Design and Test of Quad Cane Structure

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***Abstract*—Degradation of body function makes older adults move slowly; use a cane to share joints weight and eliminate the imbalance caused by sudden interference. Physicians do not recommend using two-handed assistive devices to ascend or descend stairs, and patients in good condition should use one-handed assistive devices. In addition to the lateral movement, the up and downstairs also include height changes. When the width of the ladder is limited, there is not enough space for the cane base, and the sudden movement and change of center of gravity can easily cause the sliding. Therefore, we propose two improved designs so that the cane shaft is perpendicular to the contact when ascending and descending the stairs. This study suggests modification design of the quad cane and obtains feedback through user testing to select its design parameters. Based on safety and strength considerations, an iron sheet was also selected. Type A provides a recessed area of the base that can be adjusted; Type B included a collapsible base. As part of the design process, seniors were invited to try it out and evaluate its feasibility. Both designs can be finalized based on the elderly's specific condition.**

***Index Terms*—quad cane, structure design, stair, folding structure**

I. Introduction

As physical function deteriorates in the elderly, canes or walkers become a necessity. A quad cane can support 30% of an individual's body weight, and it provides higher support and stability suitable for elders with limited mobility (Fig. 1). To avoid functional decline, elders who have difficulty walking are encouraged to use quad canes to reduce the chance of falling. Most elderly are using wheelchairs, walkers, or canes. The base of single-point cane was too small to provide secure stability, and sometimes the user needs to lean on a wall for balance [1]. Ipsilateral cane use on gait in people with knee osteoarthritis and response to stair ascending and descending with walkers are harmful [2]. The elderly require assistance in using stairs [3]; a quad cane is a tool for independence. Ascend and descend stairs with a climbing device is expected. Cane training supports walking independently through utilizing the practicing therapy stairs to ascend the stairs [4], [5]. A narrow base quad cane required contact-guard assistance [6], [7]. Conventional fall prevention strategies were questioned on the holistic nature of postural control. A systems-oriented conceptual framework explains the instability of a postural control system's ability to adapt [8]. The center of mass is outside the base of support and challenging the stabilizing of the gait pattern [9].

When choosing the right weight and length, the grip of the cane should be level with the hip joint. When holding a single rod, the cane must be held in hand, belonging to the good side to avoid the center of gravity shift to the affected side. When an elderly person goes out on uneven roads, the extended claw-like design of the cane base can play a role in avoiding falls. However, the existing quad cane design is challenging to use when climbing stairs. Because of the stair width, all four legs of the cane base cannot wholly contact the stair, which poses a significant fall risk.

Figure 1. Existing cane, stainless steel, 68 ~ 85cm high, and weight 1.3 kg and a Tripod cane with seat.

II. Concept Design

The stability of quadrupeds comes from the base in contact with the ground. A method of free gait generation for quadrupeds is presented [10] with constraints. Article [11] analyzed framework to extend the principles of passive dynamic walking to quadrupedal locomotion. The improvement use of a wobbling mass elastically attached to the main body of the quadruped. A stair-step with a limited width will cause two tips to hang over the edge of the step, so a design improvement needs to take into account both the contact area and structure.

After the integration of expert interviews, a sketch was drawn, and a doctor of rehabilitation was invited to review ideas. As shown in Fig. 2a, one cane design has an adjustable base angle with a 90 ° notch in the middle of the base. The notch fits into the outer edge of the step, which increasing surface contact when the user ascends and descends stairs. Fig. 2b shows another design with a

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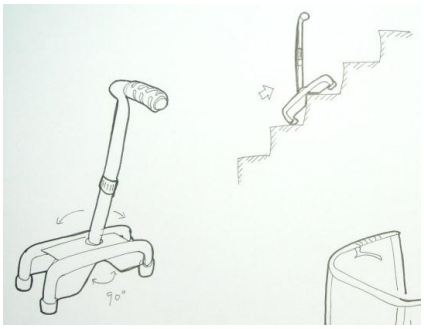
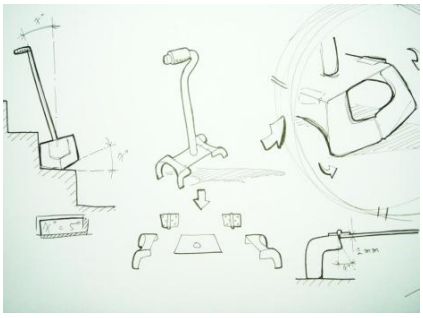
collapsible base. This allows users to access the stairs without the base exceeding the edge of the stairs.



(a)



(b)

Figure 2. Quad cane design concept: in Type A, the recessed area of the base can be adjusted; in Type B, the base can collapse.

