EFFECT OF SPRING CANE TIPS ON MEASURES OF PEAK VERTICAL GROUND REACTION FORCES DURING WALKING

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This study examined the effect of different spring cane tips on measures of peak vertical ground reaction forces (GRFs) transferred to the cane and foot during walking. Thirty-three participants were fitted with a T-Scope Knee Brace® to simulate a knee flexion contracture. Participants performed cane-aided walking tests under four different spring cane conditions. Each participant walked five trials for each cane tip over two force plates to measure GRFs for the cane and foot respectively. Four (spring cane tip conditions) x two (cane and foot) repeated measures ANOVA was conducted on measures of vertical GRFs. This analysis revealed a significant main effect on measures of vertical GRFs between the cane and foot, $F(1,32) = 225.79$, $p < .05$, $\eta^2 = .876$. This outcome has implications for cane tip designs to prevent upper extremity injuries occurring due to cane use.

KEYWORDS: Cane, ground reaction forces, upper extremity and lower extremity.

INTRODUCTION: Canes assist patients during rehabilitation to reduce the load placed on the injured leg and to minimize the risk of further injuries (Bateni, Heung, Zettel, McIlroy, & Maki 2003). The use of canes, however, influences a patient's GRFs by shifting and changing his/her center of mass (COM) during ambulation (Marasovic, Cecic, & Zanchi, 2009). With contralateral cane use, for example, a portion of the body weight transfers to the cane and the rest to the injured limb. This shift creates a reduction in GRFs at the injured limb and an increment in GRFs at the cane shaft (Bateni & Maki, 2005; Gross, 2010). Unfortunately, with the use of a cane, GRFs transferred via the cane shaft may result in musculoskeletal injuries in the upper extremity due to repetitive impacts occurring during walking (Bateni & Maki, 2005; Koh, Williams, & Povlsen, 2002). In addition, the use of a cane may cause a disruption in the healing process of the lower extremity as the patient may not put enough weight on the injured leg as prescribed by the health care provider. Spring-loaded canes seem to provide a solution to this issue because they mitigate GRFs transferred to the upper extremity via the cane shaft and cause an increase of GRFs at the foot of the injured leg, creating an avenue for health care providers to rehab patients with ambulation problems (Murphy, 1965; Varga et al., 2018). The research literature, however, has uncovered insufficient information in regards to the use of spring-loaded cane tips as an avenue to reduce GRFs transferred to the upper extremity via the cane shaft and redirect these forces to the foot of the injured leg during patient rehabilitation. Based on this gap in existing literature, the purpose of this study was to examine the effect of different spring cane tips on measures of vertical GRFs transferred to the upper extremity via the cane shaft and simulated injured leg via the foot during walking.

