REVIEW ARTICLE

Assistive Devices for Balance and Mobility: Benefits, Demands, and Adverse Consequences

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ABSTRACT. Bateni H, Maki BE. Assistive devices for balance and mobility: benefits, demands, and adverse consequences. Arch Phys Med Rehabil 2005;86:134-45.

Objectives: To provide information on the advantages and possible disadvantages of using canes and walkers.

Data Sources: English-language articles were identified by searching MEDLINE and PubMed (1966–May 2003) for key words *cane* or *walker*, excluding articles unrelated to mobility aids. Bibliographies were reviewed and ISI Web of Science citation searches were run to identify additional references. Over 1000 articles were selected for further evaluation.

Study Selection: We extracted all studies of single-tip canes or pickup walkers addressing: (1) functional, biomechanic, or neuromotor benefits; (2) biomechanic, attentional, neuromotor, metabolic, or physiologic demands; and (3) falls, injuries, or other problems. We included approximately 10% of the articles originally identified.

Data Extraction: The methodology of each selected article, and findings relevant to the benefits, demands, or adverse effects of cane or walker use were summarized.

Data Synthesis: Findings were synthesized by considering their relation to basic biomechanic principles. Some biomechanic findings appear to support the clinical view that canes and walkers can improve balance and mobility for older adults and people with other clinical conditions. However, a large proportion of users experience difficulties, and the use of such devices is associated with increased risk of falling. A small number of studies have characterized some of the specific demands and problems associated with using mobility aids.

Conclusions: Clinical and biomechanic evaluations of canes and walkers confirm that these devices can improve balance and mobility. However, they can also interfere with one's ability to maintain balance in certain situations, and the strength and metabolic demands can be excessive. More research is needed to identify and solve specific problems. Such research may lead to improved designs and guidelines for safer use of canes and walkers.

Key Words: Accidental falls; Aging; Assistive devices; Canes; Gait; Posture; Rehabilitation; Walkers.

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MORE THAN 4 MILLION PEOPLE use canes and more than 1.5 million use walkers in the United States alone.[1-3] Such mobility aids are often required by older adults or by people with various clinical conditions so that they can move about independently and maintain their balance. In addition, these aids can help reduce lower-limb loading and thereby alleviate joint pain or compensate for weakness or injury. Mobility aids can improve balance control by providing mechanical advantages as well as somatosensory feedback. Conversely, some research indicates that mobility aids are significantly associated with falls and injuries. There are several attentional, neuromotor, musculoskeletal, physiologic, and metabolic demands associated with using these devices, and several potential mechanisms by which they may adversely affect balance control; however, the degree to which mobility aids actually contribute to causing falls has yet to be firmly established.

The purpose of this review was to examine the biomechanic principles and related literature about the advantages and the possible disadvantages associated with the most commonly used types of mobility aids: the single-tip support cane and the pickup walker (fig 1). Other types of aids, such as the 4-tip cane or rolling walker, have not been given as much attention in the literature. The reader is cautioned that the effects of using those types of canes and walkers may well differ in some significant ways.

METHODS

We identified English-language articles by searching MEDLINE and PubMed (1966–May 2003) for key words *cane* or *walker*; articles unrelated to mobility aids (eg, baby walkers, Dandy-Walker syndrome, Walker tumor) were excluded. Bibliographies were reviewed and ISI Web of Science citation searches were run to identify additional references. More than 1000 articles were selected for further evaluation. We then extracted all studies of single-tip canes or pickup walkers that addressed: (1) functional, biomechanic, or neuromotor benefits; (2) biomechanic, attentional, neuromotor, metabolic, or physiologic demands; and (3) falls, injuries, or other problems. Approximately 10% of the articles originally identified met at least 1 of the aforementioned criteria and were included. The methodology of each study was reviewed, and findings relevant to the benefits, demands, or adverse effects of cane or walker use were summarized. Findings were synthesized, primarily by considering their relation to basic biomechanic principles pertaining to postural stabilization, control of gait, and limb and joint loading. Table 1 summarizes subject characteristics and sample sizes for the studies that addressed specific biomechanic, neuromotor, or physiologic benefits or demands (ie, criteria 1 or 2). Many of the studies (see table 1) involved only healthy people with no mobility-related clinical conditions (13/36 studies) or people who were not experienced mobility-aid users (17/32 studies; information not provided in 4 studies), and many involved small numbers of subjects (≤10 subjects in 20/36 studies); therefore, the generalizability of the findings from specific studies may be limited.

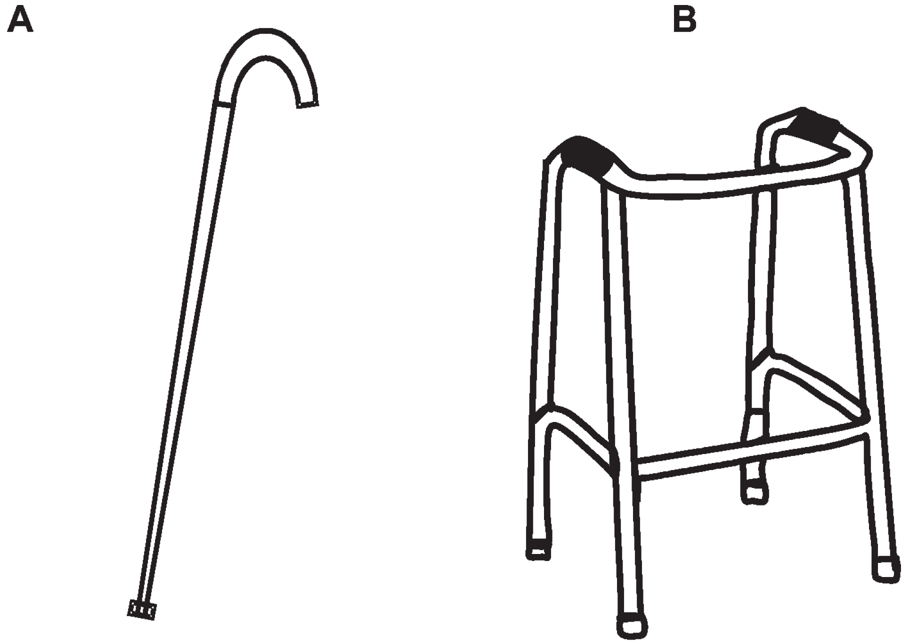

Fig 1. Schematic of the most commonly used types of cane and walker: (A) the standard support cane, which consists of a crooked handgrip, shaft, and single tip; and (B) the standard pickup walker (or walking frame), consisting of 4 posts (adjustable in height) and 1 handgrip for each hand. Support canes can vary in the design of the handgrip and base (eg, the 4-tip quad-cane); however, canes used by the visually impaired to assist in way-finding are different in design and purpose. Other types of walkers may have 2 or more wheels, handbrakes, and other features. Readers are directed to other articles[2,3,7,10,19,30] for descriptions of the various designs of mobility aids, as well as currently accepted clinical guidelines for the correct prescription and use of these devices.

