Changes in lower-limb joint torques when using a passive back-support exoskeleton for level walking

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Occupational back-support exoskeletons (BSEs) are being promoted as potential interventions for reducing physical demands on the low back (e.g., Alemi et al., 2020). BSE use in the workplace, however, may also introduce some unexpected safety challenges. For example, recent studies have shown that walking was perceived as more difficult when wearing a BSE (Laevo™; Baltrusch et al., 2018) and that both preferred speed and stride length decreased during walking (Baltrusch et al., 2019). In addition to kinematic changes, gait kinetics are also important to understand, as a stable and economical gait pattern is enabled by appropriate magnitudes of lower limb joint torques generated at specific times (Sloot & van der Krogt, 2018). Since a BSE generates external hip extension torque, wearing a BSE may alter lower limb joint torque in an unexpected way. Thus, this study aimed to assess the effects of different external torque levels of a BSE on lower limb joint torque during level walking.

The backX™ AC (US Bionics Inc., USA), designed to reduce physical demands on the back during forward bending, was used in this study. The backX™ torque profile was first assessed using the Humac Norm™ isokinetic dynamometer (CSMI, Stoughton, MA), with the backX™ attached to a mannequin. This mannequin has a hinge joint at the hip, mimicking hip extension/flexion; the mannequin was usd to avoid any active voluntary or reflexive movements that may have resulted from involving human subjects.

Subsequently, 20 young and healthy participants (10 males and 10 females) completed multiple trials of level walking on a linear walking track (1.5 × 15.5 m) at their preferred walking speed, while wearing the backX™ at three different levels of external torque: no torque [EXO_{OFF}], low torque [EXO_{LOW}], and high torque [EXO_{HIGH}]. Trials were also completed in a control (NoExo) condition. Triaxial ground reaction forces and moments were recorded from a force platform embedded in the middle of the track. Body segment kinematics (bilateral foot, shank, and thigh, as well as the pelvis and trunk) were captured using an optical motion capture system, with passive reflective markers placed on relevant anatomical landmarks.

Sagittal plane torques at the ankle, knee, and hip (for the limb that contacted the force platform only) during a stride were subsequently calculated based on the ground reaction forces/torques and body segment kinematics, using a bottom-up inverse dynamics model (Kingma et al., 1996). The calculated hip torque ($T_{HIP-TOTAL}$) includes torques generated by both the participant and the backX™ device. Hip torque generated by the participant only ($T_{HIP-HUMAN}$) was estimated by subtracting the torque generated by the device ($T_{HIP-EXO}$) from $T_{HIP-TOTAL}$. Note that $T_{HIP-EXO}$ was computed using the dynamometer. Outcome measures here included peak hip extension ($Hip_{EXT-TOTAL}$) and flexion ($Hip_{FLX-TOTAL}$) torques by the participant plus backX™, peak hip extension ($Hip_{EXT-HUMAN}$) and flexion ($Hip_{FLX-HUMAN}$) torques by the participant only, peak knee extension ($Knee_{EXT}$) and flexion ($Knee_{FLX}$) torques, and peak ankle plantarflexion ($Ankle_{PLT}$) and dorsiflexion ($Ankle_{DRS}$) torques.

Results from repeated measures analysis of variance (ANOVA) models indicated that $Hip_{EXT-HUMAN}$ was lower (8-9%) in the EXO_{HIGH} condition compared to other conditions, while $Hip_{EXT-TOTAL}$ did not differ between exoskeleton conditions. $Knee_{EXT}$ was lower in EXO_{HIGH} (6%) than in EXO_{OFF}. $Knee_{FLX}$ was higher in control condition (5-11%) as compared to other conditions, and was also higher in EXO_{OFF} (4-6%) than in EXO_{LOW} and EXO_{HIGH}. Although EXO_{LOW} condition led to higher $Ankle_{PLT}$ than NoExo and EXO_{HIGH}, simple effects analysis showed that these differences were significant only among females. No significant main or interaction effects were shown in $Ankle_{DRS}$.

While hip extension torques are required specifically in the initial 0-10% and final 75-100% portions of a gait cycle, the backX™ generated substantial external hip extension torque. Hence, a decrease in $Hip_{EXT-HUMAN}$ when wearing the backX™ with high supportive torque suggests that participants adapted their walking patterns appropriately. Decreased $Knee_{EXT}$ in EXO_{HIGH} condition may reflect the co-dependence between the hip and knee as they go into extension during the initial phase of gait. It can be assumed that a decrease in $Hip_{EXT-HUMAN}$ when wearing the backX™ led to a synchronized change in the knee, reflected as a decrease in $Knee_{FLX}$. Such change is because decreased activation in the biceps femoris, a biarticular muscle, to decrease hip extension torque, would also lead to a decrease in knee flexion torque during walking.

While hip flexion torques are required for walking (i.e., during 20-70% of the gait cycle), the hip was flexed less than ~10º or mostly extended throughout the gait cycle. Hence, wearing the backX™ had minimal effects on hip flexion torque during walking. It is important to note, however, that these same results might not be found for other activities, in which the hip needs to be more flexed than for level walking. Thus, future work should extend kinetic analyses to other tasks that may be encountered in a workplace, such as obstacle crossing/negotiation, stair climbing, and recovering from perturbations.

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