulation in sprint swimming performance. *The Journal of Strength & Conditioning Research*, 26(2), 497-505.
- Gondin, J., Guette, M., Ballay, Y., & Martin, A. (2006). Neural and muscular changes to detraining after electrostimulation training. *European journal of applied physiology*, 97(2), 165-173.
- Gray, R. (2009). A model of motor inhibition for a complex skill: baseball batting. *Journal of Experimental Psychology: Applied*, 15(2), 91.
- Hussain, R., Kee, K., Razman, R., Ismail, S., Shari, M., & Ideris, N. (2016). *Relationship Between Electromyostimulation and Free Weight Exercises in Multiple Repetition Maximum Strength Test*. Paper presented at the International Conference on Movement, Health and Exercise.
- Kemmler, W., Schliffka, R., Mayhew, J. L., & von Stengel, S. (2010). Effects of whole-body electromyostimulation on resting metabolic rate, body composition, and maximum strength in postmenopausal women: The training and electrostimulation trial. *The Journal of Strength & Conditioning Research*, 24(7), 1880-1887.
- Kemmler, W., & von Stengel, S. (2013). Whole-body electromyostimulation as a means to impact muscle mass and abdominal body fat in lean, sedentary, older female adults: subanalysis of the TEST-III trial. *Clinical interventions in aging*, 8, 1353.
- Kemmler, W., Von Stengel, S., Schwarz, J., & Mayhew, J. L. (2012). Effect of whole-body electromyostimulation on energy expenditure during exercise. *The Journal of Strength & Conditioning Research*, 26(1), 240-245.
- Kraemer, W. J., & Ratamess, N. A. (2005). Hormonal responses and adaptations to resistance exercise and training. *Sports Medicine*, 35(4), 339-361.
- Kraemer, W. J., Spiering, B. A., Volek, J. S., Ratamess, N. A., Sharman, M. J., Rubin, M. R., . . . Van Heest, J. L. (2006). Androgenic responses to resistance exercise: effects of feeding and L-carnitine. *Medicine & Science in Sports & Exercise*, 38(7), 1288-1296.

- Kreuzer, S., Kleinoeder, H., & Mester, J. (2006). Effects of whole body electro stimulation training and traditional strength training on various strength and blood parameter in juvenile elite water polo players. *H. Hoppeler et al.(Eds.), 11, 264.*
- Maffiuletti, N. A., Cometti, G., Amiridis, I., Martin, A., Pousson, M., & Chatard, J. (2000). The Effects of Electromyo-stimulation Training and Basketball Practice on Muscle Strength and Jumping Ability. *International journal of sports medicine, 21(6), 437-443.*
- Nakata, H., Miura, A., Yoshie, M., Kanosue, K., & Kudo, K. (2013). Electromyographic analysis of lower limbs during baseball batting. *The Journal of Strength & Conditioning Research, 27(5), 1179-1187.*
- Nybo, L., Sundstrup, E., Jakobsen, M. D., Mohr, M., Hornstrup, T., Simonsen, L., Low, J. B., Randers, M. B., Nielsen, J. J., Aagaard, P., Krstrup, P. (2010). High-intensity training versus traditional exercise interventions for promoting health. *Medicine & Science in Sports & Exercise, 42(10), 1951-1958.*
- Ratamess, N., Alvar, B., Evetoch, T., Housh, T., Kibler, W., & Kraemer, W. (2009). Progression models in resistance training for healthy adults [ACSM position stand]. *Med Sci Sports Exerc, 41(3), 687-708.*
- Ratamess, N., Falvo, M., Mangine, G., Hoffman, J., Faigenbaum, A., & Kang, J. (2007). The effect of rest interval length on metabolic responses to the bench press exercise. *European journal of applied physiology, 100(1), 1-17.*
- Reilly, T., Morris, T., & Whyte, G. (2009). The specificity of training prescription and physiological assessment: A review. *Journal of sports sciences, 27(6), 575-589.*
- Ruivo, R., Carita, A., & Pezarat-Correia, P. (2016). Effects of a 16-week strength-training program on soccer players. *Science & Sports, 31(5), e107-e113.*
- Sugimoto, D., Mattacola, C. G., Bush, H. M., Thomas, S. M., Foss, K. D. B., Myer, G. D., & Hewett, T. E. (2017). Preventive neuromuscular training for young female athletes: comparison of coach and athlete compliance rates. *Journal of athletic training, 52(1), 58-64.*
- Szymanski, D. J., Albert, J., Hemperley, D., Hsu, H., Moore, R., Potts, J., Reed, J. E., Walker, J. P. & Winstead, R. C. (2008). Effect of overweighted forearm training on bat swing and batted-ball velocities of high school baseball players. *J Strength Cond Res, 22, 109-110.*
- Szymanski, D. J., DeRenne, C., & Spaniol, F. (2009). Contributing factors for increased bat swing velocity. *The Journal of Strength & Conditioning Research, 23(4), 1338-1352.*
- Szymanski, D. J., McIntyre, J., Szymanski, J., Bradford, T., Schade, R., Madsen, N., & Pascoe, D. (2007). Effect of torso rotational strength on angular hip, angular shoulder, and linear bat velocities of high school baseball players. *The Journal of Strength & Conditioning Research, 21(4), 1117-1125.*

- Szymanski, D. J., Szymanski, J., Bradford, T., Schade, R., & Pascoe, D. (2007). Effect of twelve weeks of medicine ball training on high school baseball players. *The Journal of Strength & Conditioning Research*, 21(3), 894-901.
- Szymanski, D. J., Szymanski, J. M., Schade, R., & Bradford, T. (2008). Relationship between physiological variables and linear bat swing velocity of high school baseball players. *Medicine & Science in Sports & Exercise*, 40(5), S422.
- Wilson, J. M., Miller, A. L., Szymanski, D. J., Duncan, N. M., Andersen, J. C., Alcantara, Z. G., . . . Bergman, C. J. (2012). Effects of various warm-up devices and rest period lengths on batting velocity and acceleration of intercollegiate baseball players. *The Journal of Strength & Conditioning Research*, 26(9), 2317-2323.
- Yanai, T. (2007). *A mechanical cause of body rotation about the vertical axis in baseball batting*. Paper presented at the Proceedings of the ASB Annual Meeting. Stanford University: California.