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Body weight support through a walking cane in inexperienced users with knee osteoarthritis

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ABSTRACT

Background: Walking canes are a self-management strategy recommended for people with knee osteoarthritis (OA) by clinical practice guidelines. Ensuring that an adequate amount of body-weight support (%BWS) is taken through the walking cane is important as this reduces measures of knee joint loading.

Research question: 1) How much body weight support do people with knee OA place through a cane? 2) Do measures of body weight support increase following a brief simple training session?

Methods: Seventeen individuals with knee pain who had not used a walking cane before were recruited. A standard-grip aluminum cane was then used for 1 week with limited manufacturer instructions. Following this, participants were evaluated using an instrumented force-measuring cane to assess body weight support (% total body weight) through the cane. Force data were recorded during a 430-metre walk undertaken twice; once before 10 min of cane training administered by a physiotherapist, and once immediately after training. Measures of BWS (peak force, average force, impulse equal to the average cane force times duration, and cane-ground contact duration) were extracted. Using bathroom scales, training aimed to take at least 10% body weight support through the cane.

Results: Before training, the average peak BWS was 7.2 ± 2.5% of total body weight. Following 10 min of training, there was a significant increase in average peak BWS by 28%, average BWS by 25%, and BWS impulse by 54% ($p < 0.05$). However, individual BWS responses to training were variable. Duration of cane placement increased by 22% after training ($p = 0.02$). Timing of peak BWS through the cane occurred at 51% of contact phase before training, and at 53% after training ($p = 0.05$).

Significance: A short training session can increase the transfer of body weight through a walking cane. However, more sophisticated feedback may be needed to achieve target levels of BWS.

1. Introduction

Knee osteoarthritis (OA) affects 24% of the population and can be extremely limiting [1]. Walking canes are a self-management strategy recommended for knee OA by several key clinical practice guidelines [2–4]. In addition to providing symptomatic relief [5], use of a walking cane following instruction has been shown to reduce surrogate measures of knee joint loading [6,7]. The extent of total body-weight support (BWS) transferred through the cane relates to the magnitude of reduction in measures of knee joint loading. Thus, ensuring adequate BWS is taken through the cane is an important consideration for people with knee OA when using this treatment strategy.

The knee adduction moment (KAM) is an external surrogate measure of knee joint loading [5,8–11], reflecting the distribution of load between the medial and lateral tibiofemoral compartments [12]. Reducing the KAM is often the target of interventions in knee OA [13,14] as both peak KAM and KAM impulse have been associated with structural degeneration [15–17]. Previous studies have demonstrated that walking cane use in people with knee OA can reduce the peak KAM by up to 16.7% and the KAM impulse by up to 32% [7]. The KAM-reducing effect of a cane has been demonstrated to be proportional to the amount of body weight support transferred onto the cane [7]. Thus, it is reasonable to infer that increasing BWS transferred through the cane during walking will better reduce medial knee joint loads. In people with knee OA who had on average 13 years of cane experience, BWS of 9% of total body weight was reported prior to training [6]. However, BWS transferred through a walking cane remains unknown in people with knee OA who are inexperienced cane users. We suggest that BWS

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of 10% is a reasonable target that has been previously demonstrated as feasible for participants to achieve, and one that significantly decreased the KAM [7].

Timing of BWS during stance also warrants consideration in walking cane use. The cane typically first touches the ground around foot contact, and the peak in BWS through a cane occurs on average at around 60% of the stance phase [7]. However, this does not coincide with the timing of either of the two peaks in the KAM - typically the first and largest peak occurs at around 26% of stance while the second, generally smaller peak occurs at 78% of stance [7]. Thus, teaching people to transfer BWS through the cane earlier may be more effective in reducing the largest KAM peak.

Cane advice and training by clinicians is variable. It is our experience that more detailed training including timing of BWS and the amount of BWS is less likely to be given by clinicians. Therefore, the primary aims of this study were to: i) describe measures of BWS (peak, average, impulse, time of peak BWS relative to cane-ground contact duration, and duration of BWS) through a cane in people with knee OA without training and ii) test the hypothesis that measures of BWS (peak, average and impulse) would increase following a brief training session conducted by a physiotherapist. Secondary aims were to determine if time of peak BWS occurred earlier in cane-ground contact following training and if the duration of cane contact increased following training.

