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Comparison of upper limb muscle activity in four walking canes: A preliminary study

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Abstract--It is hypothesized that the cane and forearm can be aligned to reduce muscular activity needed during ambulation. In this prospective study, 10 nonimpaired control subjects were tested both in stationary and dynamic weight-bearing states while using different cane prototypes and the platform cane (PC) as compared to the standard cane (SC). The outcome measures were: 1) root mean square (RMS) voltage (μV) of electromyographic (EMG) signal as a measure of muscle power and 2) distance of ambulation. Results of stationary cane use showed that Prototype 1 decreased RMS output by 19 percent ($p=0.01$), Prototype 2 with wrist splint decreased it by 23 percent ($p=0.003$), and the PC decreased it by 68 percent ($p<0.0001$) as compared to the SC (ANOVA, posthoc LSM). In conclusion, the two prototypes and the PC significantly decrease RMS voltage muscle output in the upper limb, compared to the SC.

Key words: *biomechanics, cane, gait aid, upper limb.*

INTRODUCTION

There has been an increase in the number of patients diagnosed with musculotendinous, neuropathic, or arthritic conditions of the arms as a result of repetitive trauma. Walking canes have also been implicated in worsening these conditions. Thus far, literature on use of the cane has focused on decreasing the muscle exertion in the leg but not the arm (1-5).

The upper limb has not been well studied as a weight-bearing limb. In evolutionary terms, clawed quadripeds bore weight through the shaft of the long bones that served as pylons. The hand or foot was used simply as a springboard and balance device. Similarly, as infants, we crawl on our hands with our wrists extended, but always bear weight predominantly through the wrist rather than the hand. Gorillas bear weight through their knuckles. This assists in maintaining a neutral wrist alignment and allows continued weight bearing through the long-bone axis. In contrast, the human who uses a cane hyperextends his wrist when weight bearing, causing a malaligned vector of force through the hand at the level of the metacarpal bones. This creates torque about the wrist joint. Any person who has temporarily required the use of a cane or crutch knows the discomfort involved. It is well documented that chronic cane or crutch use leads to repetitive stress disorders such as tendinitis, carpal tunnel syndrome, and osteoarthritis (6-8). Unfortunately, many people with arthritis are already at risk for these problems due to their inflamed joints (9-11). For patients with carpal tunnel syndrome, Gelberman, et al. has shown that hyperflexion or extension of the wrist can lead to increased intracarpal wrist pressures (12).

The basic design of the cane has not changed over time. People with arthritis continue to be issued crook-shaped aluminum or wooden canes, with their only adaptation being height adjustment. For the occasional cane user, this may be adequate; however, for a person with painful hand and wrist problems, daily use of a simple cane over several years to decades may be deleterious. Consequently, patients may opt to sit in a wheelchair, which leads to further physical deconditioning and joint contractures and may preclude future attempts to regain the ability to walk, decreasing the person's access to environment and work. It is the goal of this project to help these patients avoid this spiral of disability through a redesign of the cane and the forearm crutch.

The specific hypothesis is that a prototype cane can be made to decrease muscle voltage output in the upper limb during static and dynamic weight bearing.

METHODS

Experimental Design

The project was a prospective study comparing the standard cane (SC) to the platform cane (PC) and two cane prototypes, in which each of the 10 nonimpaired subjects served as his/her own control. Inclusion criteria were healthy male and female subjects aged 18 to 65; exclusion criteria were cardiopulmonary and neurocognitive disorders. Informed consent was obtained according to the rules of the local institutional review board and OSHA regulations. Confidentiality was maintained throughout the study.

Protocol

Stationary Measurements of Cane Prototypes All canes were adjusted to the height of the individual; that is, from floor to femoral head (13). The subject was asked to weight bear maximally on the cane with his right arm against a force gauge (Newtons). Seventy-five percent of maximal force was used as the subject's individual load. This load was constant throughout the testing of the different canes. The foot-flat stage of gait was used for this portion of the study.