Clinical Perspective

Reported clinical benefits. Canes and walkers are often prescribed to improve people's mobility and help them maintain balance while performing activities of daily living.[4-7] By decreasing weight bearing on 1 or both legs, mobility aids may also help alleviate pain from injury or clinical pathology (eg, hip fracture, arthritis), or compensate for weakness or impaired motor control of the leg (eg, from stroke).[6-9] Additional clinical benefits ascribed to cane use include the reacquisition of walking skills after trauma.[8] Generally, canes are prescribed for people who have a moderate level of impairment, whereas walkers are prescribed in cases of generalized weakness, extreme inability for lower-limb weight bearing, debilitating conditions, or poor balance control.[10]

Mobility aids have a direct physical and psychologic effect on the health of users. Mobility aids can increase older adults' confidence and feelings of safety, which, in turn, can raise their levels of activity and independence.[11-13] By enabling users to stand up and walk, mobility aids can also lead to physiologic benefits such as prevention of osteoporosis and cardiorespiratory deconditioning, enhanced circulation (venous return), and improved of renal function.[14] An additional psychosocial benefit is that the mobility aid may make it possible for older adults or people with other impairments to maintain their occupational skills.[15]

Clinical evidence for falls, injuries, and other problems. Clinical observation and empirical evidence indicates a high prevalence of disuse and abandonment of mobility aids among older adults.[11,12,16] Studies show that 30% to 50% of people abandon their device soon after receiving it.[16] Furthermore, surveys indicate that almost half of the reported problems associated with cane or walker use fall under the category of "difficult and/or risky to use."[2,3] Such high rates of disuse and/or dissatisfaction raise questions about the devices' effectiveness. Inappropriate device prescription, inadequate user training, or use of unprescribed devices may exacerbate the problem.[17-21]

Problems reported in the clinical literature include discomfort, pain, and injury. The repetitive stresses on upper-extremity joints resulting from chronic cane or walker use can contribute to pathologies such as tendonitis, osteoarthritis, and carpal tunnel syndrome.[22-25] People with arthritis, who often use canes or walkers to reduce weight bearing on their legs, are at particularly high risk of developing joint inflammation resulting from repetitive forces.[26,27] In a study of long-term poliomyelitis patients, the prevalence of upper-limb pain was 64% and this was strongly associated with the use of mobility aids.[28] Upper-limb loading can even lead to fracture, as evidenced by a case report of scapular-body stress-fracture that occurred with extensive cane use after a total knee replacement.[29] It has also been suggested that selection of an improper mobility aid may contribute to the development of a disability because of the potentially excessive forces placed on the body.[30]

The relation between mobility-aid use and risk of falls is less clear. Several studies have found that use of a mobility aid is a prospective predictor of increased risk of falling in older adults[31-34] or is associated with falls and related injuries.[35-41] Although some have suggested that use of a mobility aid may simply be an indicator of balance impairment, functional decline, and/or falling risk,[33,42] others have argued that use of the devices may actually increase risk of falling by causing tripping or by disrupting balance control through other mechanisms (eg, by competing for attentional resources).[2,3,31,43]

Table 1: Summary of Biomechanic, Neuromotor, and Physiologic Studies

Study	Clinical Condition	Sample	Aid User	Age Range (y)	Mean Age ± SD (y)	Aid Tested	Task	Main Focus
Anglin et al[89,93]	None	3M, 3F	No	51–64	55±NA	C	Walk	L
Ashton-Miller et al[53]	Peripheral neuropathy	5M, 3F	No	52–78	66±8	C	SP	B
	None	4M, 4F	No	50–80	65±9			
Bachschmidt et al[95]	None	4M, 3F	No	NA	28±8	W	Walk	L
Baruch and Mossberg[106]	None	25F	No	60–80	68±5	W	Walk	P
Bateni et al[49]	None	5M, 5F	No	22–27	23±NA	C, W	SP	B
Bateni et al[50]	None	8M, 8F	No	23–34	27±NA	C	SP	B
Bennett et al[6]	Severe hip-joint pain	9M	Yes	31–76	54±15	C	Walk	G, L
Brand and Crowninshield[9]	Total hip reconstruction pre- or postoperative	24(M/F?)	17 No 7 Yes	47–80	NA	C	Walk	L
Chen et al[54]	Hemiplegia from stroke	14M, 6F	Yes	42–62	58±7	C	Walk	G, L
Chiou-Tan et al[99]	None	4M, 6F	No	24–46	35±8	C, O	Walk	L
Deathe et al[81]	Unilateral AK or BK prosthesis	7M, 4F	Yes	NA	65±16	W	Walk	G, L
Edwards[87]	Hip or knee replacement pre- or postoperative	4M	Yes	41–78	61±15	C	Walk	G, L
Ely and Smidt[58]	Hip disease or arthroplasty	15(M/F?)	NA	NA	56±NA	C	Walk	G, L
Engel et al[8]	Fracture, vascular disorder, or unilateral BK prosthesis	15M, 15F	NA	18–60	NA	C	Walk	L
	None	5M, 5F	No	18–60	NA			
Fast et al[92]	Various gait dysfunctions	5M, 7M	NA	24–90	63±22	W	Walk	G, L
Foley et al[102]	None	3M, 7F	No	50–74	60±8	C, W, O	Walk	P
Hamzeh et al[107]	Unable to ambulate without aid	9F	Yes	67–91	81±NA	W, O	Walk	P
Holder et al[104]	None	9F	No	NA	29±3	W, O	Walk	P
Ishikura[64]	None	15M, 15F	No	NA	22±3	O	Walk	G, L
Jeka et al[68]	Congenitally blind	3M, 2F	No	19–44	NA	C	S	B
	None	4M, 1F	No	20–40	NA			
Kuan et al[48]	Hemiplegia from stroke	10M, 5F	Yes	32–73	57±11	C	Walk	G
	None	2M, 7F	No	52–68	61±NA			
Lu et al[52]	Hemiplegia from stroke	10M	Yes	44–66	59±7	C	S, Walk	B, G
Maeda et al[70]	Visual impairment	11M, 33F	NA	NA	79±7	C	S	B
	None	9M, 30F	NA	NA	76±7			
Maeda et al[71]	Hemiplegia from stroke	21M, 20F	NA	NA	70±8	C	S	B
	None	15M, 21F	NA	NA	72±7			
McBeath et al[101]	None	5M, 5F	No	22–32	NA	C, O	Walk	P
Melis et al[65]	Incomplete spinal cord injury	7M, 3F	Yes	24–72	41±24	C, W, O	Walk	G, L
Mendelson et al[57]	None	7M	No	23–50	33±10	C	Walk	G, L
Milczarek et al[51]	Hemiparesis from stroke	8M, 6F	Yes	26–74	60±13	C, O	S	B
Murray et al[5]	Various unilateral disabilities	53M	Yes	32–77	56±NA	C	Walk	L
Neumann[61,62]	Unilateral hip replacement	15M, 9F	No	40–86	63±11	C	Walk	G, L
Pardo et al[56]	Unilateral AK prosthesis	1M	Yes	45	45	W	Walk	B, L
Pardo et al[91]	Uni-/bilateral AK/BK prosthesis	3M, 3F	Yes	57–76	66±6	W	Walk	L
Pugh[103]	Hip replacement, preoperative	1M	Yes	64	64	W, O	Walk	P
Waters et al[105]	Rheumatoid arthritis, pre- and postunilateral knee replacement	49 (M/F?)	19 No 30 Yes	NA	54±16	C, W, O	Walk	P
Winter et al[94]	None	1M	No	24	24	C	Walk	L
Wright and Kemp[43]	None	5M, 5F	No	22–49	31±8	W, O	Walk	G, N