2. Methods

An observational study design was used to investigate how people used a walking cane and a pre-post study design was used to investigate the immediate effect of a brief training session. This study was approved by the Human Research Ethics Committee and participants provided written informed consent.

2.1. Participants

Individuals with knee OA were recruited via advertisements on social media and from our existing database of volunteers. Inclusion criteria were i) able to walk comfortably for 20 min, ii) sufficient understanding of the English language, iii) live independently; iv) able/willing to use a cane for a week and attend a testing session at the University of Melbourne, and v) have knee OA. A clinical diagnosis of knee OA was confirmed according to established criteria; i) aged 50 years or older [18]; ii) knee pain on most days of the past month [19]; iii) activity-related joint pain [19]; iv) either no morning stiffness or morning stiffness less than 30 min [19]. Participants were excluded if they had: i) a history of neurological conditions that would affect leg and/or arm function; ii) total knee replacement in the study knee (most painful knee); iii) bilateral knee pain with equal severity in both knees; iv) upper limb or hand pain that would affect the person's ability to hold a cane or that may be aggravated by using a cane; v) a history of lower limb surgery in previous 6 months; vi) history of using a walking cane or similar gait aid; vii) a known diagnosis of unstable heart and lung disease, asthma, morbid obesity (body mass index (BMI) > 35 kg/m^2) or any other comorbid conditions that affect ability to walk; or viii) body mass > 100 kg (due to the cane manufacturer's guidelines).

2.2. Descriptive measures

Descriptive data including age, gender, height, body mass and duration of symptoms were acquired. Subscales of the Western Ontario and McMaster Universities (WOMAC) Osteoarthritis Index [20] were used to evaluate pain (five items, score range 0–20) and physical function (17 items, score range 0–68), where higher scores indicate greater symptom severity. Overall pain intensity and pain during walking was assessed using the Numeric Rating Scale (NRS 0–10) [21], where higher scores indicate greater pain severity. Participants were

Fig. 1. Study canes. (A) Cane. (B) Instrumented cane with an embedded lightweight uniaxial load cell [1], and data logger [2].

asked the number of hours of cane use per day in past 7 days, prior to training.

2.3. Walking cane use and instructions

Participants were sent a swan neck, aluminium walking cane (BE1674, Sunrise Medical, NSW, Australia) to their home, and encouraged to use it whenever walking over the following week. To mimic the common scenario of a patient purchasing a cane directly from a pharmacy, the standard printed manufacturer's instructions supplied with this cane were also sent to the participant. Instructions included cane length adjustment to allow the user to "maintain an upright posture with the elbow slightly flexed", "placing the cane on the ground at the same time as the affected leg", and holding the cane "in the hand opposite the affected leg" (See Appendix A for more detail on cane instructions). After 7 days, participants attended a testing session.

2.4. Body weight support measurement and training intervention

An instrumented walking cane (nCounters, Kew, Victoria, Australia) with a uniaxial force cell (UMM, Dacell, Korea) (Fig. 1) was calibrated to measure force (Newtons) through the cane [22]. It was set to the same height as the cane the participant had been using for a week at home. An initial 430 m walk around the block outside the laboratory at a self-chosen walking pace using the cane was completed. The block was a standard paved footpath with minimal impediments, with four sides each of approximately 100 m in length. A data logger mounted on the cane recorded the force applied on the cane at 50 samples/second (Sparkfun Logomatic v2, Colorado, USA).

Participants then underwent a 10-minute training session delivered by a physiotherapist (CM) on optimal cane technique for offloading approximately 10% of total body weight (10% BWS) onto the cane. The 10-minute session was developed following discussions and consensus

