DOES PEAK GROUND REACTION FORCE AT INITIAL CONTACT OF WALKING CHANGE DEPENDING ON THE PHASE OF RESPIRATION?

Paolo Sanzo[1,2], Cassandra Felice[1], and Carlos Zerpa[1]

School of Kinesiology, Lakehead University, Thunder Bay, Canada[1]
Northern Ontario School of Medicine, Thunder Bay, Canada[2]

This study explored if there was a difference in peak ground reaction force (GRF) of walking depending on the phase of respiration (inspiration or expiration) at initial contact. Twenty-five individuals were tested and grouped as inhalers or exhalers. Data was collected for peak GRF using an Advanced Mechanical Technology force platform and phase of respiration using a CapnoTrainer® capnography unit at initial contact for 5 walking trials at a controlled velocity. An Independent Samples t-Test was used to examine the data with an alpha level *p<.05*. The results suggested that there was no difference in peak GRF for those that inspired/expired at initial contact. Future research will explore the effects of breathing on walking/running at different speeds/inclinations where breathing retraining has been proposed in treating some overuse injuries.

KEYWORDS: Inspiration, expiration, breathing, loading

INTRODUCTION: Breathing is a constant and automatic action that occurs without much thought of the intricate processes and systems at work; yet there is very little evidence to explain or support the relationship between breathing and many body mechanics and sport and functional movement patterns. Locomotion and respiration both rely on cyclic rhythms of the body (Bramble & Carrier, 1983). For those individuals whose breathing and gait cycles are coupled, the beginning and end of a respiratory cycle are often associated with the same footfall (Bramble & Carrier, 1983). Since it has been reported that during ambulation, the amount of force generated when the foot makes initial contact with the ground can be equivalent to two to three times one's body weight (Coates, 2013) and that during running, the greatest impact and stress occurs when the foot strikes the ground during exhalation (Bramble & Carrier, 1983), some injuries may be related to these factors.

As you inhale, the diaphragm contracts moving downward, and the intercostal muscles expand the rib cage to increase the volume of the thoracic cavity (Novotny & Kravitz, 2007). The increase in volume lowers the air pressure in the lungs and the air moves from an area of high concentration to an area of low concentration into the alveoli where gas exchange occurs (Novotny & Kravitz, 2007). Conversely, as you exhale, the diaphragm and intercostal muscles relax, which creates less stability within the core (Coates, 2013). The thoracic cavity is restored to its original volume and air is forced out of the lungs into the atmosphere (Novotny & Kravitz, 2007). The decreased muscular activity and stability of the core musculature at the time of greatest impact may contribute to the development of repetitive soft tissue strains and overuse injuries and stress fractures in bone that may occur in the lower limb; these may be a function of the relationship between breathing and what occurs at initial ground contact (Zadpoor & Nikooyan, 2011).

There is a reported coordination between breathing and exercise rhythms that may be beneficial to performance by reducing fatigue and decreasing the amount of unnecessary energy expenditure (Bernasconi & Kohl, 1993). This coordination may be velocity dependent, however, as it has been reported that increased load and velocity may enhance the coordination between exercise and breathing (Raßler & Kohl, 2000). Further evaluation is needed to see if this in fact impacts on walking and/or running at different speeds.

It is not only important to determine how the phase of respiration affects gait during walking and running but also identify whether or not exercise rhythms and breathing are coupled.

One way to examine respiration and the pattern of breathing used is with capnometry. Capnometry devices can measure the rise and fall of carbon dioxide (CO_2) throughout the breathing cycle and monitor CO_2 concentration (Chaitow, Gilbert, & Bradley, 2014). Capnography provides physiological input indicating respiratory endurance and fatigue which can be used to assist with training and enhance performance (Chaitow et al., 2014). Furthermore, using capnography to measure the phase of respiration in combination with other biomechanical measures (e.g., electromyography, kinetic, kinematic, motion capture analysis) may assist with exploring the relationship between breathing and the spatial and temporal properties of the gait cycle.

With walking and running, the action forces exerted by the feet on the ground are counteracted by reaction forces which provide propulsion and equilibrium control (Nilsson & Thorstensson, 1989). Ground reaction force (GRF) is essential to the study of gait biomechanics as it shows the physical relationship between the ground and the body (Kowalski & Li, 2016) and are also important factors associated with repeated loading and overuse injuries of the lower extremities (Keller et al., 1996).

Although research has been completed using force platforms to examine the GRFs associated with running, there is very little research done in combination with capnography to explore the link between the walking cycle and the phases of respiration. Therefore, the purpose of this pilot study was to explore if there was a difference in the peak GRF of walking depending on the phase of respiration (e.g., inspiration, expiration) at the time of initial contact. It is hypothesized that peak GRF will be lower at initial contact when it occurs with inhalation of the breathing cycle. Also, peak GRF may be impacted by velocity and may not be a factor when examined in walking.

METHODS: Once ethical approval from the academic institution and consent were obtained from prospective participants, nasal cannula were placed in the participant's nostrils and attached to the CapnoTrainer® capnography unit via the hose and filter, and placed on a moving cart. As the participant walked across the Advanced Mechanical Technology Incorporated (AMTI) force platform, the capnography unit moved along side. The AMTI force platform was reset, calibrated, and zeroed and the acquisition setting was set to a duration of 5 seconds with a frequency of 200 Hz. The participant was then asked to complete five walking trials across the force platform at his/her normal walking speed. A set distance of 5 meters was measured to allow the participant to complete six steps at a controlled and standardized walking velocity.

