THE EFFECT OF TRUNK ROTATION ON LOWER LIMB KINEMATICS DURING RUNNING – PRELIMINARY STUDY

Kayla Hordyk and ChengTu Hsieh

Department of Kinesiology, California State University, Chico, USA

The purpose of this study was to examine the running kinematics such as stride length, stride rate, speed, and joint range of motion when trunk rotation was manipulated. Six female recreational runners were recruited to perform a total of nine trials of over ground running in their comfortable speed (≈ 3.31 m/s) for natural gait, restricted trunk rotation, and exaggerated trunk rotation conditions. Exaggerating trunk rotation during running resulted in greater stride length and smaller stride rate significantly when compared to natural and restricted trunk rotation conditions. Although some of the significant change of the running kinematics were observed, the manipulation of the trunk rotation did not alter the overall running kinematics such as speed and range of motion at hip, knee, and ankle joints during braking and propulsive phases.

KEYWORDS: gait, lower extremity, range of motion, stride length, stride rate

INTRODUCTION: Running is a form of exercise that is associated with many different health benefits. It attracts healthy individuals to run either recreationally or competitively worldwide. To enhance performance, a vast body of studies have examined footwear, technique, injury prevention, etc. (e.g., Ceyssens, Vanelderen, Barton, Malliaras, & Dingenen, 2019; Cheung & Ngai, 2016; Moore, 2016). Of course, runners have also been using their own experience through trial and error in an effort to improve their running performance. Although extensive investigation has been done on running biomechanics, most studies have focused on the biomechanics of the lower extremity during running. The function and the influence of the upper extremity during running has received very little attention. A few studies have identified that the main function of the upper extremity (including head, arms, and trunk) is to counterbalance the angular motion about the three anatomical axes of the lower extremities during running (Arellano & Kram, 2011 & 2014; Hinrichs, 1987; Hinrichs, Cavanagh, & Williams, 1987).

Hinrichs (1987) described that the swinging of the arms coordinates with the trunk to balance the angular momentum of leg movements during running. In addition, the angular impulse of the arms and trunk about the vertical axis plays an important role in assisting the alternation of both legs during the airborne phase of running. From the perspective of running economy, Arellano and Kram (2011 & 2014) controlled arm swing during running and found that natural arm swing benefitted the metabolic demands of running. Additionally, Fisher, Louw, Cockcroft, and Tawa (2018) compared fast-paced to self-selected running pace and found that the trunk range of motion about the three axes increased significantly in fast-paced running. Other than these main findings, the studies related to trunk rotation were focused on lower back pain/injury in walking (e.g., Seay, Van Emmerik, & Hamill, 2011).

Studies have shown inconclusive results regarding the effects of applying research findings to enhance running performance (e.g., Moore, 2016). This could be due to the selection of biomechanical factors such as stride length, rate, time, etc. that could be influenced by other factors from the proximal end of the body segment (i.e., trunk). The trunk comprises the largest percentage of body mass and strongly influences body movement. However, there is little understanding of its impact on running kinematics due to acute manipulation of the trunk rotation. It was found that the walking stride rate increased with restricted trunk rotation in the transverse plane (Konz, 2006). Additionally, Fontecchio and Savilonis (2012) found a positive association between stride length and trunk rotation during running. Therefore, there might be more parameters that are influenced by controlling trunk rotation in the transverse plane. Thus, the purpose of this current study was to examine the effect of the trunk rotation on running kinematics in the following conditions, 1) preferred natural running gait, 2) exaggerated trunk rotation, and 3) restricted trunk rotation.

METHODS: Six healthy and active female recreational runners with no adverse running injuries were recruited (Age: 20.3 ± 0.82 years old; Body Height: 1.6 ± 0.04 m; Body Mass: 59.72 ± 7.12 kg). All the subjects met a physical standard of activity for 30 minutes 3 times/week. All policies and procedures for the use of human subjects were followed and approved by the university's Institutional Review Board.