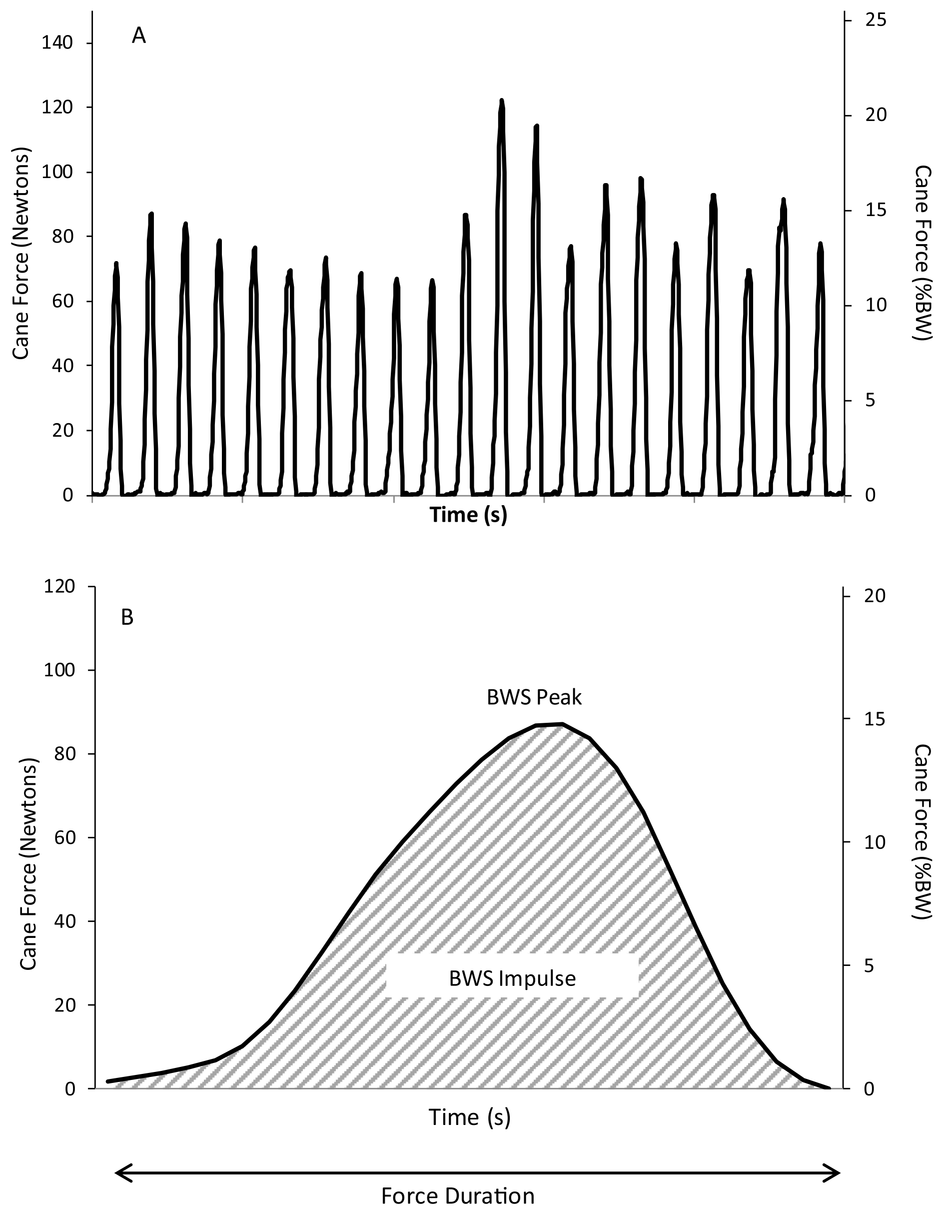

Fig. 2. [A] Representative cane force-time curves (over 25 s) for 60 kg adult during walking and [B] illustration of peak body weight support, body weight support impulse, and duration extracted from each curve for the entire walk.

involving several authors (CM, KLB, TVW, JH). Mimicking clinical practice, the training was tailored to each individual, depending on how correctly they already used the cane; but it invariably involved instruction on cane height setting [23], two-point gait pattern [24], and the amount of force to be applied [7]. See Appendix A for training details. The cane was set to the height of the distal wrist crease when the participant was standing with their arms relaxed by their sides, to allow for 15-20° of elbow flexion [5,23]. The timing of cane placement was corrected as necessary to ensure that the cane first touched the ground at the same time or just before the affected leg. Conventional bathroom scales were used to demonstrate 10% body weight onto the cane in static standing. Scales was used during training to mimic what is feasible in clinical practice. Neither the physiotherapist nor the participant was aware of the real cane force data during walking. Participants were given 3–4 attempts with the scales until they felt confident about how much force to put through the cane. After the 10-minute training session, participants then repeated the 430 m outdoor walk at a self-chosen walking pace, using the instrumented cane set to the correct height, while force applied to the cane was again recorded.