Abbreviations: AK, above-knee amputee; B, balance; BK, below-knee amputee; C, single-tip cane; F, female; G, gait; L, loading (device or limbs); M, male; N, neuromotor or attentional demands; NA, data not available; No, did not use mobility aid in daily life; O, other types of mobility aid; P, physiologic or metabolic demands; S, standing; SD, standard deviation; SP, standing on moving platform; Walk, walking; W, pickup walker; Yes, used mobility aid in daily life.

Biomechanic and Neuromotor Benefits

Biomechanic stabilization. Balance involves regulating the position and motion of the body's center of mass (COM) with respect to the stability limits defined by the base of support (BOS).[44-46] To achieve static postural equilibrium (ie, no net force acting on the body), the COM must be positioned over the BOS. Postural instability (loss of balance) can result when the COM is displaced in relation to the BOS because of volitional movement or external perturbation (eg, slips, trips, pushes). Use of a mobility aid increases the BOS[7,47] and thereby allows a greater range of COM motion to be tolerated without loss of stability (fig 2). The effect can be particularly

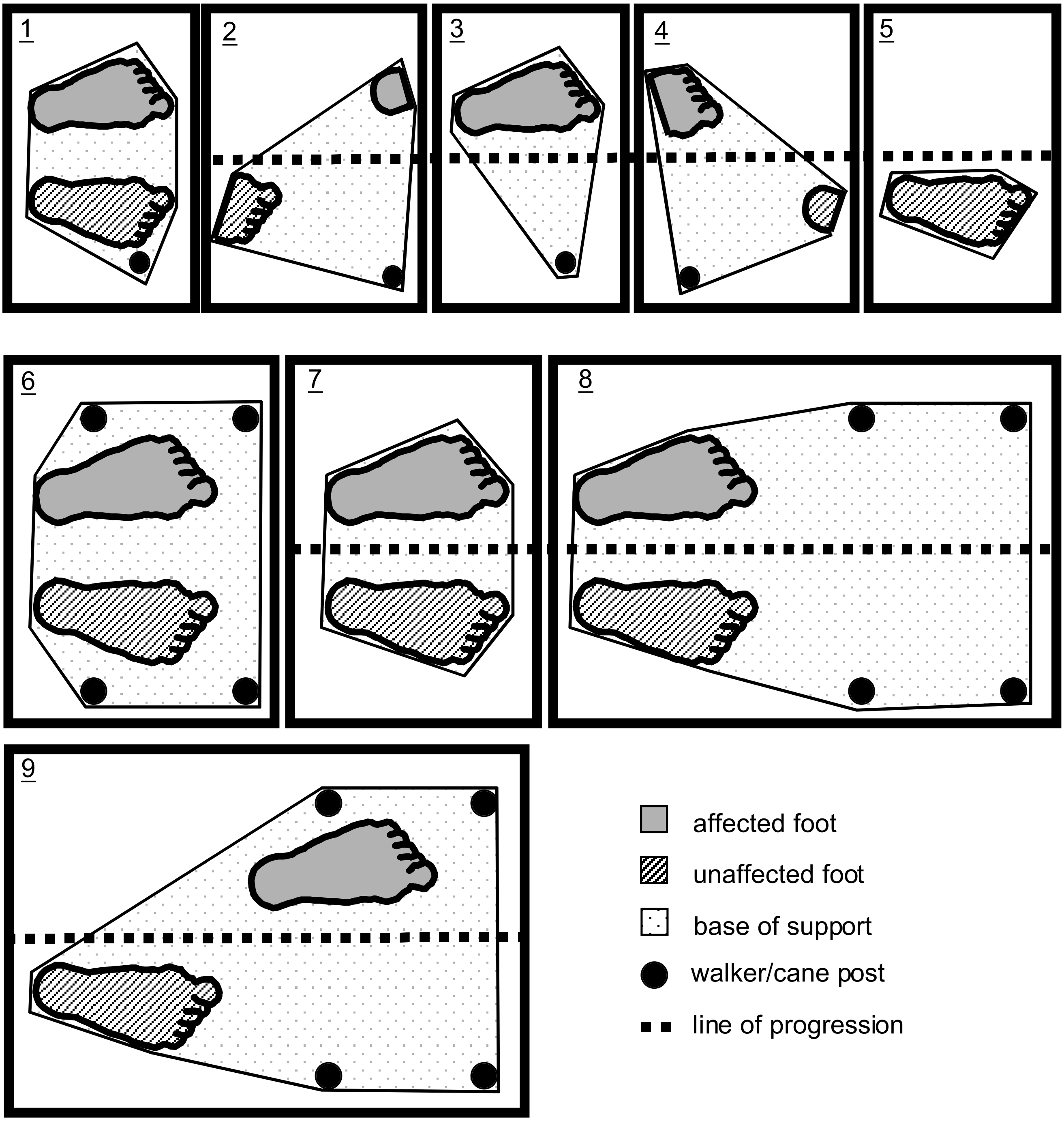

Fig 2. Schematic illustrating how use of a cane or walker can increase stability by increasing the effective size of the BOS during stationary stance and during ambulation. Panels 1 to 5 depict use of a cane (cane held contralateral to the affected limb): (1) stationary stance with cane support; (2) triple support, with cane used to generate braking force; (3) affected limb and cane in contact with ground and sound limb in swing; (4) triple support, with cane used to generate propulsive force; and (5) sound limb in stance and affected limb and cane traveling forward. Panels 6 to 9 depict use of a walker (step-to gait pattern): (6) stationary stance with walker support; (7) walker lifted to be placed ahead; (8) walker placed on the ground; and (9) step with affected leg completed (completion of the gait cycle, by taking a step with the sound limb, results in the configuration depicted in panel 6).

dramatic during the single-leg support phase of gait. By expanding the BOS, the mobility aid potentially allows the user to keep the COM within the BOS limits for a greater proportion of the gait cycle. Mobility aids can also contribute to biomechanic stabilization by allowing stabilizing reaction forces to be generated at the hands. By helping to control the motion of the COM, these reaction forces can help users prevent instability and recover equilibrium if instability does occur (fig 3). For example, in hemiparetic gait, these forces can reduce lateral instability by helping to shift the COM toward the sound