Each subject was required to complete a warmup run lasting 5 minutes prior to data collection. The participants performed 3 sets of 3 randomized trial conditions: 3 trials at a preferred running pace with natural trunk rotation, 3 trials with exaggerated trunk rotation, and 3 trials with restricted trunk rotation. All runners ran at a self-selected speed in all three conditions and were provided with instruction and reminders. Four cones were used to speed up (1st to 2nd cone), maintain speed (2nd to 3rd cone), and slow down (3rd to 4th cone). The distance from 1st to 2nd cone and 3rd to 4th cone were all 3 meters. Between the 2nd and 3rd cone was 6 meters. Instructions for both restricted and exaggerated trunk rotation was given before each condition started. Ample time was provided for subjects to familiarize the running for each condition. The runners were required to rotate their upper trunk greater than their natural trunk rotation in an exaggerated condition and limit their trunk rotation in the restricted trunk rotation condition. The instruction for the arm swing was to follow the rhythm of the trunk rotation naturally in each condition. All subjects were given multiple practice trials until they felt comfortable to perform the running condition before data collection.

Kinematic data were obtained over one stride from the right side of the body. The means from each condition were obtained for the comparisons. Three-dimensional coordinates were obtained and analysed with a motion analysis system (Vicon Motus: 10.0). A marker set was used to obtain the location of the shoulder, hip, knee, ankle, heel, and toe. The coordinate data were filtered using quantic spline processing. The peak to peak (P-P) separation between shoulder and hip joints in the horizontal direction was used to determine if the subject followed the instruction about trunk rotation. The average speed over a stride was obtained from the distance covered by the right heel over time. Stride length and rate were calculated from the coordinates and time of the right heel. The hip, knee, and ankle joints' range of motion were obtained during the braking and propulsive phases of a stance phase (right heel contact to toe-off). Repeated measurement ANOVA was performed to determine the kinematic difference among the three conditions (SPSS 22). Greenhouse-Geiser corrections were used if the assumption of sphericity was violated. The contribution of the difference due to the factor (effect size), the partial eta squared (η_p^2), was reported. Bonferroni-Holm's correction was applied to perform pair-wise comparisons with adjusted p-values.

RESULTS: There was a significant P-P shoulder and hip separation between exaggerated trunk rotation condition and both natural gait and restricted trunk rotation conditions ($p < 0.01$; $\eta_p^2 = 0.74$). This indicated that the participants all adhered to the running instruction to manipulate the trunk rotation. However, the P-P difference was not observed between natural gait and restricted trunk rotation conditions ($p = 0.52$). Figure 1 (A & B) showed significant differences among the conditions in stride length ($p < 0.05$; $\eta_p^2 = 0.57$) and rate ($p < 0.05$; $\eta_p^2 = 0.62$). The contact time in the exaggerated trunk rotation condition was significantly longer than restricted trunk rotation condition ($p < 0.01$).

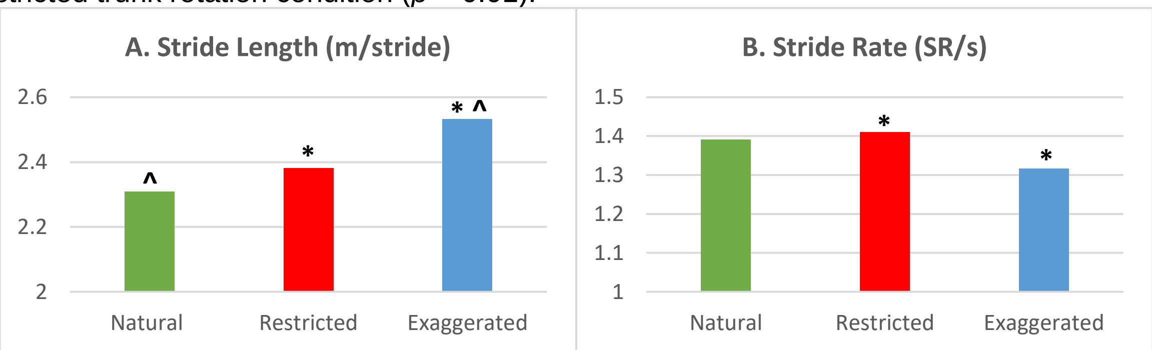

Figure 1: Symbols represents the significant difference between the conditions.