2.5. Outcome measures

Force data were processed in custom Matlab code (Mathworks, Mass., USA). The applied cane force peaks (Newtons) associated with each ground contact phase were converted to percentage of body weight (BWS%) using each individual's body weight (Newtons). The average of all peaks, as well as the average BWS and force-time impulses (BWS.s) calculated from each force-time curve area (Fig. 2), during both outdoor walks were analyzed. The BWS impulse is essentially equivalent to the average cane force times the duration of force application on the ground. The duration of BWS was calculated each time the cane contacted the ground, and averaged. Additionally, the average timing of peak body weight support as a percentage of each force curve was calculated. The time and number of steps taken to complete the 430 m outdoor walks were recorded using a stopwatch and a manual counter, respectively. Average walking speed was calculated from the known distance and the time taken to complete the walk.

Table 1
Participant characteristics, presented as mean (SD) unless otherwise stated (n = 17).

Age, years	63.5 (7.9)
Sex, number (%)	4 (24)
Male	13 (76)
Female	
Body mass index, kg/m^2	28.5 (3.8)
Symptom duration, years	10.6 (7.0)
Symptoms, number (%)	1 (6)
Unilateral	16 (94)
Bilateral	
Numerical Rating Scale pain, score range 0-10	4.6 (2.3)
Average severity over past week overall	5.2 (2.3)
Average severity over past week while walking	
WOMAC Index	7.6 (2.8)
Pain, score range 0–20	27.3 (13.4)
Physical function, score range 0-68	

WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index. Higher scores indicate greater pain and greater functional impairment.

2.6. Statistical analysis

Stata Statistical Software (v14.1) was used for statistical analysis. We aimed to detect a moderate training effect size of 0.4 for peak BWS. Using power of 80%, an alpha level of 0.05 and correlation between measurement on the same individual of 0.875, a sample of at least 15 participants was required. Descriptive analyses were performed, including means, standard deviations (SD), 95% confidence intervals and frequencies as appropriate. Biomechanical data were assessed for normal distribution by inspection of Q-Q plots and using Shapiro-Wilk tests. Wilcoxon signed-rank tests and paired t-tests were performed to examine the change in variables before and after training, as appropriate. McNemar chi-square test compared the proportion of participants who placed at least 10% peak BWS before and after training. Pearson correlations were used to evaluate relationships between symptoms (NRS pain during walking and WOMAC physical function) and measures of BWS before training. Statistical significance was set at $p < 0.05$.

3. Results

Seventeen people participated in this study. The cohort had a mean age of 63.5 years and most were female (76%). Overall, participants had mild-to-moderate symptoms and the majority (94%) had bilateral knee pain (Table 1). Participants used the cane on average 3.5 h per day (range 30 min. to 12 h) during the week before training. Ninety-four percent (16/17) had their cane set to the incorrect height, as inspected visually before training. Specifically, the criteria to determine this were ipsilateral shoulder elevation if cane is set too high or ipsilateral trunk lean if cane is set too low. Walking speed and step count were not significantly different before and after training. The mean (SD) and individual change scores (post-training minus pre-training) in peak BWS, average BWS, BWS impulse, along with timing related measures are presented in Table 2 and Fig. 3 respectively.

Immediately after training, there was a significant increase in peak BWS, average BWS and BWS impulse by 28%, 25% and 54% respectively ($p < 0.05$; Table 2). However, one participant was considered an outlier as all measures of BWS were two standard deviations from the mean. Following the removal of this outlier, the 19% increase in peak BWS ($p = 0.08$) and 16% increase in average BWS ($p = 0.06$) no longer reached statistical significance, but the 34% increase in BWS impulse ($p = 0.02$) remained statistically significant.

Before training, four participants achieved a BWS peak of at least 10% total body weight, and five participants achieved this 10% peak BWS after training. The proportion of participants achieving at least 10% peak BWS did not significantly change from before to after training ($p = 0.71$). Results from analysis including 17 participants indicated a 22% increase in the duration of cane placement on the ground from before training to after training ($p = 0.02$). The timing of peak BWS through the cane occurred at 51% force curve duration before training, and 53% after training ($p = 0.05$). There were no significant relationships between symptoms and peak BWS (pain: $r = 0.43$; $p = 0.09$; physical function: $r = 0.32$; $p = 0.21$), average BWS (pain: $r = 0.35$; $p = 0.35$; physical function: $r = 0.18$; $p = 0.48$), and BWS impulse (pain: $r = 0.23$; $p = 0.38$; physical function: $r = 0.14$; $p = 0.58$), before training.