Metal surface disc EMG electrodes (Ag/AgCl, 1 cm) were coated with electrode gel and taped to the skin overlying the following muscles: infraspinatus (IS), rhomboid, latissimus dorsi (LD), biceps, triceps, deltoid, brachioradialis (BR), extensor carpi radialis (ECR), flexor carpi radialis (FCR), flexor digitorum profundus (FDP), flexor carpi ulnaris (FCU), and flexor digitorum superficialis (FDS). The active electrode was placed over the midpoint of the muscle belly and the reference electrode over the tendon. A 3-cm ground electrode was placed over the adjacent bony prominence.

The subject was then asked to bear weight for 4 s at 75 percent maximum load against a force gauge for each different cane tested. These included: the SC, Prototype 1 (P1: weight bearing on the heel of the hand), Prototype 2 (P2: weight bearing on the knuckles), and the PC. The sequence of the canes presented was randomized. Diagrams of these prototypes are shown in **Figure 1.** The first three of these were evaluated with and without wrist splints to determine whether this accessory were needed.

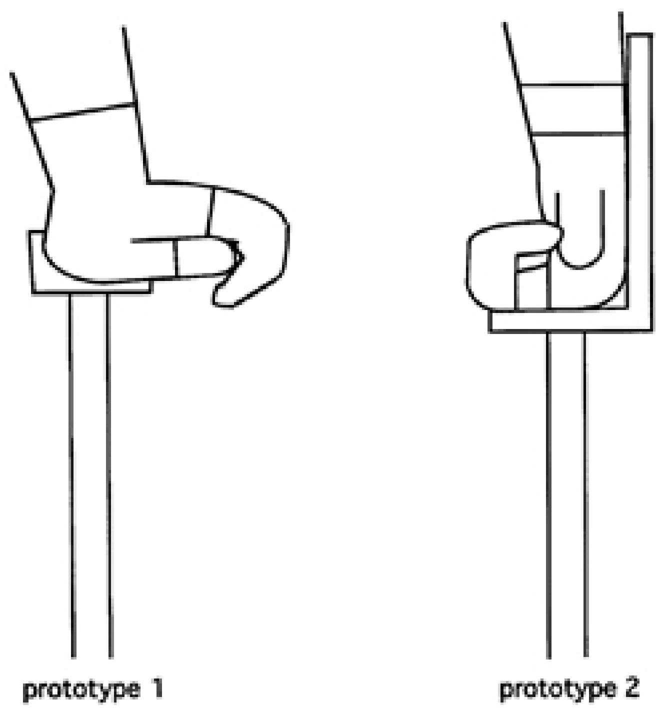

Figure 1.
Illustration of prototype canes used in this study.

The surface EMG signal was acquisitioned with a Viking IVD EMG instrument. The root mean square (RMS) value was measured in µV for each cane in a stationary postition. The RMS is accepted as a reflection of the muscle power (14). Settings for the EMG machine were a sweep speed of 20 msec/division and gain setting of 500 µV/division. The filter band pass was set at 10-

10,000 Hz. A 400 ms sample of EMG activity with average RMS voltage output (μV) was recorded to floppy disc and printed out for data analysis.

Kinetic Measurements of Cane Prototypes

To evaluate the effect of gait on the different cane prototypes, the subject was wired with telemetric surface EMG electrodes. Disposable electro-cardiogram surface electrodes with a 1-cm active recording area surrounded by a 1-cm adhesive ring (Blue Sensor, M-00-s, Medicotest, Olstykke, Denmark) were used for active, reference, and ground recordings. The electrodes were placed in active and reference pairs 4 cm apart on the following muscles: IS, LD, deltoid, biceps, triceps, ECR, FCR, FCU, and FDS. The ground electrode was placed on the elbow; all were connected to a waist pack that sent the telemetric signal to a receiving antenna on a preamplifier, after which it was processed by the telemetric EMG system provided by Noraxon, Inc. The voltage output of these eight muscles was displayed over eight individual channels on the EMG machine. Instrumentation was as described previously, except the gain setting was 1,000 μV/ division. The sweep speed was 100 pt/s. With this sweep speed, up to 14 full gait cycles can be recorded with each sampling.