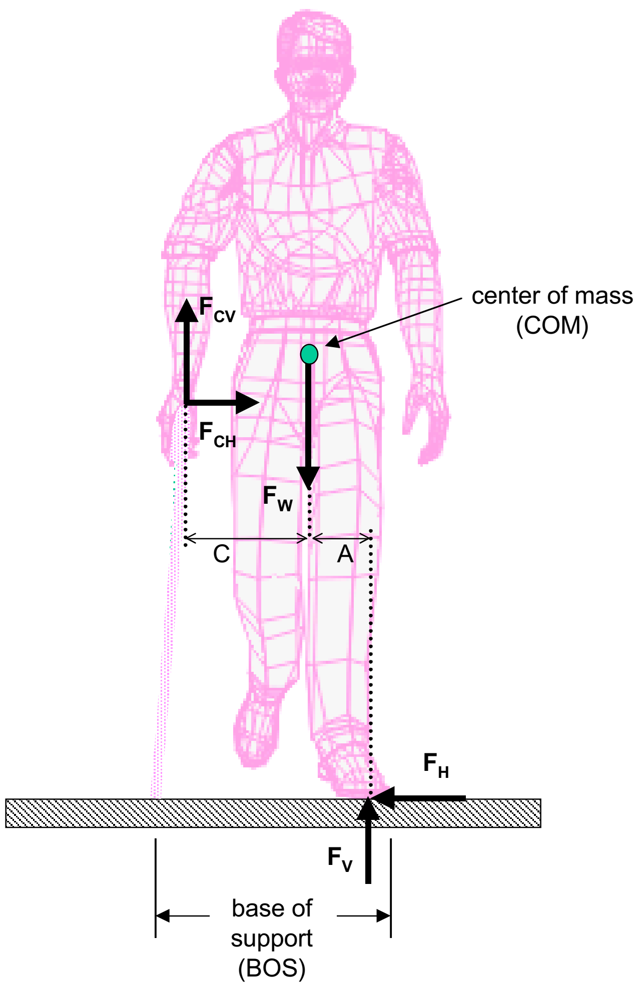

Fig 3. Schematic illustrating how use of a cane can increase stability by allowing a stabilizing hand reaction force (with components F_{CV} and F_{CH}) to be generated. During single-leg support, the body weight creates a destabilizing moment ($F_W \times A$) with respect to the supporting foot that causes the COM to fall toward the unsupported side. F_{CV} and F_{CH} act to oppose the downward and lateral COM motion. Moment $F_{CV} \times (C+A)$ acts to oppose the rotational motion of the body. In addition, as seen in figure 2, the cane allows a greater range of COM motion to be tolerated without loss of equilibrium by increasing the effective size of the BOS. Finally, note that the loading of the cane can reduce the vertical ground reaction force acting at the supporting limb ($F_V = F_W - F_{CV}$ if the body is static).

limb.[48] Use of a cane or walker to rapidly generate stabilizing force in reaction to externally applied balance perturbations was recently demonstrated in healthy young adults by Bateni et al.[49,50]

Empirical evidence that a cane provides biomechanic stabilization is found in several studies, although enhanced somatosensation may have also contributed (see Augmentation of Somatosensory Cues section). In terms of controlling standing balance, cane use led to a reduction in center of pressure (COP) displacement in studies involving 24 stroke patients.[51,52] Ashton-Miller et al[53] found that with use of a cane, 8 patients with peripheral neuropathy improved their ability to maintain equilibrium while transferring from a bipedal to a unipedal stance on an unsteady surface that was controlled to tilt during the weight transfer. A report that 15 stroke patients who used a cane had increased step length and decreased step width, in comparison to the unaided gait of 9 age-matched healthy control subjects,[48] may also indicate a stabilizing effect from use of a cane; however, interpretation of these results is confounded by other factors (eg, slower cadence in stroke subjects). The duration of cane loading during the gait cycle can vary widely,[5] and is likely an important factor that affects stabilization. In a study in which 15 stroke patients walked with and without a cane, Kuan et al[48] found that cane use did not change the duration of single-leg support (21%–23% of the gait cycle for the affected limb, 30% for the sound limb); however, Kuan did not identify the duration of the most unstable phase (ie, where the cane and 1 foot were both lifted). Chen et al,[54] in a study of cane-assisted gait in 20 stroke patients, defined this latter interval as the "single-support" phase and found that it comprised 9.8% of the gait cycle for the sound leg and only 0.2% for the affected leg, whereas "double-support" (both feet, or cane and 1 foot) and "triple-support" (both feet and cane) phases comprised 52% and 40% of the gait cycle, respectively. In comparison with those results, each single-leg support phase in normal unaided gait comprises about 40% of the gait cycle and the duration of double support is limited to about 20% of the gait cycle.[55]

Although there are little quantitative data available, one would expect a walker to have even greater potential than a cane to increase postural stability. A walker greatly enlarges the BOS (fig 2) and eliminates the challenge of balancing solely on 1 leg. The walker can be advanced during double-leg support, and the extended BOS it provides potentially allows either swing foot to be lifted and advanced while maintaining the COM in a stable position with respect to the BOS limits. A walker also aids stabilization by allowing large stabilizing hand-reaction forces and moments to be generated bilaterally. The Walker User Risk Index (WURI) developed by Pardo et al[56] actually quantifies, at any given time, the proportion of the total required stabilizing sagittal-plane moment (computed in relation to the ankle axis) that is contributed by the hand-reaction forces and moments generated at the walker. (The total required stabilizing moment is defined, at any given time, as the product of the body weight and the horizontal distance between the body's COM and the ankle axis.) In pilot tests with a 45-year-old above-knee amputee, Pardo found that the walker provided a large proportion of the moment required to stabilize the body during ambulation, with the WURI ranging from about 30% to 50% during advancement of the prosthetic leg, to about 100% when standing on the prosthesis and advancing the other leg. In support of the stabilizing benefits associated with walker use, Bateni[49] found that 10 healthy young adults were able to recover equilibrium without stepping in a larger proportion of trials when using a walker, in responding to large lateral moving-platform perturbations. The change in the proportion of trials involving stepping was, however, modest ($\approx$10%). Apparently, no other studies have quantified the effect of walker use on the control of reactions to balance perturbations nor have other studies addressed the effects on the control of balance during unperturbed stance or locomotion.