4. Discussion

Our study aimed to describe peak BWS transferred through a cane in people with knee OA before training and to determine if measures of BWS improved following a brief, simple cane technique training session. We found an average peak BWS of 7.2% total body weight before training. Overall, 10 min of training increased measures of BWS and increased duration of cane contact with the ground. However, inspection of individual participant data suggests that only 29% (n = 5) of individuals in the study reached a peak BWS of 10% following training. Understanding the immediate effects of a brief training session on BWS through a walking cane in people with knee OA is helpful to facilitate the correct use of this recommended self-management strategy.

In this study, inexperienced cane users with knee OA offloaded a mean of less than 10% of their total body weight onto a cane prior to training. Previous research has demonstrated that offloading 10% of total body weight through a cane is equivalent to an average of 6.1% peak KAM reduction in people with knee OA [7], may be clinically relevant. Prior to their training session, participants achieved an average peak BWS of 7.2% of total body weight (range 4.1% to 12.1%; n = 4; ≥10% total body weight). This is less than the peak BWS of 9% reported by others [6] in cane users with knee OA with on average 10 years of cane experience. Following training delivered by a physiotherapist, the average peak BWS achieved by participants in our study increased to 9.3% of total body weight (range 6.4% to 19.8%; n = 5 reached at least 10% total body weight). Although these results

Table 2
Descriptive data relating to contralateral cane use, reported as mean (SD) (n = 17).

	Pre-training N = 17	Post-training N = 17	Mean difference (95% CI) [post training - pre training]	p-value
Walking speed (m/s)	1.21 (0.27)	1.18 (0.25)	−0.03 (−0.10, 0.04)	0.36
Step count	578 (92)	573 (77)	−5 (−22, 12)	0.55
Peak body weight support (%BW) †	7.2 (2.5)	9.3 (3.4)	2.0 (0.1, 4.1)	0.04
Impulse (%BW.s) †	2.4 (1.1)	3.7 (2.2)	1.3 (0.0, 2.6)	0.02
Average body weight support (%BW) †	4.7 (1.9)	5.9 (2.1)	1.9 (−0.7, 2.4)	0.04
Duration of BWS (seconds)	0.49 (0.14)	0.60 (0.16)	0.11 (0.02, 0.19)	0.02
Timing of peak BWS (% contact)	50.8 (7.9)	53.0 (7.5)	2.2 (−0.02, 4.4)	0.05

BWS = body weight support.
† Wilcoxon-ranked statistical tests performed.