A. Stability Testing and Models

First, we used a test model to find the relevant design parameters of quad cane Type A and evaluate its effectiveness. Does it offer sufficient support when the base is planted on the stair edge? Because actual force testing was required, to avoid injury to the elderly, we invited young adults to test the model and collected their opinions. The design prototype was a simple wooden 1:1 model (Fig. 3). During the test, we observed that the participants would lean forward slightly when going up the stairs. This observation reveals the quad cane itself should exhibit a forward lean. We adjusted the angle of the wooden model to 85 degrees and 90 degrees to compare the difference of the forward-leaning angle.

Figure 3. Wooden model

Seven subjects (five males and two females) with an average age of 26 years were asked to ascend and descend one flight of stairs using the quad cane. We then interviewed them about their subjective stability. The seven subjects indicated that the rods demonstrated security and supportability, and no slippage occurred during using (Fig. 4). After the test was performed at 90 degrees, the subjects were invited to adjust the angle to 85 ° and report the differences between the two settings after use. We found that the majority of subjects found it more comfortable to apply force through the forward tilt angle of 85 °, which verified our hypothesis of forward tilt support.

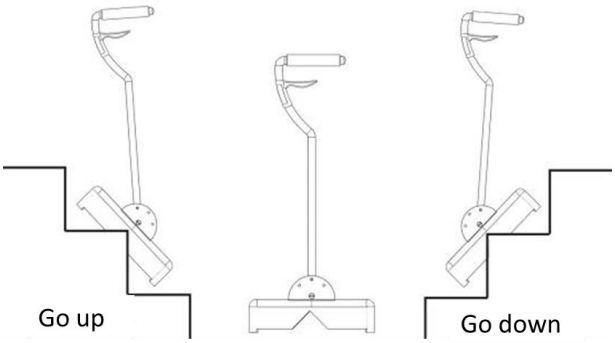


Figure 4. Adjustable mechanism of a Type-A: base with an inverted V-notch

The base of quad cane Type B has a design with a folding base. When ascending or descending stairs, side part of the base can be folded via a linkage mechanism (Fig. 5). This design avoids the problem of narrow steps; the central axis of the cane is fixed at the center of the base.

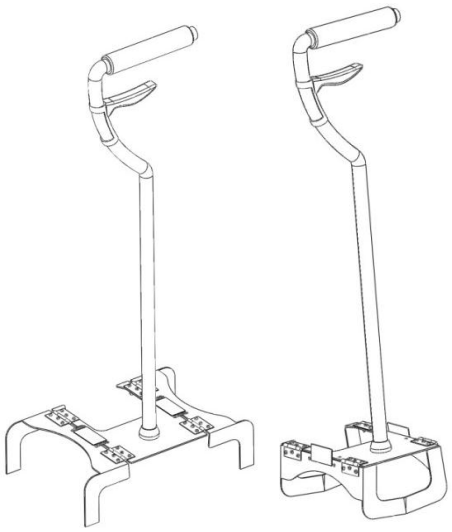


Figure 5. The base of the Type-B can be collapsed.

B. Prototyping

A prototype of Type A was made with the existing cane model as a reference. The cane shaft was trimmed, and a turning mechanism and a 90 ° notched iron piece were added (Fig. 6). The added material was also made of iron to support the load and resist deformation. The

structure of Type B's base was more complicated. The shape of the mechanical components was drawn by computer, and the parts were assembled by laser cutting. A tension spring bar was installed under the base. When the bottom was retracted by the base retracting lever, it caused the L-shaped components on both sides to retract inward (Fig. 7).

Figure 6. Type-A angle adjusting tenon

Figure 7. Type-B iron base and folding method

III. Tests and Results

Because the test required physical exertion, we recruited young adult students to avoid falls and injuries in elderly participants. In phases 1 and 2, we collected feedback during trials and adjusted the design parameters to make the final prototype. Finally, in step 3, the elderly were encouraged to use the prototype and provide feedback.

A. Phase 1: Student Tests

There were eight subjects in the Phase 1 test, of which five were male, and three were female, with an average age of 24 years. Before the test, the researchers explained the usage method of the improved cane but did not inform the subject that the rod was designed with a forward lean. Participants used both new cane designs and were interviewed after ascending and descending a flight of stairs (Fig. 8).

Figure 8. Type A and Type B test scenarios

Five subjects believed that the stability of Type A was relatively high; only two subjects reported that the security of Type B was high, due to the unevenness of the base. Therefore, the flatness of the support needed to be improved to increase stability. Five people believed that Type B was stable when ascending the stairs; five people thought that Type A was relatively stable when descending the stairs, which was attributed to the adjustable angle. During the experiment, six subjects felt the forward lean of the cane shaft and said that leaning forward helped them ascend and descend the stairs. In terms of suggestions, 6 subjects reported the cane felt heavy, and three thought that the base of Type B would slide when used. The test subjects indicated that they were unaccustomed to the rods at first, and they needed time to learn and grow accustomed to the canes before they could use them smoothly. When using Type A, the concave angle is intended to fit onto each step, which slows gait speed.