The subject's left leg was placed in a knee-immobilizing brace to alter normal gait pattern, it having been previously shown by Diaz, et al. that use of a knee brace alters the EMG activity in the leg muscles (15). The subject was then tested with the SC, PC, P1, and P2 with wrist splint. The sequence of the canes tested was randomized. The subject's distance of ambulation after walking for 1 min was measured in feet. There was a 10-min rest period between ambulation with each cane to avoid fatigue.

Data Analysis

Statistical analysis for the experiments was performed using ANOVA with post-hoc least square mean (LSM) analysis. If the expected difference in measurement was 25 percent reduction in electromyogram RMS muscle voltage, a power analysis indicates that with alpha=0.05, beta=0.20, and power=0.80 or greater, n=10 subjects would needed for each experiment.

RESULTS

Static Measurements

There were four men and six women in the study. The average height (±SD) was 66(±3) in, average weight was 139(±31) lb. The age ranged from 24 to 46 yr, with a mean of 35(±8) yr.

Results showed a significant decrease in upper limb RMS output from static use, with and without wrist splint, of the SC (194 and 195 μV, respectively) to P1 (157 and 163 μV, respectively), the P2 (162 and 150 μV, respectively), and PC (64 μV: **Table 1, Figure 2**). Of the individual muscles examined, the biceps (p=0.004) and latissimus dorsi (p=0.026) muscles showed significant changes on the one-way ANOVA, on which several muscles showed borderline changes (**Table 2**).

Table 1.
Stationary surface electromyographic voltage recordings in weight-bearing upper limbs using walking canes.

Cane	RMS (μV ±SE)*	p value**
SC	194±14	--
SC***	157±14	0.935
P1	157±14	0.010
P1***	163±14	0.033
P2	162±14	0.027
P2***	150±14	0.003
PC	64±14	<0.0001

* Mean of all muscles tested; ** statistical analysis performed with one-way ANOVA (<0.0001) with post hoc pairwise comparison with Least Square Means (LSM); *** with wrist splint; SC=standard cane; P1=prototype 1; P2=prototype 2; PC=platform cane; values shown are in reference to the standard cane.

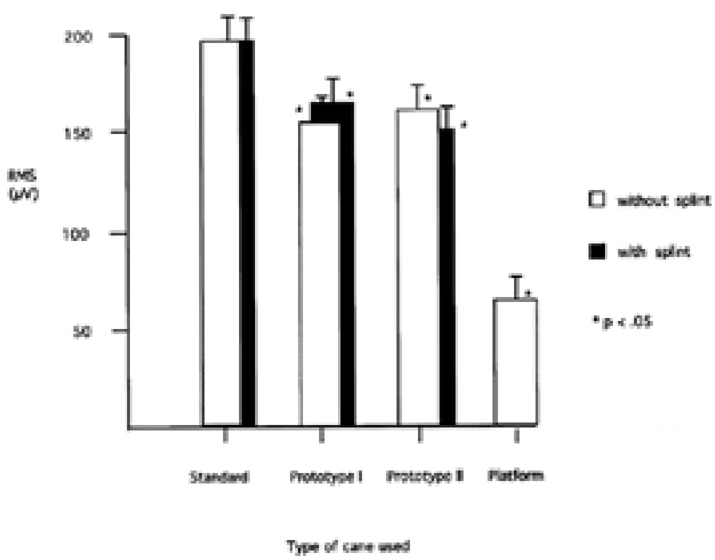

Figure 2.
Graph of **Table 1** displaying average stationary surface EMG voltage muscle output for the upper limb for each type of cane used in control subjects. * Indicates p<0.05, ANOVA with post hoc LSM analysis. Error bars indicate SE.

Table 2.
Stationary surface EMG voltage recordings in individual muscles using walking canes.

