Short Communication

Energy expended and knee joint load accumulated when walking, running, or standing for the same amount of time

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Evidence suggests prolonged bouts of sitting are unhealthy, and some public health messages have recently recommended replacing sitting with more standing. However, the relative benefits of replacing sitting with standing compared to locomotion are not known. Specifically, the biomechanical consequences of standing compared to other sitting-alternatives like walking and running are not well known and are usually not considered in studies on sitting. We compared the total knee joint load accumulated (TKJLA) and the total energy expended (TEE) when performing either walking, running, or standing for a common exercise bout duration (30 min). Walking and running both (unsurprisingly) had much more TEE than standing (+300% and +1100%, respectively). TKJLA was similar between walking and standing and 74% greater in running. The results suggest that standing is a poor replacement for walking and running if one wishes to increases energy expenditure, and may be particularly questionable for use in individuals at-risk for knee osteoarthritis due to its surprisingly high TKJLA (just as high as walking, 56% of the load in running) and the type of loading (continuous compression) it places on cartilage. However, standing has health benefits as an “inactivity interrupter” that extend beyond its direct energy expenditure. We suggest that future studies on standing as an inactivity intervention consider the potential biomechanical consequences of standing more often throughout the day, particularly in the case of prolonged bouts of standing.

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1. Introduction

Exercise is a widely promoted intervention for treating and preventing obesity and various comorbid conditions like osteoarthritis. Along with encouraging more physical activity, there has been a recent movement towards also encouraging less physical inactivity, such as prolonged sitting. Extensive sitting is linked with all-cause mortality [1], and a bout of exercise alone may not compensate for an inactive lifestyle throughout the rest of the day [2]. Consequently, numerous public health messages have recently recommended standing more and sitting less:

- The American College of Sports Medicine suggests “whenever possible, stand up as opposed to sitting down” in workplaces [3].
- The American Medical Association encourages employers to make standing workstations available [4].
- Ergotron Inc.’s JustStand.org states that “most people don’t have time for more exercise”, “standing is like walking”, and “the obvious remedy to sitting disease is standing” [5].

However, it is not clear if standing specifically, versus more vigorous activity like walking, is sufficient for improving health [6]. Most studies on standing have focused on metabolic aspects, with practically no attention on biomechanical aspects. Standing loads the knee cartilage in continuous compression, which induces wear-promoting lubrication modes [7]. Intermittent compressive loading (i.e. locomotion) increases cartilage stiffness and proteoglycan synthesis, while continuous loading (i.e. standing) has the opposite effects [8]. Individuals with moderate knee osteoarthritis accumulate more total knee joint loading throughout the day than individuals with healthy knees [9]. Before recommendations to stand more as a specific inactivity intervention can be made with confidence, a better understanding of the biomechanics of standing versus other physical activity options (e.g. locomotion) is needed.

In this study, we extended our recent work on knee joint loading in walking versus running [10] to include standing and
metabolic energy expenditure. Since many individuals exercise for a specific duration of time (e.g. 30 min), we compared the total energy expended (TEE) and total knee joint load accumulated (TKJLA) when walking, running, or standing for the same amount of time. We hypothesized that TKJLA would be similar between the three activities due to the intermittent nature of joint loading in locomotion.

2. Methods

Experimental motion capture, ground reaction force, and steady-state metabolic rate (indirect calorimetry) data were collected from 14 healthy adults (7 males, 7 females; ages 21–58, BMI 17.4–30.5 kg/m²) in an instrumented gait analysis as described previously [10]. Data for bipedal standing were also obtained. Lower limb joint angles and resultant kinetics were calculated by inverse dynamics and input to a lower limb musculoskeletal model [11] scaled geometrically to each subject’s limb lengths. Unilateral axial knee joint contact forces during walking, running, and standing were estimated using static optimization [10]. The cost function for muscle force prediction was the sum of squared muscle stresses.

To compare walking, running, and standing, a common duration of 30 min was used. The results are independent of this duration, but 30 min grounds the data in a typical exercise bout duration or potential uninterrupted period of standing. TEE was calculated by multiplying the metabolic rate by 30 min. TKJLA was the impulse of the axial knee joint contact force each activity would actually incur over 30 min (subjects did not actually walk, run, or stand for 30 min). For walking and running, TKJLA was the impulse of the average contact force curve from at least five strides, times the number of strides that would be completed during 30 min. TKJLA for standing was the average contact force times 30 min. All values were scaled by bodymass.