B. Phase 2: Further Student Tests

The two designs were adjusted according to the feedback from the subjects in Phase 1, and anti-slip pads and support bars were added at the relevant positions. A total of 13 subjects (10 males and 3 females), with an average of 25 years, tested the revised designs in phase 2. Six of them had also participated in Phase 1 testing. Step 2 also included testing with a traditional cane. All subjects at this stage were asked to wear a geriatric simulation suit (Fig. 9) to simulate elderly cane users and experience reduced mobility. After an explanation, subjects used all three crutches to ascend and descend a flight of stairs, evaluated the canes' stability and convenience. A Likert 5-point scale and interviews were used for evaluation, and the data analyzed with SPSS software.

Figure 9. Counterweight geriatric simulation straps

The statistical analysis software SPSS analyzed the data of 11 individuals. The results of phase-2 are shown in Table I. Reported stability when ascending the staircase was highest with Type B (4 points), and stability when descending the staircase was also highest with Type B (3.9 points); both designs were rated higher than the existing commercial quad canes. The average reported convenience of Type A was 3.5 points (3.6 points for ascending and 3.4 points for descending); the average score of Type B was 4 points (4.2 points for ascending and 3.9 points for descending). Based on the above results, the stability and convenience of the commercially available quad cane were only 2.67 points, the Type A was 3.19 points, and Type B was 3.98 points. We performed a pairwise comparison between categories using the comparative average method. It was found that the p-value of the part was less than 0.05, indicating a significant difference (Table II). In terms of stability, when going downstairs, Type B was significantly better than the others. Users reported increased convenience when ascending stairs with the Type B cane because its base was collapsible. Users did not need to fit a notch on every step of stairs, which they felt was more inconvenient. Of the six subjects who participated in the phase 1 test, five indicated that the degree of shaking had been significantly reduced after the non-slip material was installed, and they felt more stable and less likely to slip.

TABLE I. AVERAGE OF PHASE 2 TEST RESULTS

	Upstairs stability	Downstairs stability	Easy to go upstairs	Easy to go downstairs	Total avg.
Traditional	3.00	2.38	2.69	2.61	2.67
Base concave	3.53	3.23	3.61	3.38	3.19
Swappable	4.00	3.92	4.15	3.84	3.98

TABLE II. P VALUES COMPARED BETWEEN CATEGORIES

Variable	Inter-group	Stability		Convent	
	Pair comparison	Downstair	Upstairs	Downstair	Upstair
1. Four-legged turn	1-2 3	.281 .038*	.170 .072	.086 .011*	.021* .002*
2. Base bump	2-1 3	.281 .133	.170 .190	.086 .053	.021* .028*
3. Fitable base	3 1 2	.038* .133	.072 .190	.011* .053	.002* .028*

*There are significant differences.

IV. PHASE 3: GERIATRIC TESTS AND DISCUSSION

After the mentioned tests, the two designs were modified, and phase 3 tests were performed at a rehabilitation center attached to a hospital in Taichung. The director of the rehabilitation department recommended that elderly individuals who were in good physical condition perform the measurement. The subjects had experience using canes, and they ascended and descended the stairs using both new designs.

A. Results

Test subject A: Male with no history of stair falls, severe kyphosis, and aging-related gait abnormalities due to decreased right footstep length. He reported that he hoped the new canes were not hard to use and that their size would support him. He reported no inconvenience when using the existing quad cane, "If it is too difficult to place the cane at an angle on the step, you can rely on the handrail." After the test, however, subject A reported that he preferred cane Type B and thought that both designs were helpful, stable, and didn't feel heavy.

Subject B is female with a history of regular exercise and in good health. She reported neck- and backaches. She said "slipping in the bathroom," after which she used a cane for a while. She agreed that quad canes have a broad base area and could be lighter (Fig. 10). She exhibited excellent stability when ascending and descending stairs, finding the operation of the convenient and safe. She expressed curiosity about the design and reported that she preferred the Type A cane.

Figure 10. Subject B behavior

Subject C: Male exhibiting slight kyphosis, unable to walk long distances due to arthritic lower limb and knee weakness when walking downstairs. He reported that he usually did not use a cane at home and only used a cane when going out. Per the subject, "Quad canes take up too much space; it is difficult to walk when the road is uneven, and it is easy to kick the cane when walking fast." He felt the weight of both experimental cane designs was in the acceptable range, reporting, "It's beneficial and stable when going up and down the stairs." He reported that he found such canes "very powerful." He also preferred Type B.

