CHANGES IN KINETIC AND KINEMATIC GAIT PARAMETERS DUE TO FIREFIGHTING AIR BOTTLE CONFIGURATION

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INTRODUCTION

Firefighters often use a self-contained breathing apparatus (SCBA) that includes a face mask and shoulder pack with air bottle, which may interfere with functional performance. Choice of air bottle is currently a controversial topic due to investment costs for lightweight, more compact, expensive bottles vs. heavier, larger but less expensive designs. Prior studies have examined the effect on balance of wearing protective clothing with SCBA packs for firefighters (Punakallio, 2003) and hazardous material workers (Kincl, 2002); however, no systematic gait assessments have investigated load carriage due to different bottle configurations (bottle weight and size). The goal of this study was to quantify changes in gait and obstacle crossing behaviors with different bottle configurations. We hypothesized that reduced weight and size would improve gait performance.

METHODS AND PROCEDURES

Twenty-one male firefighters (age 27±5 yrs) walked at either of two speeds ("normal, comfortable pace" or "as fast as possible without running"). Three obstacle conditions were tested (no obstacle, 10 cm, or 30cm obstacle). Three SCBA air bottles were tested: a low-budget, heavy aluminum (AL) bottle of 9.1kg; an expensive, light carbon fiber (CF) bottle of 5.4 kg; and a novel redesigned bottle (RD) constructed to provide a light, short design that was 5.4 kg and half the length of the others. Walking speeds and bottle configurations were randomized. Outcome parameters were averaged over two trials per condition.

Five kinetic parameters were obtained from the vertical ground reaction force (GRF) for the trailing foot when crossing the obstacle as measured by a force plate (BP600900, AMTI; sampled at 1000 Hz): time to 1st peak, peak force in early and late stance, and impulse in early and late stance. Early and late stance were defined as the breaking (heelstrike) and propulsion (toe-off) portions of the vertical GRF curve, respectively. Impulse was the integral of contact force with respect to time.

Six kinematic parameters were collected using a motion capture system (Datastation 460, Vicon; sampled at 100 Hz): overall gait speed (GS), time in single leg support while crossing the obstacle (SLST), minimum horizontal clearance from the obstacle of the trailing toe (HCT) and leading heel (HCL), and minimum vertical clearance of the trailing (VCT) and leading foot (VCL). Multivariate analysis of variance tests examined whether bottle configuration, obstacle height, and walking speed affected the kinetic and kinematic parameters.

RESULTS/DISCUSSION

Interesting observations were noted with bottle configuration. Six subjects (29%) hit

the 30 cm obstacle while wearing the heavier AL bottle and walking at normal speed. Four hit the obstacle during both trials. Two of these four also hit the obstacle during fast walking. Therefore, the 30 cm obstacle was contacted in 13 out of 84 trials (15%). No obstacle contacts were observed for lighter bottles (CF, RD). All obstacle contacts were due to trailing foot contact. Although not statistically significant (*p=0.076*), vertical clearance for the trailing foot VCT was less for the AL bottle than others (AL: 17.0 ± 1.4 cm (SE); CF: 17.8 ± 1.4; RD: 19.1 ± 1.0). A bottle × obstacle interaction effect for VCL (*p=0.076*) also suggested a trend for close vertical contact with the lead foot while wearing the AL bottle and crossing the 30 cm obstacle (12.1 ± 0.8 cm for AL-30 vs. 14.6 ± 0.7 for all others). Thus, it appears that the heavier bottle might pose a greater tripping risk.

Kinetic gait parameters suggest significant main effects in both early and late stance peak GRF associated with bottle configuration. No other kinetic or kinematic parameters had significant main or interaction effects due to bottle configuration. Peak GRFs were greater for the AL than CF/RD bottles during early stance ($p = 0.004$; AL: 1.66 ± 0.05 %BW vs. CF/RD: 1.60 ± 0.04) and late stance ($p < 0.001$, AL: 1.59 ± 0.03 %BW vs. CF/RD: 1.53 ± 0.03). No difference was found between CF and RD suggesting that only weight affects peak GRF. A recent study also found that peak vertical GRF increased with applied load during gait (Birrell et al., in press).

All kinetic parameters except time to 1st peak increased with the obstacle height ($p \leq 0.007$). HCL, HCT and SLST ($p \leq 0.010$) also increased, while VCL and GS decreased with the obstacle height ($p < 0.001$). High peak and impulse values suggest that greater effort is required by the trailing leg as obstacle height increases.

Walking speed statistically affected ($p \leq 0.001$) all gait parameters except, interestingly, vertical clearances. Peak GRF (early and late) and horizontal clearance (HCT and HCL) increased with walking speed, whereas time-related parameters of peak GRF time, GRF impulse (early and late), and SLST decreased, as might be expected. Thus, more challenging fast walking conditions appear to cause larger and more forceful steps around an obstacle.

SUMMARY

Increasing load weight with the heavier AL bottle resulted in 29% of the subjects contacting the challenging 30 cm obstacle while passing over it with the trailing limb. No subjects contacted either obstacle while wearing the lighter CF or RD bottles. Peak ground reaction forces were also significantly larger with the heavier bottle, but were the same for the other bottles. Thus, changing bottle length (and effectively lowering the bottle center of mass along the back) had no apparent effect on gait performance. Obstacle height and walking speed also influence gait behavior; therefore, firefighters need to cognizant of how gear and environment may affect their gait performance.

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