master degree project

transformable crutch

by rimgaile samsonaite

Transformable Crutch

Master Thesis from Lund University, Industrial Design/LTH
Department of Design Sciences

Rimgaile Samsonaite

Examiner: Claus-Christian Eckhardt
Professor
Division of Industrial Design

Supervisor: Lena Sperling,
Associate Professor
Division of Industrial Design

Co-supervisor: Elin Olander
Licentiate in Philosophy
Division of Industrial Design

Consultant: Gunilla Knall
Physiotherapist
Division of CERTEC - Centre for
Rehabilitation Engineering Research

Consultant: Niklas Ekstrand
Technical Product Manager
"Human Care"

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introduction

Mobility aids help you walk or move from place to place if you are disabled or have an injury. They include crutches, canes, walkers, wheelchairs and motorized scooters. You may need a walker or cane if you are at risk of falling. If you need to keep your body weight off your foot, ankle or knee, you may need crutches. You may need a wheelchair or a scooter if an injury or disease has left you unable to walk.

The market of assistive devices is flushed with products that look mostly the same. It is very common to a crutch market too. A crutch itself has not evolved much during many years - neither its function, nor appearance. Producers try to produce them as cheap as possible and to make one that fits all. Users are not satisfied but they cannot choose.
Finally, some people consider use of a walking aid as unfashionable, or a sign of increased frailty, resulting in not wanting to use a walking aid.

So what about individual human needs? Does a crutch interfere with daily activities? Does it effect user's self-esteem?

The aim of this project is to answer questions mentioned above, formulate the main problems and suggest a research based solution of a crutch.

research phase

- Disabled people represent 50 million persons in the European Union (10% of the population. (Http://www.migrationinformation.org/)

- People with reduced mobility represent more than 40% of the population. (Including people with reduced mobility temporarily, elderly people and other people who are not being considered as disabled.) (Http://www.edf-feph.org)

- The use of mobility devices has grown in recent years, with the populations using wheelchairs and walkers doubling from 1980 to 1990. Crutch and cane use also increased by 14 percent and 53 percent, respectively, over this period. Growth in the usage of these devices continued from 1990 to 1994, far exceeding what could be attributed to the aging of the population. It is likely that improved survival of trauma patients has also contributed to the growth in mobility device use. (Http://dsc.ucsf.edu/)

- Due to the continuously increasing life expectancy of people in western countries, the percentage of motor impaired people is constantly increasing. Less recent Europe-wide statistics denoted that 1% of the population is in need of a wheelchair and an additional 5,6% of people need some kind of walking aid. (Http://dsc.ucsf.edu/)

- The proportion of the population using mobility devices increases sharply with age. While only 0.2 percent of children under age 18 use any kind of mobility device, that proportion increases sevenfold, to 1.5 percent, among those of working age. Among the elderly, the 14.0 percent overall rate of mobility device use is almost a factor of 10 times that of working-age adults. Just under 40 percent of persons aged 85 or over use mobility devices. (Http://dsc.ucsf.edu/)

- Loss of motor abilities (manipulation and locomotion) especially affects the aged female population not only due to their higher life expectancy, but also as a result of gender-specific chronic diseases. Whereas 31% of the male population aged 75-84 report mobility problems, the figure for the female population is as high as 52%. (Http://dsc.ucsf.edu/)

- About half of people or their families pay for devices solely on their own. (Http://dsc.ucsf.edu/)

Walking sticks have aided bi-pedal man since the dawn of our evolution. Since antiquity humans have fashioned support devices to hold themselves up when they became sick or injured. Such devices are dated to 2830 B.C. A carving on the entrance of an Egyptian tomb depicts a figure leaning on a crutch like stuff. The walking stick has served well as an assist to climbing, an aid to steadying people themselves, as a reaching tool, a weapon, as weight-bearing device to facilitate ambulating when debilitated and for some it was a matter of fashion.

As we became more sophisticated our walking sticks developed specialized functions for individual needs such as hook shaped top to herd sheep or a T shaped top to nestle in the pit of the underarm for a rudimentary crutch.

Crutch design has evolved from the basic "T" to aluminium braces with ice-gripping tips or energy storing tips that function as shock absorbers. For lower-limb injuries, crutches remain useful today to decrease discomfort, reduce recovery time, and assist walking. The form was driven by its need to function and was shaped for the individuals needs.

Many companies in the world currently manufacture all types of crutches. These mass-produced crutches have many similar attributes in common. They are mostly made out of aluminium tubing with adjustment holes above and below the handgrip so that one size fits all. The arm cuffs are made of metal and the handgrips and crutch tips are made of solid elastomers.