METHODS: The research design of this study was a non-experimental developmental cross-sectional study. This design accounts for the cane and foot as independent factors measured at the same time across different conditions using the same instrumentation. Thirty-five participants including 18 males and 17 females were recruited for the purpose of this study. All participants were between 18-30 years of age. Two participants were removed from the study due to incomplete data, leaving a total of 33 participants. Before collecting any data for this study, ethical approval was obtained from the Lakehead University research ethics board. All of the participants were screened for inclusion and exclusion criteria. More specifically, participants were eligible to partake in the study if they were able to ambulate unaided without a gross deviation or anatomical impairment in their gait (e.g., multiple sclerosis, foot drop, hip and knee osteoarthritis), able to understand verbal/written instructions, and to have the ability to give informed consent. For this study, the researchers used one rigid cane tip (no spring), two metallic spring-loaded commercial cane tips (one soft spring and one firm spring), and one innovative cane tip made out of thermoplastic polyurethane (TPU) material. Thermoplastic material exhibits hysteresis and cyclic softening. The area enclosed by the hysteresis loop represents energy absorbed during a loading-unloading cycle (Qi & Boyce, 2005). During the data collection process, the spring-cane tip conditions were randomly selected via the Latin square method, which assisted the researchers in minimizing the order effect. In the testing session, a participant was given time to familiarize himself/herself with the instrumentation. A T-Scope Knee Brace® was fitted onto the participant's dominant leg locked at 30 degrees of knee flexion to simulate a knee flexion contracture and create an antalgic gait pattern that might be present due to a lower limb injury. The participant's dominant leg was determined by asking him/her to kick a ball (Velotta, Weyer, Ramirez, Winstead, & Bahamonde, 2011). Next, the researchers asked the participant to stand with his/her shoes on and hold the cane on the contralateral hand lateral to the base of the fifth metatarsal to adjust the cane relative to the participant's height (Lam, 2007). Canes affect the GRFs regardless of whether the patient uses the cane on the contralateral or ipsilateral side of the injured leg and clinicians prescribe either approach during rehabilitation (Gross, 2010). For this study, the researchers asked the participants to hold the cane contralateral to the simulated injured leg to be able to examine the force loading on the symptomatic lower limb separately from the cane (Gross, 2010). The researchers used a 10-inch goniometer to adjust the cane to the height of the participant. The goniometer was used to make sure the participant flexed the elbow between 15-30 degrees, while the cane contacted the ground. After fitting the cane to the participant, the researchers provided the participant with instructions on how to properly ambulate with the use of a cane. The researchers ensured that the cane and the simulated injured leg of the participant moved simultaneously followed by the uninjured leg (Lam, 2007). The participant was then given approximately 10 minutes to get comfortable with the equipment and practice proper cane aided ambulation to minimize the risk of injury and ensure reliability across the walking trials. Each participant performed three practice trials with a rigid cane before collecting the data. After proper instruction and practice on how to walk over the Advanced Mechanical Technologies Incorporated© force platforms, the researchers began the data collection for the study. The two force platforms were positioned side by side, to separately capture the cane and foot impact of the simulated injured limb during the walking cycle. The force platforms collected the GRFs from the cane and foot of the simulated injured leg simultaneously during the walking cycle. The data collection consisted of the participant performing cane assisted ambulation with four randomly assigned spring cane tips. The participant completed five trials per cane tip, at a self-selected pace ranging from 1.25 to 1.5 m/s as an inclusive speed for both older and younger adults (Usroads, 2015). The speed was recorded using Brower Timing Gates set up in parallel orientation to the force platforms at the start and the end of the force platforms. Each trial was confirmed to be valid if the cane hit the force platform with the base of the cane tip and with no secondary impacts. If this requirement was not achieved, the trial was retaken before completing the number of required trials and protocol. All measures were normalized based on the participant's body weight. Descriptive statistics using means and standard deviations was used to tabulate and describe the data. A 4 spring loaded cane tips (rigid, soft, firm, and TPU) and 2 (cane and foot) repeated measures ANOVA was used to examine the interaction effect between these two independent variables on measures of vertical GRFs. The researchers conducted this statistical analysis because they were interested in detecting an interaction effect between (cane tip type) and (cane and foot conditions) to examine the extent to what spring loaded cane tips were able to mitigate GRFs transferred to the upper extremity via the cane shaft and increase GRFs at the foot of the simulated injured leg during the walking cycle.

RESULTS: Descriptive statistics as shown in Table 1 indicates that the vertical GRFs transferred to the upper extremity via the cane shaft appear to be slightly lower when using TPU and soft cane tips than when using rigid and firm cane tips. These differences, however, are not statistically significantly. On the contrary, the vertical GRFs for the lower (foot) extremity in Table 2 appear to be slightly higher when using firm and soft cane tips than when using TPU and rigid cane tips. Again, these differences are not statistically significant. The standard deviations appear to be homogeneous for the measures of GRFs regarding the cane and foot across cane tips. The two way repeated measures ANOVA revealed no significant interaction effect between the cane type condition and cane foot on measures of vertical GRFs, $F(3, 96) = 1.732$, $p > .05$. The results, however, indicated a significant main effect on measures of peak vertical GRFs between the cane and foot of the simulated injured leg, $F(1,32) = 225.79$, $p < .05$, $\eta^2 = .876$. A closer inspection of the mean differences seemed to indicate higher significant differences between the cane and foot for the TPU, $t(32) = 14.86$, $p < .05$, $d = 2.58$ and soft, $t(32) = 15.15$, $p < .05$, $d = 2.64$ cane tip conditions respectively. These differences, however, were only statistically significant between the cane and foot, but not across cane tip conditions.

