

The vertical component of the ground reaction force does not reflect horizontal braking or acceleration per se

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Letter to the Editor

The vertical component of the ground reaction force does not reflect horizontal braking or acceleration per se

With great interest we read the recent paper by Akashi et al. (2008). They investigated muscle activation patterns and ground reaction force in people with diabetic polyneuropathy with (UDG) and without (diabetic neuropathic group (DG)) a history of plantar ulceration and in healthy controls (control group (CG)). The most interesting implication of their study is that increased plantar pressures under the forefoot are related to dysfunction of muscles in the leg, i.e. *m.vastus lateralis* (VL) and *m.gastrocnemius lateralis* (LG). This idea was initially conceived by Abboud et al. (2000), but has received little attention in later studies.

Akashi et al. showed that in UDG-participants the second peak in the curve of the vertical component of the ground reaction force was lower than in the other groups and that also activation of LG was delayed and lower; moreover the activation of VL was less than that of the participants in the other groups. They explained the relationship between plantar pressures and muscle function by pointing to the reduced second peak of the GRF and the affected activation of LG. The authors interpreted both phenomena as indications of affected push off, and thus an extended stance phase, resulting in longer loading of the forefoot. The authors suggested that the lower second peak of the vertical component of GRF is a manifestation of decreased LG activity.

We think that a few points of criticism should be made to this interpretation. A first remark is pure methodological, no information of gait velocity was obtained or at least presented. It is known that, if allowed to walk at their preferred velocity, people with diabetes walk slower than healthy controls. This will affect propulsive requirements and thus activation of LG. Moreover acceleration at

push off can be lower if the inistrade variation of gait velocity is smaller. That is for example if braking at heel strike is affected. Meier et al. (2001) showed that braking of forward velocity is a problem in people with diabetes. Another issue here is that only data of three muscles have been presented, while a proper interpretation of this kind of phenomena and adaptation in diabetes would require information on activation of extensors and flexors at ankle, knee and hip joints.

A more theoretical point is that the authors interpret a reduced second peak of the vertical component of the ground reaction force as reduced (forward) acceleration. Indeed in literature often the suggestion occurs that the first peak of the M-shaped vertical component of the GRF gives information of the impact and of braking of the velocity at heel strike while the second peak should be a measure of push off. To our understanding the suggestion that differences in vertical 'support' forces are matched by equivalent differences in horizontal 'propulsive' forces is incorrect. Mechanically these magnitudes are independent. Horizontal forces cause horizontal accelerations and vertical forces represent vertical accelerations.

Then how should the M-shaped curve of the vertical component of GRF and its peaks be interpreted? During normal gait the centre of mass (CoM) of the human body describes roughly a sinusoidal vertical displacement. At midstance the centre of mass reaches the highest position in this sinusoidal trajectory, in the bipedal stance phase it is at its lowest excursion. Double differentiation of this vertical displacement trajectory will result in a sinusoidal curve for the vertical acceleration with its lowest value at midstance and highest vertical acceleration at the bipedal phase. The total force experienced by the CoM will be the body mass (m) multiplied by the sum of the constant gravitational acceleration (g)