Reduction of lower-limb loads. The reduction in loading of the lower limbs is an important benefit of cane and walker use, for example, in patients with weakness, injury, or joint pain in the lower limb.[6,8,9,57] By supporting a proportion of the body weight, a mobility aid can reduce the vertical ground reaction force exerted on the supporting leg in a static situation (fig 3). A study of people with hip disorders found that peak vertical limb loading is also reduced during ambulation when a cane is used.[58] However, changes in cadence and stride length

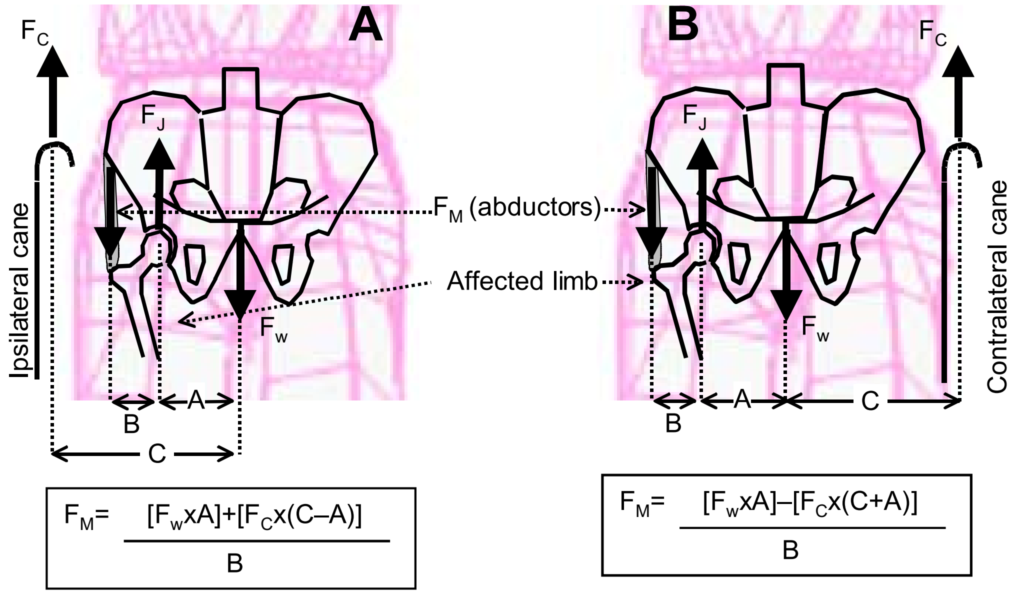

Fig 4. Effect of holding the cane (A) ipsilaterally or (B) contralaterally with respect to the affected (weakened or painful) limb during single-leg support. When the cane is held ipsilaterally, the moment about the hip joint due to the cane force ($F_C \times [C-A]$) actually acts to augment the moment due to the body weight ($F_W \times A$). This must be countered by the hip-abductor moment ($F_M \times B$); hence, the required hip-abductor force (F_M) must increase and so too does the joint reaction force ($F_J = F_M + F_W - F_C$). When the cane is held contralaterally, the moment due to the cane ($F_C \times [C+A]$) is larger and acts in the opposite direction, thereby diminishing the required hip abductor moment and hip joint reaction force.

may have influenced these findings. Unfortunately, the decrease in limb loading does not necessarily ensure a reduction in loading of the hip joint, which is often the clinical objective (eg, to reduce joint pain). This is because the load on the hip joint is heavily influenced by the hip-abductor muscle activity, and the required level of abductor activity is dependent on the side of the body on which the cane is held[4,58-62] (fig 4). Holding the cane on the side ipsilateral to the affected limb can actually increase the force on the affected hip joint, whereas holding it contralaterally reportedly reduces this hip force by up to 60%, compared with the joint loading that occurs in normal unassisted gait.[63]

The capacity to push against a stable frame and to generate large hand-reaction forces bilaterally when using a walker (see Upper-Limb Loading and Strength Demands section) would be expected to result in a much greater reduction in lower-limb weight bearing during ambulation, in comparison with using a cane. Ishikura[64] measured the peak lower-limb vertical ground reaction forces in 30 healthy young adults and found that the peaks that occurred during walker-assisted gait were substantially (nearly 50%) lower than during normal unassisted gait. What is not clear, however, is the extent to which the decrease in loading was a direct result of the support provided by the walker versus reduction in speed of ambulation, or use of a different gait pattern (eg, the "step-to" pattern; see fig 2) when using the walker. One would expect that the reported reductions in lower-limb weight-bearing could also help reduce the hip-joint reaction force; however, the effect of using a walker on hip-joint force has apparently not yet been quantified.

Propulsion and braking during gait. Using a mobility aid to generate horizontal ground reaction forces (fig 5) can help to provide propulsive and/or braking forces during gait and thereby augments the fore-aft component of the ground reaction force vector acting on the feet. This could benefit patients who have difficulty initiating or terminating movement because of pain, muscle weakness, or impaired motor control in the lower limbs, and could also help a patient achieve smoother and more efficient movement of the body during gait.[6,54,65] It appears that all research to date in this area has focused on canes.

Bennett et al[6] studied the anteroposterior (AP) cane impulse generated by 9 subjects with hip pain. The cane impulse was determined as the time integral of the AP ground reaction force with respect to time, which is equal to the resulting change in AP body momentum. The subjects applied propulsive impulses that were larger than the braking impulses. In contrast, Chen et al[54] found that 20 stroke patients tended to generate larger braking impulses. Chen concluded that the stroke patients relied primarily on the sound limb to generate propulsion and used the cane to help the affected limb decelerate the motion, whereas patients with hip pain tended to use the cane more to reduce the required joint forces when pushing forward with the painful limb. Ely and Smidt[58] adopted a different approach, using strain gauges to measure the bending moments applied to the cane during gait. They found that 15 subjects with hip disorders used the hand to apply a forward bending moment during the propulsive phase, but they acknowledged that the horizontal component of the axial cane force can probably make a much larger contribution to propulsion (compared with moments applied at the hand), provided that the cane is tilted forward (fig 5). Similarly, the horizontal component of the axial force can help in braking if the cane is tilted backward. In general, it appears that the capacity to use the cane to generate substantial propulsive or braking force is heavily dependent on the user's ability to hold the cane at an appropriate angle; however, it is not clear whether the subjects in the aforementioned studies were taught to use the cane in a particular manner or whether the pattern of use was learned through experience. This should be addressed in future studies.