Table 1: Normalized means for the peak vertical ground reaction forces transferred to the upper extremity via the cane shaft

	Mean	Std. Deviation	N
Upper TPU	0.21	0.15	33
Upper Rigid	0.22	0.15	33
Upper Firm	0.22	0.14	33
Upper Soft	0.21	0.14	33

Note: The means and standard deviations for the peak vertical ground reaction forces for the cane were measured in Newtons

Table 2: Normalized means for the peak vertical ground reaction forces transferred to the simulated injured leg via the foot

	Mean	Std. Deviation	N
Lower TPU	1.08	0.45	33
Lower Rigid	1.07	0.44	33
Lower Firm	1.09	0.44	33
Lower Soft	1.09	0.45	33

Note: The means and standard deviations for the peak vertical ground reaction forces for the foot were measured in Newtons

DISCUSSION: The purpose of this study was to examine the effect of spring cane tips on measures of vertical GRFs transferred to the upper extremity via the cane shaft and simulated injured leg during walking. The outcome of the study, however, shows no significant interaction effect between spring cane tips and cane foot on measures of peak vertical GRFs. While these results are similar to Mohammed (2016) who also found no significant interaction effect between these two factors on measures of vertical GRFs, the outcome of the current study differs from Mohammed (2016) in terms of significant main effects across spring cane conditions. Mohammed (2016), for example, found significant differences across spring cane conditions with soft springs mitigating more vertical GRFs transferred to the upper extremity via the cane shaft. The current study, however, did not find significant differences across spring cane tips on measures of vertical GRFs. This outcome is also contradictory to Murphy (1965) who stated that spring canes reduced the GRFs transferred to the upper extremity during cane aided walking. The lack of significance on measures of vertical GRFs across cane tips in the current study may be related to the design of the spring mechanisms. Mohammed (2016) and Murphy (1965) used spring mechanisms instrumented inside the shaft of the cane; whereas, the current study used spring cane tip mechanisms attached to the bottom of the cane shaft. Although the spring cane tips appear to provide comfort to the participants during cane aided walking, the outcome seems to suggest that these mechanisms did not have enough compliance to mitigate the GRFs generated by the upper extremity muscles and body weight of the participant while walking. These results, however, provide useful information for cane designers and engineers to create modifications and improve cane tip designs to better mitigate GRFs transferred to the upper extremity via the cane shaft. In terms of the lower extremity, the results of the study did not find significant differences on measures of GRFs generated by the foot across spring cane tips. This outcome, however, supports the work of Mohammed (2016) by highlighting the need to design adjustable springs to accommodate participants' body weights for rehabilitation purposes. The outcome of the study did find a significant main effect between the cane and foot on measures of GRFs for each cane tip, respectively but not across cane tip comparisons. This outcome was expected, as the vertical ground reaction forces were larger for the foot than the cane. Yet, this outcome highlights important information to be considered in future research for cane tip designs to increase the compliance of the spring loaded cane tips for comfort, prevention of upper extremity injuries and rehabilitation of lower extremity injuries. Future research will include a no cane condition to compare the ground reaction forces of the lower extremity during cane aided walking across spring tip conditions.

CONCLUSION: The outcome of this study shows no significant differences on measures of peak vertical GRFs across cane tips for the cane and foot respectively. The results, however, provide an avenue to examine the usefulness of spring cane tips in mitigating GRFs, which cause upper extremity injuries when these forces get transferred to the body via the cane shaft. The results also demonstrate the need to improve spring cane designs to account for participant upper body weight and properly mitigate vertical GRFs transferred to the upper extremity via the cane shaft. Furthermore, the results highlight the need to develop better spring cane technology to redirect forces to the injured leg as prescribed by clinicians during the rehabilitation process in cane aided walking. More specifically, a redesign of the TPU spring cane tips for clinical applications.

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