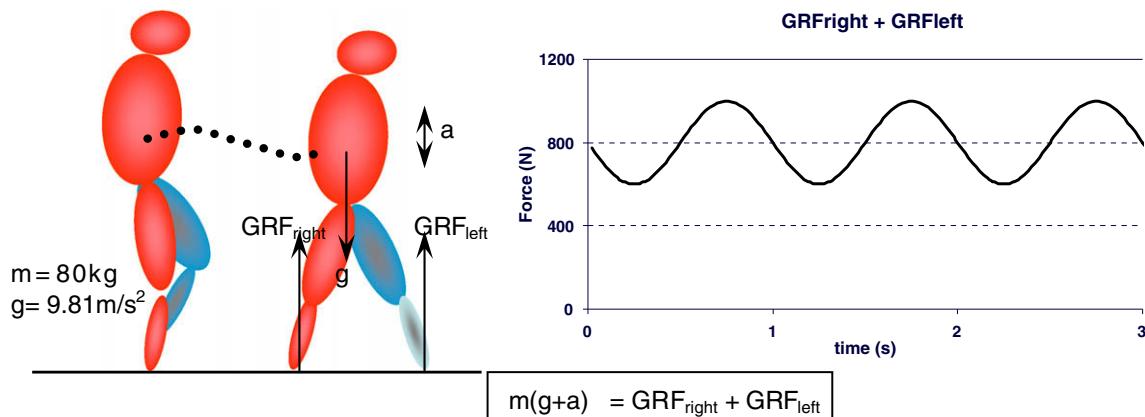


Fig. 1. Illustration of the vertical displacement of the Centre of Mass (CoM) during walking, with a subject in midstance (left image) and in the bipedal phase (right image). In the right image (bipedal phase) force (GRF_{right} and GRF_{left}) acting on the body and accelerations (gravitational (g) and required for the vertical displacement (a) experienced by the body have been drawn. The graph on the right gives the simulated force acting on the CoM. This force equals the force experience under the right and the left foot (GRF_{right} and GRF_{left}) and is the body mass (m) multiplied by the sum of g and a .

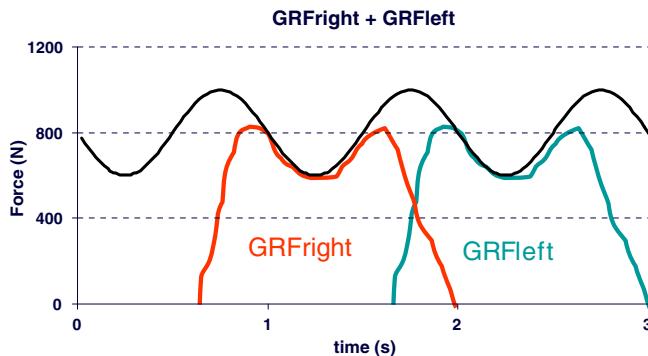


Fig. 2. Illustration of the distribution of the total force working on the CoM over the ground reaction force measured at left and the right foot.

and the sinusoidally changing acceleration (a) necessary for the vertical displacement of the body (Fig. 1). This total force on the CoM is equal to the sum of the vertical ground reaction forces at both feet (Fig. 2). During midstance when only one foot is on the ground the force acting on the CoM ($m(g + a)$) is the force measured as the ground reaction force. In the bipedal phase the force acting on CoM is distributed over both feet. At heel strike only a limited amount of the total force will be measured as the ground reaction force on one foot, as the bipedal phase precedes increasingly more force will be distributed to the newly placed foot (Donelan et al., 2002). Oppositely the other foot carries most of the force at the beginning of the bipedal phase and this force will be reduced to zero at toe off. This analysis shows that both peaks of the M-shaped curve of the vertical component of GRF are the result of a redistribution of the vertical force acting on the CoM from one foot to the other during the bipedal phase. If the transfer from one foot to the other occurs evenly both peaks reach the same height. If the newly placed foot is loaded fast, the first peak will be higher and the second one will be lower. A faster transfer occurs if subjects find it hard to brake the forward velocity (Meier et al., 2001). As a consequence of the latter the forefoot might be loaded earlier.

So following this analysis, the vertical component of the GRF might indirectly be used to draw conclusions on the forward displacement of the centre of mass and centre of pressure. However for that purpose it would have been more appropriate to consider the ratio of the first and second peak of the vertical component of the GRF than analyzing both peaks separately. The data in Table 2 (Akashi et al., 2008) suggest that in the UDG group Fz2 is lower than Fz1, while this is opposite in the CG group. As deduced above a second peak that is lower than the first peak, might indicate a faster transfer of the loading to the newly placed foot, and might be related to relatively early loading of the forefoot. So in the end this analysis would come to the same conclusion as Akashi

et al. have drawn: longer loading of the forefoot. However, a more direct approach would have been to analyze and present data on the for-aft component of the ground reaction force and compare them to data on plantar pressures.

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