Comparison of Modular Control during Sidestepping with versus without Groin Pain

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The activity of muscles in the trunk and lower limbs during sidestepping was recorded in nine healthy young men (control group) and three young men with groin pain syndrome. Muscle synergies among subjects were compared. Non-negative matrix factorization was used to extract muscle synergies from electromyographic data. Thereafter, to compare muscle synergies, a scalar product evaluating synergy coincidence was calculated. Three muscle synergies were extracted in both groups from non-negative matrix factorization analysis. In both groups, two out of three synergies were found to be the same by scalar product analysis. In one of these synergies, the oblique muscle, rectus femoris, and adductor muscle were activated before landing in mid-stance during the sidestep motion in the control group. Therefore, this synergy is thought to suppress excessive hip abduction. However, the peak timing of this synergy in the groin pain group was at mid-stance. This delay may cause hip instability because muscles must be activated before landing to enhance joint stability. Risk factors for groin pain are dysfunctional coordination between trunk and lower-limb muscles and decreased hip stability. Even though the number of subjects in this study was small, it is possible that delayed activation of this synergy may be related to the mechanism of injury in groin pain.

Keywords: Muscle synergy, module, non-negative matrix factorization, sports injuries

1. Introduction

Groin pain (GP) syndrome occurs frequently in football players, who perform repetitive sidestepping motions, similar to soccer and rugby players (O'Connor, 2004; Verrall et al., 2007; Werner et al., 2009; Avrahami and Choudurl, 2010). One risk factor for GP is a lack of trunk and lower-limb muscle coordination (Niga and Ikeda, 2011). Recently, evaluation of muscle coordination was refined by non-negative matrix factorization (NMF) analyses based on Bernstein's concept (1967). NMF analysis divides electromyographic (EMG) data into two factors: "muscle synergy" and "activation coefficient". Muscle synergy indicates muscle coordination, whereas the activation coefficient indicates the activation timing of muscle synergy. We applied the NMF method to sports activities (Matsunaga et al., 2017a; 2017b; Matsunaga and Kaneoka, 2018). Thus, this study aimed to clarify trunk and lower-

limb muscle coordination in individuals with GP.

2. Methods

2.1. Subjects

Three young men with GP in the GP group (21 ± 2 years, 174.7 ± 6.0 cm, 70.0 ± 6.0 kg) and 9 young healthy men in the control group (21 ± 2 years, 174.4 ± 6.2 cm, 67.3 ± 5.7 kg) participated in this study. Each performed physical activities two or three times per week at the recreational level. Exclusion criteria included a history of lower-limb disorder including neurological disorders and lower-limb surgery. This study was approved by Waseda University's ethics committee (2010-270). Before participation, all subjects read and signed an informed consent agreement.

2.2. Data measurement

The test exercise included 5 repeated sidestep motions with a width of 1.1 times the subject's height. We measured trunk and lower-limb muscle activity using a wireless EMG system (EMG-025; Harada Electronic Co., Sapporo, Japan) at 1000 Hz during the test exercise. Before surface electrodes were attached, the skin was rubbed with an abrasive and alcohol to reduce skin impedance to a level $<2\text{ k}\Omega$. Pairs of disposable Ag/AgCl surface electrodes (Vitrode F-150S; Nihon Kohden Co., Japan) were attached to the right side of the rectus abdominis (RA), external oblique (EO), internal oblique/transversus abdominis (IO/TrA), erector spinae (ES), rectus femoris (RF), semitendinosus (ST), gluteus medius (Gmed), and adductor (ADD) muscles. Each electrode measured $18 \times 36\text{ mm}^2$, and the electrodes were spaced 2 cm apart. A maximum voluntary contraction test was performed on the individual muscles before the test exercise to normalize EMG data. Manual resistance was gradually increased up to the subject's limit and then held for 3 s.

To clarify the timing of foot contact and push-off, a three-dimensional motion capture system (Oqus; Qualisys, Göteborg, Sweden) was used. A reflective marker was attached to the toe and heel on the right shoe. The measuring frequency of the motion capture cameras was 200 Hz. Furthermore, the motion capture cameras were synchronized with the EMG system.

2.3. Data analysis

We analyzed the third round of sidestep motions during the test exercise. Foot contact timing was decided on the basis of the acceleration of the edge of the toe marker. Thereafter, we recorded EMG data from 200 ms before landing to 200 ms after push-off on the basis of the marker acceleration data. Raw data were band-pass filtered between 20–450 Hz and full-wave rectified. EMG data were normalized relative to maximum voluntary contraction data. Muscle synergy was calculated according to the methods used by Lee and Seung (2001) and Tresch et al. (2006). Moreover, to evaluate analysis precision, variance accounted for (VAF) was calculated according to the method used by Hug et al. (2010). Global VAF indicates analysis precision in all mus-

cles, and Local VAF indicates that in each muscle. A scalar product (SP) was calculated based on Cheung et al. (2012) to compare synergies between groups.

2.4. Statistical analysis

To evaluate the time lag between groups, Mann-Whitney's U-test was performed in SPSS 24.0 (IBM, Armonk, NY, USA) according to the methods used by Vaz et al. (2016). The significance level was set at less than 0.05.