Subject D: Male, in good health, no history of stair falls. He reports he does not usually use assistive devices, preferring to use the handrail when ascending and descending stairs. He felt that the experimental designs were "a lot heavier than a cane" and felt relieved to have additional help climbing stairs. He also preferred Type B.

Subject E: Male exhibiting slight kyphosis, no history of stair falls, and the oldest of the subjects. Because of weak knees, he reported that he usually used a walking stick. He said the improved canes were "satisfying and felt stable." He said that when going down the stairs, Type A needed to be placed in front, and he felt like he was about to slide down, so using it was stressful. He also preferred Type B.

Subject F: Female, exhibiting slight kyphosis but otherwise in good health. She suffered a car accident a year ago and sustained severe injuries to her feet and hands. When she went up and down the stairs at home, she would turn her quad cane 90 ° so that all four tips could contact the stairs, but "sometimes I accidentally trip over them. "She stated that she believed the improved designs could help people climb stairs and increase their stability (Fig. 11). She preferred Type B.

Figure 11. Subject F behavior

Subject G: Male presenting with a prior neck injury that did not affect walking, with no history of stair falls. He reported that he used the handrail only when he needed to go upstairs to reduce the burden on his knees. He reported that "traditional stairs are inconvenient. Stairs in homes are often narrow and dangerous to use." He thought the improvement of turning the type B cane helped him and increased his sense of security (Fig. 12) while hoping to control the cost of such a rod. He felt that cane Type A was the most stable.

Figure 12. Subject G behavior

Test subject H: Female, hard of hearing, severe kyphosis, slow gait speed due to age-related lower limb weakness, no history of stair falls. She reported that she usually used a walking stick instead of a quad cane and that she held the handrail when going up the stairs. She believed that "the cane is too big to walk with," and "it will be tiring after taking a long time." However, she believed that the canes helped her up and down the stairs and preferred Type B.

Subject I: Female with poor eyesight, that did not affect walking. She exhibited slight kyphosis and knee weakness. She reported that she tried to take the stairs less often. She felt that traditional quad canes were not convenient on flat ground or stairs because they are too wide at the base. She thought both new models helped her to go up and down the stairs, reporting that they were "stable and safe, but a bit heavy." She felt that Type B was the most stable.

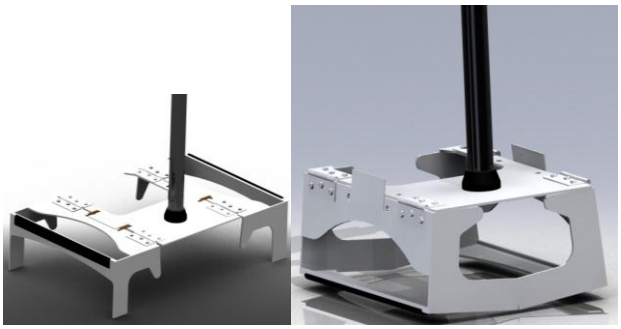


Figure 13. Type-B base improvement

B. Discussion

The nine subjects recruited by the physician were over 60 years old on average. In this test, three users said that the canes were slightly heavy. Seven subjects preferred the Type B cane and felt that its stability helped them ascend and descend stairs. They valued both designs higher than traditional quad canes. Based on the subjects' and physicians' recommendations, the cane material can be changed in the future to make it lighter. Because of the need to match the corners of the cane to the edge of the stairs, Type A may not be easy to use for stroke patients or those with fine motor deficits. Although there were no falls during the test, some subjects reported the sensation of slipping, and the Type A adjustment joint shook slightly during use (Fig. 13).

V. Conclusion

The problem of limited steps' width caused cane base does not have enough space for placement, and the movement of the force point can easily slide the bottom of the cane. Base area, weight, and interference with walking are three design aspects that conflict with each other. Negotiating a balance between the three is a problem that is worth exploring. Type B's retractable design adjusts the base of the cane when it needs to be smaller; it also adds a folding mechanism, which requires simplified parts to control costs. After three stages of testing and integration analysis, possible improvement ideas were proposed. Previously, the cane's rounded corners may have increased the risk of sliding. This problem can be prevented by installing anti-skid pads at the right angles. Also, after the folded cane base's surface area is increased, it will provide more support.

The individual physical condition of the elderly is also very different. Some people have a stroke, a fall, or an operation that affects the freedom of walking. However, these various reasons cannot change by a single design. If necessary, choose suitable crutches, and practice the correct way of applying force.

This research adjusts the design parameters through the experiment and modification of simple models through experience and creative proposals. Human factors engineering is the interaction between people and things, and the human body's settings are complicated. Future research can simplify the characteristics of the interaction between the human body and the cane. When the factors considered a conflict with each other, the assistance of numerical tools can be used.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Chao conducted the research; Huang generate concepts; Xiao built the model and analyzed the data; all authors had approved the final version.

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