TEE and TKJLA were compared between walking, running, and standing by repeated-measures ANOVA with a critical $p < 0.05$. Post hoc comparisons were made using a False Discovery Rate adjustment [12]. Effect sizes (d) were calculated using Cohen’s [13] criteria.

3. Results

The peak knee joint loads during walking and running (Fig. 1) were 2.72 ± 0.41 and 8.02 ± 1.62 bodyweights, respectively. The average speeds were 1.45 ± 0.14 m/s for walking and 3.17 ± 0.43 m/s for running. The average time for one stride in walking and running and the duration of the trial in standing. The stride begins and ends at initial ground contact. Vertical dashed lines indicate toe-off.

![Fig. 1. Axial knee joint contact forces predicted by static optimization for (a) standing, (b) walking, and (c) running, in multiples of bodyweight (bw). Shaded areas indicate one between-subjects standard deviation. Horizontal axis is the time for one stride in walking and running and the duration of the trial in standing. The stride begins and ends at initial ground contact. Vertical lines indicate toe-off.](image1)

TKJLA (Fig. 2a) was similar for walking (18.7 ± 1.3 kN/s/kg) and standing (18.1 ± 3.6 kN/s/kg), but greater for running (32.0 ± 3.5 kN/s/kg) than both walking and standing.

![Fig. 2. (a) Total knee joint load accumulated (TKJLA) and (b) total metabolic energy expended (TEE) for standing, walking, and running, that would be accumulated over 30 min of each activity. Error bars indicate ± one between-subjects standard deviation. * = significantly greater than standing ($p < 0.05$). ** = significantly greater than both walking and standing ($p < 0.05$).](image2)
and standing. TEE (Fig. 2b) was greater for walking (8.5 ± 0.9 kJ/kg) than standing (2.1 ± 0.1 kJ/kg) and greater for running (25.8 ± 3.3 kJ/kg) than both walking and standing. All differences were significant at p < 0.001. All effects sizes were “large” (d > 1.0).

The same statistical results were found using two other cost functions to predict TKJLA, suggesting the results were driven by the experimental data rather than the cost function assumption.

4. Discussion

In this study we compared TEE and TKJLA in walking, running, and standing for a common exercise bout duration (30 min). The hypothesis was partially supported: TKJLA was similar in walking and standing but greater in running. Some interesting interpretations of these results when considering TEE (Fig. 2) are:

• It would take over 2 h of standing to burn as much energy as 30 min of walking.
• It would take nearly 6 h of standing to burn as much energy as 30 min of running.
• To burn the same total amount of energy, one would accumulate about four times as much knee joint loading in standing compared to walking, and about seven times as much loading in standing compared to running.

If one has 30 min available for exercise, we therefore suggest that standing is a poor replacement for walking or running, from both energetic and biomechanical perspectives.

An emerging paradigm in exercise and public health science is that spending most the day in uninterrupted sedentary behavior can be a health risk, even if a vigorous exercise bout is performed at some point. To date, research has shown the metabolic benefits of breaking up long bouts of sitting with intermittent standing or low-intensity activity [2]. However, these results have also been extended to recommendations for prolonged standing within the workplace [3,5]. Our results suggest that long bouts of standing are energetically inefficient compared to locomotion. Additionally, for the same duration of activity, standing accumulates the same TKJLA as walking and over half the load of running, even though peak knee joint loads in running are tremendously compared to standing (Fig. 1). Individuals demographically at risk for knee osteoarthritis (e.g. obese) may not necessarily benefit biomechanically from standing more. Standing places the knee cartilage under continuous compression, which is generally a detrimental loading environment, while cyclical loading like that experienced in locomotion can benefit cartilage health [8]. Running, despite its high peak knee joint loads, does not often cause osteoarthritis in otherwise healthy knees, and may even provide a protective effect [10,15].

In conclusion, the present results suggest biomechanical aspects of standing are an important consideration when recommending standing as an inactivity intervention. We hope the results will motivate future studies to include a biomechanical component when identifying the optimal activities to replace prolonged sitting. A public health message of “be less inactive” may be more appropriate than “stand more” at this stage.

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