3. Results and discussion

Table 1 shows the correlation between number of synergies and VAF. When there were 3 synergies, global VAF exceeded 90% and local VAF exceeded 75% in both groups. Therefore, there are 3 synergies. Figure 1 shows the extracted synergies and activation coefficients. For the control group, the mean $\pm$ SD of all subjects combined is plotted. For the GP group, the data for each individual subject is plotted. The SP of synergies 1 and 2 were 0.97 and 0.84, respectively. These results indicate that these synergies were the same in both groups.

Our main finding was a difference in the peak activation timing of synergy 1 between groups. Synergy 1 primarily engaged the IO/TrA, RF, and ADD muscles, and its activation timing differed between the groups ($p=0.039$). In the control group,

Table 1 Mean global and local VAF values of two and three extracted synergies.

		number of synergy=2		number of synergy=3	
		Control	Groin pain	Control	Groin pain
Global VAF (%)		91.8 $\pm$ 5.0	95.8 $\pm$ 4.6	96.4 $\pm$ 2.7	96.8 $\pm$ 4.2
Local VAF (%)	RA	35.2 $\pm$ 17.9	34.6 $\pm$ 12.6	81.1 $\pm$ 10.7	77.6 $\pm$ 13.4
	EO	64.6 $\pm$ 22.6	43.2 $\pm$ 13.4	86.5 $\pm$ 12.1	89.4 $\pm$ 4.7
	IO/TrA	54.6 $\pm$ 35.0	47.7 $\pm$ 40.6	95.6 $\pm$ 7.1	98.2 $\pm$ 1.5
	ES	69.0 $\pm$ 24.2	37.1 $\pm$ 30.5	88.3 $\pm$ 16.3	83.3 $\pm$ 5.6
	RF	50.7 $\pm$ 23.6	39.6 $\pm$ 15.1	89.8 $\pm$ 8.5	83.3 $\pm$ 13.2
	ST	48.9 $\pm$ 24.5	57.4 $\pm$ 38.4	86.7 $\pm$ 10.6	87.5 $\pm$ 14.1
	Gmed	44.4 $\pm$ 30.6	57.7 $\pm$ 40.9	88.7 $\pm$ 11.0	91.7 $\pm$ 11.7
	ADD	45.5 $\pm$ 24.5	51.0 $\pm$ 45.8	82.0 $\pm$ 13.4	82.7 $\pm$ 15.4

VAF, variance accounted for; RA, rectus abdominis; EO, external oblique; IO/TrA, internal oblique/transversus abdominis; ES, erector spinae; RF, rectus femoris; ST, semitendinosus; Gmed, gluteus medius; ADD, adductor muscle

synergy 1 activity was seen during the first half of the sidestep sequence, which corresponded to a sequence from before landing to the middle stage of the stance. Muscles must be activated before landing in order to enhance joint stability (Brazier et al., 2004); therefore, this synergy plays a role in suppressing excessive hip abduction. On the other hand, in the GP group, this synergy was seen in the second half. Although only 3 subjects with GP participated in this study, this timing delay may cause hip instability and may be related to the development of GP.

Synergy 2 primarily engaged the oblique muscles and ST. Trunk muscles make the body rigid and translate ground reaction force into a propulsive force during running (Saunders et al. 2004). The activation of synergy 2 began before landing to mid-stance and increased again during push-off. There-

fore, synergy 2 is thought to function in producing a propulsive force by coordinating trunk and hip extension muscles. There was no difference in the activation timing of synergy 2 between groups ($p = 0.760$).

The SP of synergy 3 in the GP group was low, which prohibited us from comparing synergy 3 between groups. Synergy 3 in the control group primarily engaged IO/TrA, RF, and Gmed, and peak synergy 3 activation was at 25-35% of the sidestep sequence and corresponded to foot landing. Therefore, synergy 3 is thought to function in response to weight loads. On the other hand, synergy 3 in the GP group differed among subjects. This may be a defense reaction to avoid pain.

This study has a few limitations. First, only 3 subjects with GP were included in this study. Additionally, we did not investigate each subject's GP

Figure 1. Synergies extracted during sidestepping.

RA, rectus abdominis; EO, external oblique; IO/TrA, internal oblique/transversus abdominis; ES, erector spinae; RF, rectus femoris; ST, semitendinosus; Gmed, gluteus medius; ADD, adductor muscle; SP, scalar product

type, because this study was performed before the Doha agreement meeting (Weir et al., 2015). A future study must, therefore, clarify synergy characteristics for each GP type. Second, this was a cross-sectional study and a longitudinal study is necessary to describe the pathomechanism of GP. The main findings of this study, however, may prove useful in elucidating these mechanisms. Third, the measuring frequency of the motion capture and EMG systems were different; therefore, it is feasible that there was slight error in timing in the analyzed range of each sequence. The length of our analyzed data was 0.40 ± 0.03 seconds. The peak activity of synergy 1 was at 0% of sidestepping in the control group (**Figure 1**) and 41% in the earliest subject of the GP group (**Figure 1**; subject c). This result indicates a peak activation delay of about 0.16 seconds. Because this delay was larger than the error in time measurement, error in time measurement is unlikely to influence this interpretation.