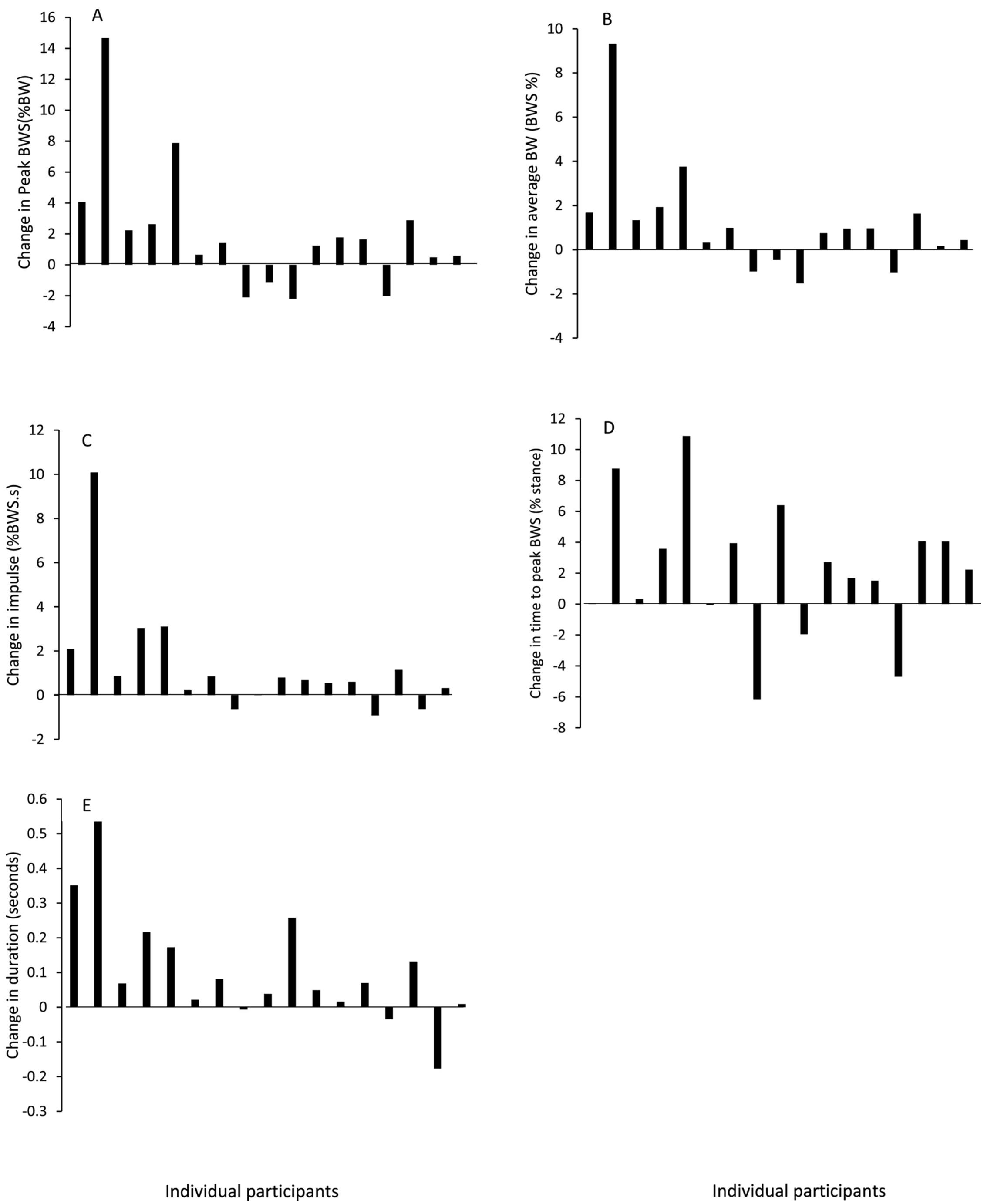

Fig. 3. Individual participant change scores (post-training minus pre-training) of peak body weight support [A], average body weight support [B], body weight support impulse [C], timing of peak body weight support [D] and duration of cane contact with the ground [E] before and after a short training session. BWS: body weight support; BW: body weight.

are similar to previous research [6], our data are likely influenced by the effect of one participant as the overall average improvement in peak BWS was less following the removal of the outlier participant (8.45% of total body weight). Sophisticated equipment may be required to provide feedback and achieve greater BWS. Previously, use of a vibrotactile force- feedback cane during walking increased BWS through a cane from 9% to 18% total body weight [6].

The average BWS increased post training by 25%, but average BWS increase was no longer statistically significant after removing the outlier. The BWS impulse, equivalent to the average cane force times duration of application, increased by 54% post training. This may be an increase in total duration of cane-ground contact by 23% following training. Notably, increased BWS remained statistically higher following the removal of the outlier. Research suggests that increasing BWS through a cane may by beneficial for knee joint loading, which has been related to the progression of bone and cartilage changes in the joint [7,15]. Our training provided slightly improved the BWS through a cane by increasing peak BWS, the BWS impulse, and the total duration of BWS. Future research is required to investigate the relationship between BWS through the walking cane and knee OA symptoms.

Contrary to our hypothesis, training did not significantly change the timing of the peak BWS through the cane. Previous studies suggest that peak KAM occurs at around 26% of the stance phase [7]. In our study, the timing of the peak in BWS occurred at approximately 50% of cane-ground contact. Theoretically, synchronizing the time of peak in KAM and the peak in BWS should result in the greatest reductions in knee joint loading. While we were not able to relate cane-ground contact directly to stance phase timing, the timing of peak BWS occurred slightly later in the cane-ground contact following training. It is possible that greater emphasis is required on early cane force application during stance in training, or that addressing both BWS magnitude and timing in one short training session was too much for participants to learn. However, to our knowledge no studies have evaluated the impact of synchronizing the peak in KAM and the peak in cane BWS, and so the clinical significance remains unclear.

This study had several limitations. First, although we powered our study to detect a moderate effect size in peak BWS, a clinically meaningful effect size in peak BWS is unknown. Second, the immediate effect of training was assessed using a pre-post design, without a control group. Hence our findings are considered exploratory. Third, the majority (94%) of our sample had bilateral knee OA and not necessarily medial OA. Thus, findings should be generalized with caution. Fourth, the cane manufacturer's instructions included some information about which hand to hold the cane in, the correct height of the cane and the timing of cane placement. This information might not be available to first-time users if a different cane was brought off-the-shelf or obtained elsewhere.