There were no significant differences of the joint range of motion at hip, knee, and ankle during braking and propulsive phases among the three conditions ($p > 0.1$; Table 1). The average speeds over a stride in all three conditions had no significant difference ($p = 0.19$).

Table 1: Running Kinematics (Mean ± SD; symbols represent significant difference)

Variables	Natural	Restricted	Exaggerated
Speed (m/s)	3.22 ± 0.46	3.36 ± 0.51	3.34 ± 0.38
P-P Separation (m)	0.1 ± 0.03**^**	0.1 ± 0.03*****	0.16 ± 0.06***^**
Contact time (s)	0.72 ± 0.03	0.71 ± 0.05*****	0.76 ± 0.04*****
Stride Length (m/stride)	2.31 ± 0.24**^**	2.38 ± 0.27*****	2.53 ± 0.21***^**
Stride Rate (stride/s)	1.39 ± 0.07	1.41 ± 0.1*****	1.32 ± 0.08*****
Braking Hip RoM (°)	-3.12 ± 2.82	-2.15 ± 3.16	-4.22 ± 5.02
Braking Knee RoM (°)	-21.97 ± 3.97	-22.2 ± 4.24	-21.72 ± 3.26
Braking Ankle RoM (°)	-16.52 ± 6.15	-18.7 ± 7.91	-17.34 ± 6.07
Propulsive Hip RoM (°)	31.66 ± 6.59	36.21 ± 6.09	32.54 ± 8.42
Propulsive Knee RoM (°)	21.5 ± 3.11	22.54 ± 4.28	22.86 ± 3.62
Propulsive Ankle RoM (°)	39.81 ± 4.36	41.14 ± 9.31	39.46 ± 4.06

DISCUSSION: Even though the participants purposely manipulated the trunk rotation during running, it did not influence overall running kinematics. The three factors that were influenced by the manipulation of the trunk rotation were contact time, stride length, and rate. As the runners purposely increased their trunk rotation, the stride length increased about 7-10% when compared to natural and restricted trunk rotation conditions (Fontecchio & Savilonis, 2012). Reversely, the stride rate decreased about 5-7%. This increase in stride length could be due to the P-P separation of the shoulder and hip joints. It was found that the exaggerated trunk rotation condition had greater P-P separation (58 & 64%) when compared to the other two conditions. This big increase of shoulder-hip separation may result in greater horizontal pelvis movement that helped the leg to reach further forward in front of the runner. This inversed finding of stride length and rate also explained the similar average running speed across the conditions. Although significant change in stride length and rate were found, the joint range of motion at lower extremity, surprisingly, had no significant difference across the three conditions in both braking and propulsive phases. Since the joint angle is a relative angle, this could represent that the body segments compensated for each other to result in a similar outcome (i.e., speed) due to the change of trunk rotation. There is a need to further examine the change of segment angles to better understand the impact of the trunk rotation in the body segment level.

Studies have well documented the association between leg stiffness and running economy and their relationship with both stride frequency and length (e.g., Cavanagh, & Kram, 1989; Farley & González, 1996; Morin, Samozino, Zameziati, & Belli, 2007; Nummela, Keränen, & Mikkelsson, 2007). In the current study, runners were running in a similar pace of 3.31 m/s across all three conditions. This represents that this running speed is predominantly achieved by the stride length rather than stride rate (Cavanagh & Kram, 1989; Nummela, Keränen, & Mikkelsson, 2007). The current findings also showed the stride length deviated more than 6% from natural gait and restricted trunk rotation conditions which can be detrimental to the running economy (de Ruiter, Verdijk, Werker, Zuidema, & de Haan, 2013). Additionally, the current study showed increases in both stride length and contact time which could result in decreasing leg stiffness (Dalleau, Belli, Bourdin, & Lacour, 1998; Morin et al., 2007).

In summary, the runners could intentionally increase trunk rotation while running. Although only a hand full of running kinematics were influenced, these factors were proven to be associated with running economy. This warrants further investigation of the impact of trunk rotation on running mechanics. The limitations of the current study were but not limited to 1) small sample size, 2) only female recreational runner were examined, and 3) running striking pattern was not controlled.