4. Conclusion

We investigated trunk and lower-limb muscle coordination during a sidestep sequence and compared it in individuals with and without GP. We found 3 synergies in both groups. One synergy was activated before landing to control hip stability in the coronal plane in subjects without GP; however, the activation timing of this synergy was delayed in the GP group. This time delay might cause pelvic instability and be related to the mechanism of injury in GP.

References

- Avrahami, D. and Choudur, H. N. (2010). Adductor tendinopathy in a hockey player with persistent groin pain: a case report. *J. Can. Chiropr. Assoc.*, 54(4), 264.
- Bernstein, N. A. (1967). The co-ordination and regulation of movements.
- Brazier, J., Bishop, C., Simons, C., Antrobus, M., Read, P. J., and Turner, A. N. (2014). Lower extremity stiffness: Effects on performance and injury and implications for training. *Strength Cond. J.*, 36(5), 103-112.
- Cheung, V. C., Turolla, A., Agostini, M., Silvoni, S., Bennis, C., Kasi, P., Paganoni, S., Bonato, P., and Bizzi, E. (2012). Muscle synergy patterns as physiological markers of motor cortical damage. *Proc. Natl. Acad. Sci. USA* 109(36): 14652-14656.
- Hug, F., Turpin, N. A., Guével, A., and Dorel, S. (2010). Is interindividual variability of EMG patterns in trained cyclists related to different muscle synergies?. *J. Appl. Physiol.*, 108(6), 1727-1736.
- Lee, D. D. and Seung, H. S. (2001). Algorithms for non-negative matrix factorization. *Adv. Neural Inf. Process Syst.* 13: 556-562.
- Matsunaga, N., Imai, A., and Kaneoka, K. (2017a). Comparison of muscle synergies before and after 10 minutes of running. *J. Phys. Ther. Sci.*, 29(7), 1242-1246.
- Matsunaga, N., Imai, A., and Kaneoka, K. (2017b). Comparison of Modular Control of Trunk Muscle by Japanese Archery Competitive Level: A Pilot Study. *Int. J. Sport Health Sci.*, 15, 160-167.
- Matsunaga, N. and Kaneoka, K. (2018). Comparison of Modular Control during Smash Shot between Advanced and Beginner Badminton Players. *Appl. Bionics Biomech.*, 2018.
- Niga, S. and Ikeda, H. (2011). Supotsu sensyu no sokeibutsu [Groin pain in athletes]. Nakamura K eds. *Sports injury in lower limbs*. Tokyo: Nakayama Publishing Company: 164-177. (in Japanese)
- O'Connor, D. M. (2004). Groin injuries in professional rugby league players: a prospective study. *J. Sports Sci.*, 22(7), 629-636.
- Saunders, S. W., Rath, D., and Hodges, P. W. (2004). Postural and respiratory activation of the trunk muscles changes with mode and speed of locomotion. *Gait posture*, 20(3), 280-290.
- Tresch, M. C., Cheung, V. C., and d'Avella, A. (2006). Matrix factorization algorithms for the identification of muscle synergies: evaluation on simulated and experimental data sets. *J. Neurophysiol.*, 95(4), 2199-2212.
- Vaz, J. R., Olstad, B. H., Cabri, J., Kjendlie, P. L., Pezarat-Correia, P., and Hug, F. (2016). Muscle coordination during breaststroke swimming: Comparison between elite swimmers and beginners. *J. Sports Sci.*, 34(20): 1941-1948.
- Verrall, G. M., Slavotinek, J. P., Fon, G. T., and Barnes, P. G. (2007). Outcome of conservative management of athletic chronic groin injury diagnosed as pubic bone stress injury. *Am. J. Sports Med.*, 35(3), 467-474.
- Weir, A., Brukner, P., Delahunt, E., Ekstrand, J., Griffin, D., Khan, K. M., Lovell, G., Meyers, W. C., Muschaweck, U., Orchard, J., Paaanen, H., Philippon, M., Reboul, G., Robinson, P., Schache, A. G., Schilders, E., Serner, A., Silvers, H., Thorborg, K., Tyler, T., Verrall, G., de Vos, R. J., Vuckovic, Z., and Holmich, P. (2015). Doha agreement meeting on terminology and definitions in groin pain in athletes. *Br. J. Sports Med.*, 49(12), 768-774.
- Werner, J., Häggglund, M., Waldén, M., and Ekstrand, J. (2009). UEFA injury study: a prospective study of hip and groin injuries in professional football over seven consecutive seasons. *Br. J. Sports Med.*, 43(13), 1036-1040.

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- Matsunaga, N., Imai, A., and Kaneoka, K. (2017). Comparison of Modular Control of Trunk Muscle by Japanese Archery Competitive Level: A Pilot Study. *Int. J. Sport Health Sci.*, 15, 160-167.
- Matsunaga, N. and Kaneoka, K. (2018). Comparison of Modular Control during Smash Shot between Advanced and Beginner Badminton Players. *Appl. Bionics Biomech.*, 2018.

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