Muscle	p value*	Cane	RMS (µV) SC/ Listed	p value**
Biceps	0.004	PC	198/53	0.0001
LD	0.026	PC	179/97	0.001
BR	0.060	PC	301/64	0.002
		P2	301/160	0.05
		P2***	301/133	0.021
		P1***	301/157	0.053
Deltoid	0.330	PC	224/60	0.020
ECRB/L	0.092	PC	186/58	0.012
FCR	0.125	PC	161/50	0.009
FCU	0.184	PC	162/72	0.029
FDP	0.092	PC	178/70	0.007
FDS	0.082	PC	153/52	0.013
IS	0.481	PC	135/62	0.105
Rhomboid	0.268	PC	135/45	0.043
Triceps	0.075	PC	314/77	0.004

* ANOVA; ** pairwise comparison to standard cane; *** with wrist splint; SC=standard cane; P1=prototype 1; P2=prototype 2; PC=platform cane; LD=latissimus dorsi; BR=brachioradialis; ECRB/L=extensor carpi radialis brevis and longus; FCR=flexor carpi radialis; FCU=flexor carpi ulnaris; FDP=flexor digitorum profundus; FDS=flexor digitorum superficialis; IS=infraspinatus.

In this comparison, there was no significant difference in any of the canes with and without the use of wrist splints (**Table 3**).

Table 3.
Comparison of EMG voltage in subjects using canes with wrist splints versus using canes without.

Cane	p-value*
SC	0.935

P1	0.674
P2	0.419

* Statistical analysis performed with one-way ANOVA with post hoc pairwise comparison with Least Square Means; SC=standard cane; P1=prototype 1; P2=prototype 2.

As a result of this first study, it was concluded that P1, P2, and PC would be compared to the SC in the second part of the experiment.

Dynamic Measurements

Results of the second study showed that during ambulation there was a significant decrease in upper limb muscle voltage when using the PC (59 µV) as compared to the SC (79 µV: **Table 4, Figure 3**). There was no significant difference in the efficiency of gait among the four types tested (**Table 5**).

Table 4.
Dynamic telemetric surface EMG voltage recordings in weight-bearing upper limbs using walking canes.

Cane	RMS (µV ±SE)*	p value**
SC	79±55)*	--
P1	66±40)*	0.065
P2/w wrist splint	73±51)*	0.40
PC	59±40)*	0.005

* Mean of all muscles tested; ** statistical analysis performed with one way ANOVA (p=0.031) with post hoc pairwise comparison with Least Square Means. SC=standard cane; P1=prototype 1; P2=prototype 2; PC=platform cane; values shown are in reference to the standard cane.