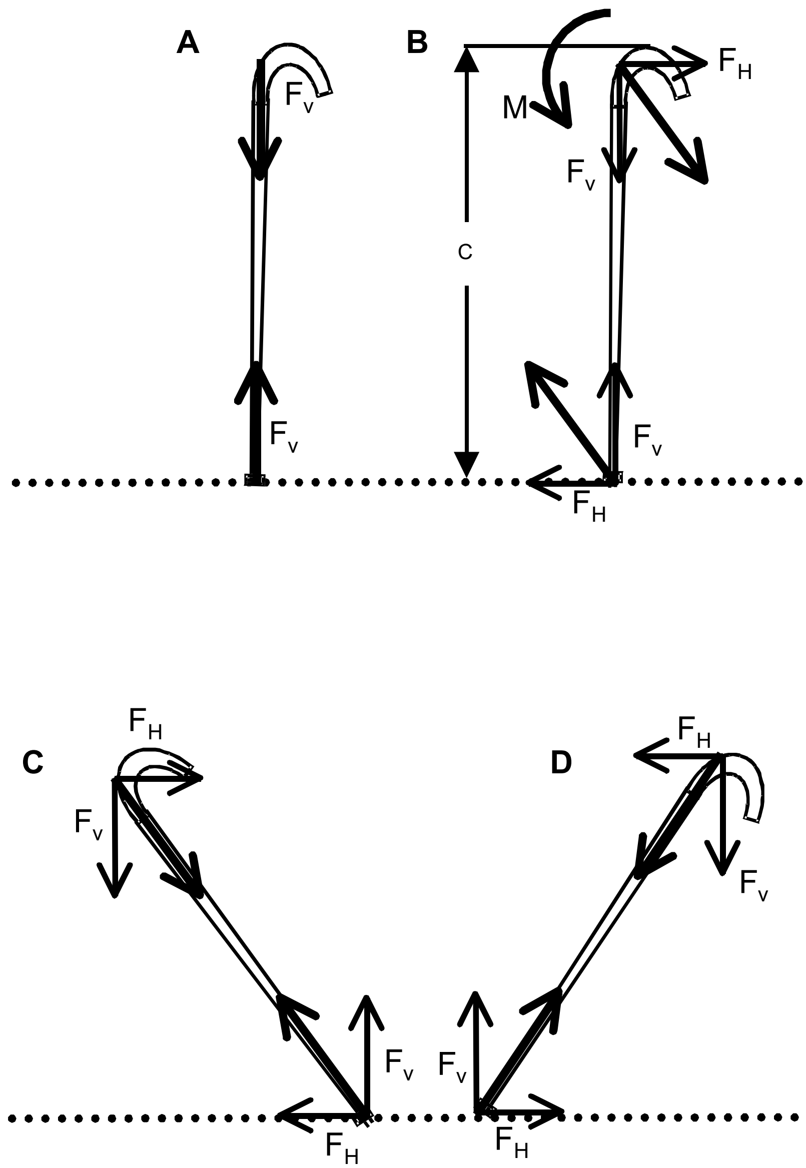

Fig 5. Free body diagram of a cane illustrating how the force and moment applied to the cane by the hand can generate a horizontal AP ground reaction force (F_H) that can provide (B, C) propulsion or (D) braking during gait. For simplicity, the weight and mass of the cane are assumed to be negligible. When the cane is vertical, it is necessary to exert a moment (M) at the hand to generate the propulsive force, as indicated in A and B (similarly, but not shown, a hand moment in the opposite direction would generate a braking force). However, because the hand can only exert a small moment, it is more effective to generate the propulsive or braking force by holding the cane at an appropriate angle (C, D).

Augmentation of somatosensory cues. For a person to maintain an upright posture, the central nervous system (CNS) requires information about the position and movement of the body segments with respect to an orientational frame of reference.[46] This information is acquired through the visual, vestibular, and somatosensory systems. Of potential relevance to mobility aids, Jeka[66] found that tactile somatosensory information from the hand (haptic cues) can contribute to postural stabilization. Light touch of the fingertip against an external surface significantly reduced COP displacement associated with the control of postural sway in 5 healthy adults aged 20 to 50 years.[67] The effect occurred with or without vision, although it was more pronounced when vision was deprived. Similar effects were demonstrated in 5 congenitally blind people[68] and in 5 subjects with complete bilateral vestibular loss.[66]

The contribution of haptic (tactile) cues from the hand to postural control suggests that mobility aids may be useful not only in creating biomechanic advantages, as outlined earlier, but also in providing additional spatial orientation information for CNS control of balance.[66,68] However, to date, most studies in this area have focused on the control of static stance using haptic cues derived from a stationary surface,[66,67,69] rather than simulating the more complex, dynamic situations that can occur when a mobility aid is used to provide the cues. Ongoing changes in the relative position and orientation of the body and mobility aid, during ambulation, could potentially affect the capacity of the CNS to utilize the haptic information. Jeka et al[68] studied the effect of haptic cues derived from a cane; however, Jeka's subjects maintained a static posture and the cane was held in a stationary position. Jeka's results indicated that touch contact of a cane at a very low force level was as effective as contact that involved much larger forces, in terms of stabilizing the postural sway, when vision was not available (in 5 congenitally blind persons and in 5 sighted subjects with closed eyes). Maeda et al[70,71] found that light touch of a cane had similar benefits, even when vision was not deprived, for 44 patients with visual impairment and for 41 stroke survivors, but the effect was less pronounced in 75 healthy older adults.

To our knowledge, the potential for walkers to provide haptic cues has not been studied. However, one might speculate that walkers could yield more effective haptic information than canes because walkers may provide a more consistent orientational reference (when in full contact with the ground). In addition, there may be further benefit from the fact that both of the user's hands are in contact with the device, although the influence of bilateral haptic cues on postural control has apparently not yet been studied.

Demands and Adverse Biomechanic Effects

Attentional and neuromotor demands. The safe and effective use of a cane or walker during ambulation or other activities requires an ability to lift and advance the device and to contact the ground in an appropriate location, in synchrony with the ongoing body movement, while avoiding inadvertent contact with the lower limbs and with animate or inanimate objects in the environment. There is also the need to accurately control the forces and moments applied to the device during ongoing movement or in response to loss of balance. One would expect these requirements to place significant demands on CNS resources related to attentional processing and neuromotor control. Unfortunately, little direct evidence is available to characterize the specific nature of the attentional and neuromotor demands associated with the use of mobility aids.

In what is apparently the only quantitative study to date in this area, Wright and Kemp[43] used a dual-task paradigm to characterize the attentional requirements of using a walker. They measured performance on an auditory reaction-time task, performed concurrently during ambulation, in 10 healthy young adults. The results showed that reaction time was delayed to a much greater degree when using a standard pickup walker, in comparison to walking with no mobility aid or using a rolling walker. These findings imply that use of the standard walker required considerable attention; however, further work is needed to determine the extent to which the effect was the result of the demands of adopting the step-to walker gait pattern versus the demands of accurately controlling the loading and placement of the walker. Furthermore, it remains to be determined whether experienced walker users would exhibit similar effects, and the effects of physical or cognitive dysfunction also need to be established.

The need to allocate cognitive resources to the control of the mobility aid is important in light of the increasing evidence that control of specific aspects of postural balance also requires attention and other types of cognitive processing.[72] Older adults, in particular, appear to experience reduction in postural stability while engaging in a concurrent activity that competes for the available attentional and cognitive resources.[72] In addition, it appears that the ability to respond rapidly to a postural disturbance is impaired in older adults because they are less able than young people to rapidly switch attention from an ongoing, attention-demanding task to the task of recovering balance.[73] On the basis of these findings, one could speculate that the attentional demands associated with the use of a mobility aid could well lead to impaired ability to maintain or recover balance in older people. In addition, it is possible that those attentional demands could lead to tripping and loss of balance by affecting one's ability to attend to obstacles or hazards in the environment.