CONCLUSION: This study found that purposely increasing trunk rotation during running has minimal influence on overall running kinematics. The exaggerated trunk rotation would increase stride length and decrease stride rate. Due to this inverse relationship, the average running speed did not change significantly across the three conditions. The joint range of motion at the lower extremity did not change significantly as well. The findings of this current study warrant further examination of the effect of trunk rotation in a different status of the runner (i.e., fatigue).

REFERENCES

Arellano, C. J., & Kram, R. (2011). The effects of step width and arm swing on energetic cost and lateral balance during running. *Journal of Biomechanics*, *44*, 1291-1295. doi:10.1016/j.jbiomech.2011.01.002

Arellano, C. J., & Kram, R. (2014). The metabolic cost of human running: Is swinging arms worth it? *The Journal of Experimental Biology*, 217, 2466-2461. doi:10.1242/jeb.100420

Cavanagh, P. R., & Kram, R. (1989). Stride length in distance running: Velocity, body dimensions, and added mass effects. *Medicine and Science in Sports and Exercise*, *21*(4), 467-479. doi:10.1249/00005768-198908000-00020

Ceyssens, L., Vanelderen, R., Barton, C., Malliaras, P. & Dingenen, B. (2019). Biomechanical risk factors associated with running-related injuries: A systematic review. *Sports Medicine*, *49*, 1095–1115. doi.org/10.1007/s4027 9-019-01110 -z

Cheung, R. T., & Ngai, S. P. (2016). Effects of footwear on running economy in distance runners: A meta-analytical review. *Journal of Science and Medicine in Sport*, *19*, 260-266. dx.doi.org/10.1016/j.jsams.2015.03.002

Dalleau, G., Belli, A., Bourdin, M., & Lacour, J. R. (1998). The spring-mass model and energy cost of treadmill running. *European Journal of Applied Physiology*, *77*, 257-263.

de Ruiter, C. J., Verdijk, P. W. L., Werker, W., Zuidema, M. J., & de Haan, A. (2013). Stride frequency in relation to oxygen consumption in experienced and novice runners. *European Journal of Sport Science*, *14*, 251-258.

Farley, C. T., & González, O. (1996). Leg stiffness and stride frequency in human running. *Journal of Biomechanics*, *29*(2), 181-186. doi.org/10.1016/0021-9290(95)00029-1

Fisher, D., Louw, Q., Cockcroft, J., & Tawa, N. (2018). Three-dimensional kinematics of the thorax during over-ground running. *Journal of Bodywork & Movement Therapies*, *22*(2), 300-307. dx.doi.org/10.1016/j.jbmt.2017.08.003

Fontecchio, T., & Savilonis, B. J. (2012). Gait analysis and spinal rotation. *38th Annual Northeast Bioengineering Conference (NEBC)*, 360-361.

Hinrichs, R. N., Cavanagh, P. R., & Williams, K. R. (1987). Upper extremity function in running. I: Center of mass and propulsion considerations. *International Journal of Sport Biomechanics, 3*, 222-241.

Hinrichs, R. N. (1987). Upper extremity function in running. II Angular momentum considerations. *International Journal of Sport Biomechanics*, *3*, 242-263.

Konz, R., Fatone, S., & Gard, S. (2006). Effect of restricted spinal motion on gait. *Journal of Rehabilitation Research and Development*, *43*(2). 161-170.

Morin, J. B., Samozino, P., Zameziati, K., Belli, A. (2007). Effects of altered stride frequency and contact time on leg-spring behavior in human running. *Journal of Biomechanics*, *40*, 3341-3348. doi:10.1016/j.jbiomech.2007.05.001

Moore, I. S. (2016). Is there an economical running technique? A review of modifiable biomechanical factors affecting running economy. *Sports Medicine*, *46*, 793-807. doi 10.1007/s40279-016-0474-4

Nummela, A., Keränen, T., & Mikkelsson, L. O. (2007). Factors related to top running speed and economy. *International Journal of Sports Medicine*, *28*(8), 655-661. doi:10.1055/s-2007-964896

Seay, J. F., Van Emmerik, R. E. A., & Hamill, J. (2011). Influence of low back pain status on pelvis-trunk coordination during walking and running. *Spine*, *36*(16), E1070-E1079. doi: 10.1097/BRS.0b013e3182015f7c