5. Conclusion

The results have shown that without training, cane users are offloading a mean of 7.2% of their total body weight during walking. A brief and simple training session by a physiotherapist increased body weight offloading immediately after training by on average 2.1% of total body weight. Further research is needed to determine the clinical implications of such an improvement and if a longer session, more frequent training sessions or the use of more sophisticated biofeedback result in a greater increase in body weight offloading through a cane.

Author contributions

JH, MH, TW, KLB conceived the idea for the paper. JH, CM and TW contributed to data acquisition. JH, MH and TW performed data and statistical analysis. JH and MH wrote the first draft of the article. All authors provided scientific input and revised the paper. All authors approved the final version of the manuscript.

Conflict of interest

None to declare.

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Appendix A. Walking Cane Training

1. Walking Cane Gait Pattern

Observation of the participant's natural walking pattern with the walking cane that was sent to them. This included looking at the height of the cane as well as their step width, step length, trunk lean characteristics and the timing of the cane to see if it was appropriate.

Cane timing was deemed inappropriate if

- The cane touched the ground too late
- The participant lifted the cane too soon before the stance phase of the affected foot had finished
- Steps were being skipped with no consistent cane placement through the cycle
- Any other reasons were noted down

No feedback was given to the patient at this stage.

2. Instrumented Walking Cane Walk: PRE-Training

The physiotherapist then exchanged the participant's walking cane for the instrumented walking cane in the laboratory. The instrumented cane height was matched with the participant's one and the participant then had up to 2 min practice in the laboratory prior to their outside walk.

The participant then walked 430 m around the block outside the laboratory with the instrumented cane and supervision. No prompting or feedback of gait was given.

3. Cane Training Inside Lab

The participants then underwent 10 min of training, covering

- Cane placement (2 min)
- Offloading technique (3 min)
- Training Body Weight Support (BWS) (5 min)

Instructions were based on the observation of the participants gait pattern

Cane placement included

- 2-point gait pattern
- Ensuring the cane touched the ground just before or at the same time as the affected leg
- Cane a little more than shoulder-width out and in line with the foot
- Cane could be placed at an angle on the ground to make it easier to offload the knee
- Keeping trunk upright

4. Cane Training Offloading Technique

Whilst the participant was conducting the correct cane placement technique they were then instructed to put weight through the cane with the goal of offloading their affected limb.

Additional prompts included

- Putting weight through the cane early
- Continuing to put weight through the cane while the affected leg was still in the stance phase

5. Training Body Weight Support

The participant was then taught to place 10% of their body weight through the cane. Ten per cent of the participant's body weight was calculated using a set of conventional bathroom scales. The participant then stood adjacent to the scales, put the end of the cane on the scales and practiced offloading 10% of their body weight through the cane.

They then walked an initial 2 lengths of the laboratory to replicate the amount of pressure through the cane. After this they could practice the 10% BWS another three times on the scales. They were instructed to maintain the 10% BWS whilst walking lengths of the laboratory (max 5 min in total).

Instructions were based on the observation of the participants gait pattern

Each participant was required to be able to perform the correct technique (per qualitative checklist see below) and without additional feedback for around 1–2 min. Specifically in the last minute the main program features (i.e. correct hand, timing of cane placement, trunk position) should be adequately performed.

Qualitative checklist

- Timing of cane placement – simultaneously on the ground or just prior to contact with the study limb on the ground
- Width of cane placement – placement should be at least 1 shoulder width apart and in line with foot of the study limb
- Step width/step length – should not vary from normal significantly, wide step and tandem gait discouraged
- Stance phase duration – encouraged not to prolong stance phase on the study limb while simultaneously using the cane
- Natural trunk lean – an increase in either direction will be discouraged
- Neutral wrist – midway between flexion and extension
- Hip extension – care given not to shorten stride lengths and maintain hip extension in terminal stance
- Knee flexion/extension – avoidance in keeping knee in sustained position through stance phase
- Upper limb motion – motion of the upper limb girdle including excessively increased scapular elevation or protraction will be discouraged

6. Instrumented Walking Cane Walk: POST-Training

Prior to the commencement of the Post-training walk the patient was instructed only once to incorporate the walking technique just learnt into their next walk. The participant then repeated the same 430 m walk around the block outside the laboratory with the instrumented cane and supervision. No further prompting was given.

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