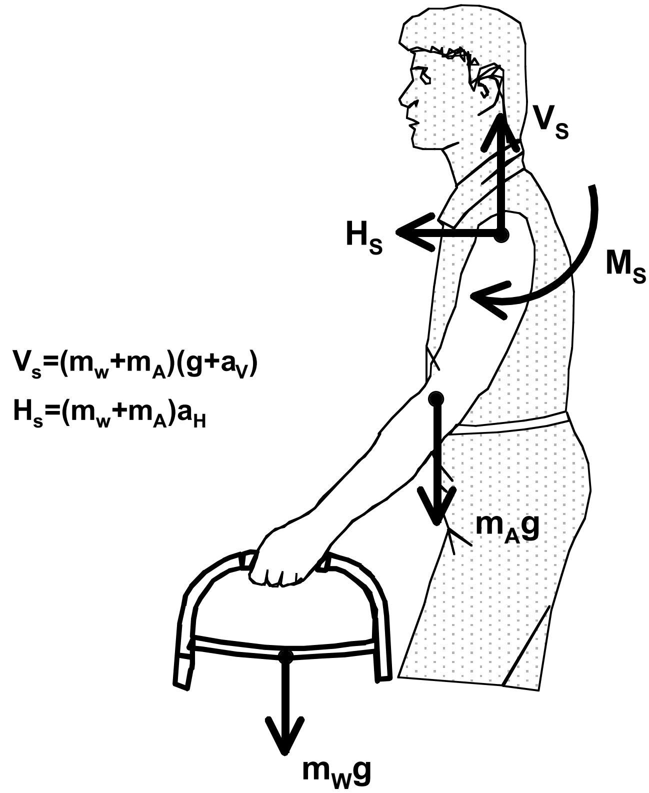

Fig 6. Free body diagram showing the forces and moments acting on the arms when lifting a mobility aid. M_S is the net moment generated by the shoulder musculature, H_S and V_S are the shoulder reaction forces, m_W is the mass of the walker, m_A is the mass of the arms, and *g* is the acceleration due to gravity. H_S and V_S will increase with the amplitude of the forward (a_H) and upward (a_V) walker acceleration, and will also increase with the mass of the walker. Note that the effect of the shoulder force and moment on the body is in the opposite direction: generation of the vertical force (V_S) required to accelerate the device upward and to support the static weight of the device induces a downward force on the body; the horizontal force (H_S) required to accelerate the device forward induces a backward force on the body; and the moment generated by the shoulder musculature (M_S) induces a counter-clockwise moment on the body.

Destabilizing biomechanic effects. Use of a cane or walker can potentially have a destabilizing biomechanic effect through several mechanisms. As a consequence of the weight and inertia of the arm and device, the act of lifting and advancing the aid creates reaction forces and moments at the shoulder that could potentially perturb the COM (fig 6), unless countered by anticipatory postural adjustments.[74-76] The biomechanic principles are the same as those described for rapid raising of the arm alone.[76] In lifting an aid, the arm movement is likely to be less rapid, and the reduced speed would tend to decrease the destabilizing effect; however, the added weight and inertia of the device could amplify the destabilization. To our knowledge, the degree to which the lifting of the device actually causes instability has not been investigated.

It is also possible that the act of lifting the mobility aid could lead to instability in the same way that lifting the foot can cause the COM to fall toward the unsupported side during unassisted gait. By suddenly reducing the BOS, lifting the device could create a state of imbalance in which the COM lies outside the BOS limits. Normally, during unassisted step initiation, an anticipatory postural adjustment acts to prevent instability by propelling the COM toward the stance limb before lifting the swing limb.[77,78] During unassisted steady-state gait, dynamic equilibrium is achieved by controlling the placement of the swing foot so that the new BOS established by each step recaptures the COM and reverses the lateral COM movement.[79,80] Presumably, similar mechanisms would act to regulate stability during assisted gait; however, control of the COM motion during assisted gait has not, to our knowledge, been studied.

Unexpected balance perturbation could arise if efforts to apply excessively large horizontal forces to a cane or walker cause the device to suddenly slip or, in the case of a walker, to tip over. Deathe et al[81] defined a Walker Tipping Index that reflects the fact that the tendency of the walker to tip increases with the magnitude of the applied horizontal force and with the height of the walker. The index also indicates how the walker is less likely to tip if there is an increase in either the applied downward force or the fore-aft distance between the walker posts.

Inadvertent contact between the mobility aid and objects in the environment can be yet another source of perturbation to the user's postural control. Many studies[32,33,35-39,41,82] have reported that mobility aids and/or environmental obstacles are associated with falls. To our knowledge, however, the possible link between these 2 risk factors has not been studied. Furthermore, it appears that walker-related injury can occur as a result of contact and/or "catching" of the mobility aid with environmental objects, such as carpets and doorframes, that would not normally be considered obstacles.[40]

Interference with limb movement during balance recovery. As described earlier, mobility aids have the potential to enhance postural stability, by increasing the effective BOS and allowing stabilizing hand-reaction forces to be generated. These forces help to control the COM motion by augmenting the stabilizing joint moments that are generated by rapid postural reactions at the ankle, hip, trunk, and neck.[83,84] However, in some situations, this may be insufficient to recover equilibrium, for example, if the postural perturbation is relatively large, or if the user cannot generate sufficient stabilizing hand forces or joint moments because of weakness or impaired neuromotor control. In such a situation, the only recourse is to alter the BOS by stepping rapidly or by reaching and grasping a handrail (or other structure) for support. These "change-in-support" reactions—compensatory stepping and grasping—are triggered automatically by the CNS and are prevalent and functionally important responses to instability[44,46,85,86]; however, there is reason to believe that using a mobility aid could interfere with the success of these reactions.

For compensatory stepping, the mobility aid could potentially impede lateral movement of the legs and thereby impair the capacity to execute compensatory stepping reactions during lateral loss of balance. Bateni et al[49] used lateral platform perturbations to study the effect a cane or walker has on one's capacity to recover balance by stepping laterally, in 10 healthy young adults. The results indicated that collisions between the swing foot and walker were frequent, occurring in more than 60% of stepping reactions. Although collisions were not as frequent when holding a cane, collisions with either device led to a significant reduction (26%–37%) in lateral step length when compared with no-collision trials. Typically, the tendency to push on the device in an effort to recover equilibrium appeared to preclude the possibility of lifting and moving the aid, either to avoid a collision or to reestablish a more stable BOS. This group of young adults was able to recover equilibrium despite the collision-related reduction in step length; however, it seems likely that aging or neuromotor impairment could lead to difficulty in coping with the consequences of a collision between the swing-foot and mobility aid, as well as increasing the frequency of such collisions.