Data was collected for peak GRF at initial contact for each trial, as well as the phase of respiration for each trial. Based on the most common phase of respiration at initial contact the participant was labelled as an inhaler or exhaler at the point of initial contact. Descriptive statistics were then used to compare the mean and standard deviations for individual peak GRF and the phase of respiration. Ground reaction force data was collected using the AMTI force platform and respiratory data through the CapnoTrainer® and analysed using IBM SPSS 25 for statistical analysis. Statistical significance was determined with an alpha level of $p<.05$. An Independent Samples t-Test was conducted to determine if significant differences existed for peak GRFs between participants that inspired compared to expired at initial contact.

RESULTS: Twenty-five participants (12 males and 13 females) completed the study (see Table 1).

Table 1: Demographic Information of Sample

Item	Mean ± Standard Deviation
Age (years)	21 ± 1.18
Height (cm)	172.40 ± 9.15
Weight (kg)	73.44 ± 17.00

At the time of initial contact, 10 participants used a pattern in which they were inspiring at initial contact (labelled as inspirators) and 15 participants used an expiratory pattern (labelled as expirators). The peak GRF for the participants that were inspiring at the time of initial contact was 811.85 N ± 180.43. The peak GRF for the participants that were expiring at the time of initial contact was 779.57 N ± 160.51. There was no significant difference in peak

GRF at initial contact based on the phase of respiration (inspiration versus expiration), *t*(23)=1.15, *p=.26* (see Figure 1).

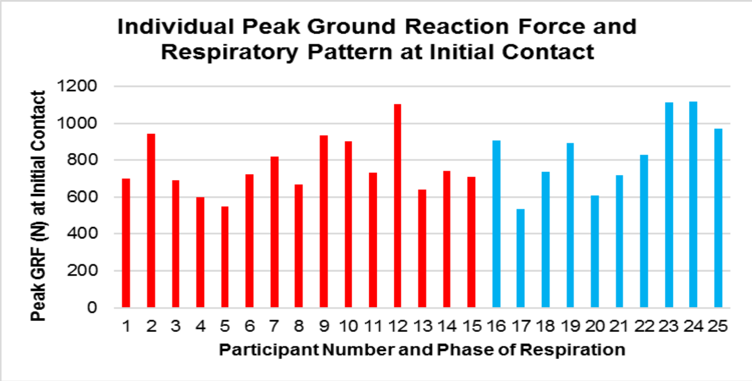

Figure 1. Individual phase of respiration at initial contact and peak GRF (N); . [red] denotes inspiration at initial contact; [blue] denotes expiration at initial contact.

DISCUSSION: The purpose of this pilot study was to explore if there was a difference in the peak GRF of the walking cycle that was dependent upon the phase of respiration at initial contact. Even though it has been reported that during running, if the foot strikes the ground at the beginning of exhalation then the impact of stress may be greatest (Coates, 2013), our findings concluded that peak GRF was not affected by the phase of respiration at initial contact while walking and is not in agreement with the initial hypothesis reported earlier.
Though walking and running are both forms of ambulation, the breathing physiology and motor mechanics are not the same. From a biomechanical perspective, walking begins when the foot strikes the ground with the heel or mid-foot, whereas running involves landing farther forward on the mid-foot or forefoot as speed increases (Maffetone, 2012). Another main difference between walking and running is the muscle activation patterns utilized and propulsion energy required (Maffetone, 2012). The walking phases are usually very distinct and the legs are stiff with locked and extended knees whereas running is continuous with a rebounding rhythm and unlocked and slightly flexed knees (Maffetone, 2012). Mechanically, running is a series of subsequent stance and flight phases characterized by a sinusoidal pattern of the centre of mass (Seyfarth, Geyer, Gunther & Blickhan, 2002) and can be described as a series of repeated bounds that use the stretch-shortening cycle (Hayes, French, & Thomas, 2011). Running is typically characterized by higher peak GRFs and shorter contact times, while walking is characterized by lower peak GRFs and longer contact times (Tongen & Wunderlich, 2010). These fundamental biomechanical differences may help to explain why the effect of breathing may be different when comparing walking to running. This aligns with the initial hypothesis that this relationship may be affected by the velocity of ambulation and be more a factor with running as compared to walking.
A limitation to consider with this study is the fact that participants were connected to a capnometer via a nasal cannula with the unit housed on a moving cart. This may have affected the participant's walking pattern and breathing pattern. While every effort was made to ensure the participant was able to walk and breathe normally, it is possible that the participants were influenced by this factor.

CONCLUSION: Though walking and running look to be very similar, when broken down to the biomechanical aspects, the two can be very different. In the current study, there was no difference in peak GRF dependent upon the phase of respiration at initial contact while walking. Further research is needed to explore the relationship between peak GRF, lower extremity biomechanics, and respiration and possibly how variations in speed or inclination may impact on this during walking and running. Examining the variability in the breathing pattern, GRF, or possibly the kinematics may be another area to explore under the above described conditions. Knowing how breathing impacts GRF or the lower quadrant biomechanics can assist athletes, coaches, and clinicians decide on the utility of developing appropriate breathing retraining programs to enhance performance and prevent injury.

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