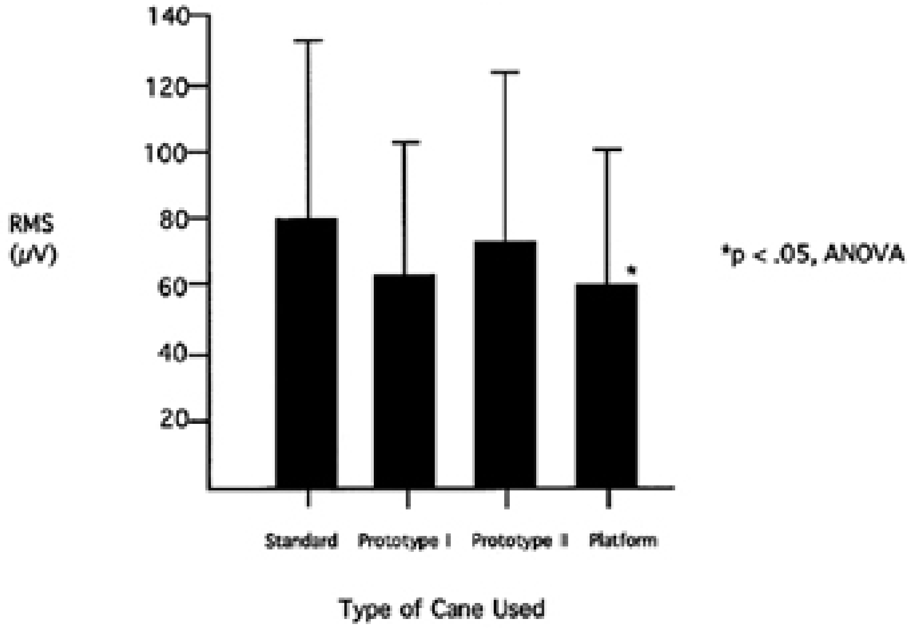

Figure 3.
Graph of **Table 4** displaying average dynamic telemetric surface EMG voltage output in upper limbs using different walking canes in control subjects. * Indicates p<0.05, ANOVA with post hoc LSM analysis. Error bars indicate SE.

Table 5.
Distance of ambulation during dynamic telemetric cane measurements.

Cane	**Distance (ft ±SE)**
SC	55±26)
P1	52±29)
P2	53±30)
PC	54±31)

Statistical analysis performed with ANOVA, repeated measures (p=0.619); SC=standard cane; P1=prototype 1; P2=prototype 2; PC=platform cane.

DISCUSSION

In this study, it was found that the three canes tested were more effective in decreasing the voltage output of muscles in the upper limb than was the SC during stationary weight bearing (**Table 1**). Therefore, we conclude that all three canes are an improvement over the SC with regard to muscle voltage output. It was interesting to note that the improvement occurred with proximal and distal muscles tested when using the PC, and with the brachioradialis in all three canes (**Table 2**). Although one would expect the PC to decrease energy output distally where the arm is immobilized, and increase proximally where muscle substitution would occur, this was not found to be the case. One possibility is that the upper fibers of the trapezius muscle may be responsible for the increased effort, but this muscle was unfortunately not included in the study. A second observation is that the BR muscle activity was decreased in all three canes relative to the SC. This is likely due to the fact the wrist-cane junction was stabilized in all three canes, thereby decreasing the work by the BR in swing through, and possibly increasing the work on the anterior deltoid muscle.

It is interesting to note that there was no significant difference in use of any canes with or without wrist splints (**Table 3**). This suggests that the lessened muscle activities were derived, not from stabilization of the wrist joint, but of the lessened demand for stabilizing the wrist/hand to the cane. It is also important to note that none of the three canes tested decrease the efficiency of gait relative to the SC (**Table 5**). This is in contrast to the subjective perception of many patients, who feel that the PC impairs their speed of gait.

Finally, it is important to note that the PC decreases muscle voltage output dynamically as well as statically. This may be reflected in the long run by increased patient endurance and therefore enhanced level of function as a result. This would need to be tested with patients in the future, however. It is important to note that the prototype canes do not increase the amount of muscle voltage more than the SC dynamically.

Limitations of Study

The limitations of the study are use of surface electrodes, possible electrode movement, training effect, and individual variability. While their use limits the representation of deep muscles, we employed surface electrodes for both portions of the study for greater consistency: fine wire electrodes were not available for dynamic recordings with the Noraxon system.

The possibility of electrode movement was minimized in the static portion of the test by limiting the movement of the subject and by fixing the position of the electrode while changing canes. In the dynamic portion of the study, snap-on electrodes similar to those found in Holter monitoring were used to allow some electrode movement without affecting the recording.

The training effect was minimized by asking each subject to practice using the cane until a level of comfort had been reached. The time it took to learn how to use each cane varied from individual to individual and cane to cane. Each training session was followed by a rest period of 10 min before testing began.

Individual variability from differences in size and strength of the subjects led to the large SE noted. Because each subject served as his/her own control in the ANOVA, the variability was accounted for.

SUMMARY

In conclusion, this study showed that the two prototype canes and the PC decrease muscle voltage output in the upper limb during weight bearing. They do not increase muscle voltage dynamically; in fact, the PC decreases output. The wrist splint is probably not needed since this was not shown to decrease muscle output. Futher studies are underway to examine the effect of these canes on muscle voltage output.

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