Bateni et al[50] also studied how the CNS resolves the conflict in task demands if a mobility aid or other object is carried in the hand and there is a need to reach and grasp a handrail to recover balance. Forward or backward platform motion was used to perturb the balance of 16 healthy young adults while they held a cane, a "neutral" object (the top handle portion of a cane), or nothing at all. To prevent stepping reactions and force reliance on compensatory grasping, foot motion was constrained by barriers. Holding an object had a profound effect, reducing the frequency of efforts to contact the handrail by a factor of 2 or more, although the consequence of not grasping the rail often involved falling against a safety harness or barriers. Bateni concluded that the CNS prioritized the ongoing task of holding the object, even when it had no stabilizing value (eg, cane during backward loss of balance) or any value whatsoever (ie, cane top). This suggests that holding a mobility aid can potentially increase risk of falling in situations where it would be more effective to recover balance by grasping an external structure; however, it remains to be determined if people with impaired balance would behave in a similar manner.

Upper-limb loading and strength demands. Some indication of the upper-limb joint loading and strength demands associated with mobility-aid use can be inferred from measurements of the force applied to the device. Several studies have measured device loading during cane-assisted locomotion.[5,6,54,58,87-89] Most have found that cane users rarely place more than 15% to 20% of body weight on the cane,[5,58,89,90] but the cane loading likely depends on the nature of the disability.[54] The highest axial cane loads that have been reported (31% of body weight, on average) occurred in a study of 4 men requiring total knee or hip replacement (1 subject was tested preoperatively; 3 were tested at least 6mo postoperatively).[87] Another factor that may explain the variation in cane loading between studies is the walking speed. In 1 study of 20 stroke patients,[54] walking speeds were very low and the measured peak axial cane force was also low when compared with other studies. Although relatively few studies have examined walker loading, the reported forces are generally much higher than with cane use, ranging up to 85% of body weight in 7 patients who used a lower-limb prosthesis,[56,91] and up to 100% of body weight in 10 subjects with spinal cord injuries.[65] In contrast, a patient with progressive supranuclear palsy, who required a walker for balance rather than for weight support, generated much lower average walker loads when ambulating ($\approx$30% of body weight).[92]

A small number of studies have directly addressed the upper-limb joint loading and strength requirements associated with mobility-aid use. The data suggest that the joint forces may be very high when loading the device. Anglin et al[93] used a biomechanic model in 6 healthy adults aged 51 to 64 years to estimate the muscle forces acting at the shoulder and found that the glenohumeral contact force can reach up to 3 times body weight during cane-assisted gait. The estimated external moment at the shoulder from the cane loading was quite large, comparable with the moment required to lift a 10-kg suitcase.[89]

Using inverse dynamics to estimate the joint moments during cane-assisted gait in a single healthy young adult, Winter et al[94] found that substantial shoulder extensor, elbow extensor, and wrist adductor moments were required. Bachschmidt et al[95] used a similar approach to study walker-assisted gait in 7 healthy young adults, and concluded that this is a demanding task for the elbow extensors, as well as for muscles such as the wrist flexors and the shoulder flexors and adductors. Kinematic data indicating that the elbow is typically flexed and the wrist extended when using a cane or walker[22,89,95,96] also suggest significant demands on the elbow extensors and wrist flexors. Previous reports highlighting the key role played by the latissimus dorsi muscle in using a mobility aid[97,98] are consistent with the reported need to generate an adductor moment at the shoulder. Few studies have directly measured upper-limb muscle activation during mobility-aid use, but 1 such study did find that activation levels could be reduced by changing the design of the cane handle.[99]

Metabolic and physiologic demands. In a literature review, Fisher and Gullickson[100] concluded that use of a mobility aid is associated with an increase in the metabolic and physiologic cost of ambulation. However, it can be difficult to distinguish the effects of the disability from the demands related to use of the mobility aid, particularly if a person is unable to walk without using the aid. In addition, differences in walking speed, with and without the aid, may confound the comparisons. Furthermore, the effect of the mobility aid may depend on the specific nature of the pathology.

In 1 study,[101] 10 healthy young adults had an increase of up to 33% in oxygen cost (ie, consumption per distance traveled) when using a cane, even though walking speed was reduced. In contrast, a study involving 10 healthy older adults found that use of a cane did not alter oxygen cost or heart rate, in comparison with unassisted gait.[102] There was, however, an apparent decrease in walking speed when the cane was used. In a case study[103] of a 64-year-old subject before a hip replacement, use of a cane did not affect oxygen uptake or self-selected speed of walking, but did make it possible for the subject to walk for a longer period of time.

As with the cane, use of a walker increased oxygen cost despite lowered walking speed, in 9 healthy young adults.[104] A study of rheumatoid arthritis patients showed similar effects: 8 patients who used a walker had reduced walking speed and elevated oxygen cost compared with 17 patients who used no mobility aid (trends were similar but less pronounced in 8 patients who used a cane).[105] In a study involving 10 healthy older adults, walker use led to large increases in heart rate as well as oxygen cost despite a much slower walking speed, in comparison with both cane-assisted and unassisted gait.[102] Baruch and Mossberg[106] found that 3 minutes of walker-assisted ambulation led to large increases in heart rate in 25 healthy older women, and concluded that the cardiac demands may be excessive for older people. Use of a rolling walker, instead of a pickup walker, reduced the energy costs by 50% in 9 older women who were unable to walk unaided.[107]

Directions for Future Research

Although many of the functional benefits of cane and walker use appear to be well established, further research is needed to better characterize specific demands and adverse consequences of using these devices. The metabolic and physiologic demands have received considerable attention and device loading has been documented, but more study is needed to quantify the upper-limb joint loading and strength requirements. Furthermore, there is a great need for further research to characterize the neuromotor and cognitive demands associated with the use of these devices, and to identify the specific ways in which mobility aids can lead to loss of balance or interfere with balance recovery. Prospective clinical studies may also be helpful in identifying the underlying design problems, as well as behavioral factors (eg, how the device was being used) and environmental factors (eg, flooring, obstacles, lighting). It will be important, in future studies, to identify the specific needs and difficulties that may be inherent to mobility-aid users with specific types of physical and/or cognitive impairment. In laboratory studies, it will be important to control for confounding effects related to variation in factors such as device loading, walking speed, and experience with using walking aids.

CONCLUSIONS

There appears to be ample clinical evidence that canes and walkers can improve balance and mobility in older adults, as well as in patients with different clinical conditions. There is also supporting biomechanic evidence from a small but increasing number of studies, although many of the studies have been limited in sample size and/or control over confounding variables. Conversely, it has been established that a large proportion of mobility-aid users have difficulties using their devices and that use of such devices is associated with an increased risk of falling. Recent studies have characterized some of the demands associated with using mobility aids and have identified specific situations in which use of a cane or walker can potentially jeopardize stability, but it is clear that much more biomechanic and neuromotor research is needed in this area. Ultimately, we anticipate that such research may lead to more cautious clinical prescription practices, improved guidelines for using walkers and canes safely, and new and improved designs for safer and more effective mobility-aid devices.

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