Unfortunately an attempt to make an inexpensive crutch to accommodate the needs of everyone ends up not meeting the needs of anyone effectively.

A crutch must do 2 things:

- Reduce weight load on one of your legs;
- Broaden your support base to improve your balance and stability.

The support also should assist upright movement and transmit sensory cues through the hands. A crutch allows people with paralysis the benefits of upright posture and lets them manoeuvre in places they cannot go with a wheelchair.

A crutch becomes necessary when a person cannot walk, or walks with extreme difficulty. Any person with leg or foot pain or injury, weak muscles, or an unstable gait may benefit from using a crutch or crutches. Regaining upright body movement aids circulation, assists kidney and lung functions, and helps prevent calcium loss from your bones.

Crutches shift the force of upright movement from your legs to your upper body. You must have sufficient arm strength, balance, and coordination to use them effectively.

There exists three types of crutches in the market:

Axillary (Underarm) crutch - is the most common type. In general, underarm crutches are intended to support the patient's weight on an upper armrest at the underarm; a hand grip is used primarily to move the crutch. Though underarm crutches have been proven less energy efficient and more cumbersome than forearm crutches, they are still preferred today by many long-term users for this reason.

Forearm crutches - include a handhold for bearing the patient's weight and a forearm brace, to allow the patient to align his or her forearm with the crutch. The forearm style crutch now dominates the world's long-term crutch user market. In fact in Europe the forearm crutch is the style of choice for the short-term user market as well.

Platform crutch, also known as a triceps crutch. Patients who can't support their weight through the wrist and hand because of arthritis or fracture can use platform crutches instead.

Axillary (Underarm) crutc **Forearm crutches** **Platform crutch**

Figure 1. Types of crutches

For design purposes, the weakest users are often relevant than the strongest, and beginners more than experienced users (Daams, 1994). This is one of the reasons why the chosen target group of this product is temporary users (short-term users).

Target group consists of:

- People who experienced various kinds of injuries, during rehabilitation period (usually having injured leg, foot or hip, have orthoses, have a surgical procedure on a lower limb, or suffer a stroke, etc.)
- Disabled and elderly people, who are switching from other walking aids to crutches every so often (osteoarthritis, polyarthritis, rheumatism, orthopaedic impairments, late effects of injury, amputees).

The long-term users will be also considered in the process.

It is generally known and has often been shown that on average, males are stronger than females. At 30 years a woman's strength is approximately 2/3 that of a man, it declines more rapidly with age and at 50 years a woman is about half as strong as a man (B.J.Daams). Moreover, the body mass center of man and woman differs man's is in his chest, while woman's - in the lower part of the abdomen.

All this means that it is much harder to use crutches and support body weight with an upper part of a body for woman than for man.

And, according to B.J. Daams, it is important to note that products that are designed for the lower percentiles of the population (where forces are concerned, these are the weaker persons) can be easier to use or operate by the average user. Those products may sell even better to 'normal' users than standard products, because they too appreciate clear, simple features and light operation. Unless, of course, these products get stigmatized as being specially made for the disabled and the elderly. Neither strong nor weak users want to be seen with a product that visibly classifies them as weak. If this negative image can be avoided, products designed for the weak can be a (commercial) success with everyone.

User opinion review

In the user opinion research, nine people, both short-term and long-term users were involved. Even though the main target group is short-term users, long-term users are more experienced in using, evaluating and testing crutches. They have broader knowledge and can give more and detailed information.
Because of the time and possibilities limitations to contact directly, most of the user opinions were taken via Internet: questioning by e-mail, taking part in forums, using other data, published on Internet.

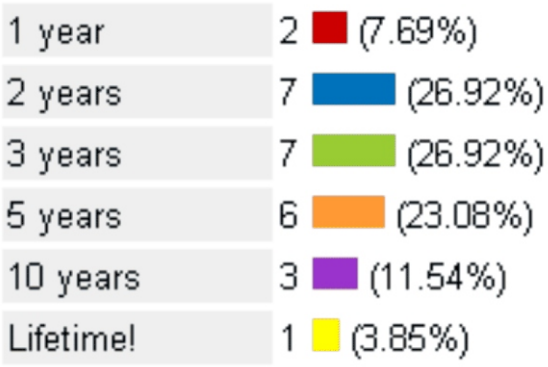
Specialist opinion review

In the specialist opinion review physiotherapists, researchers within this area (ergonomics, biomechanics, medical engineering) were involved. Specialists were contacted both meeting them directly and via Internet.

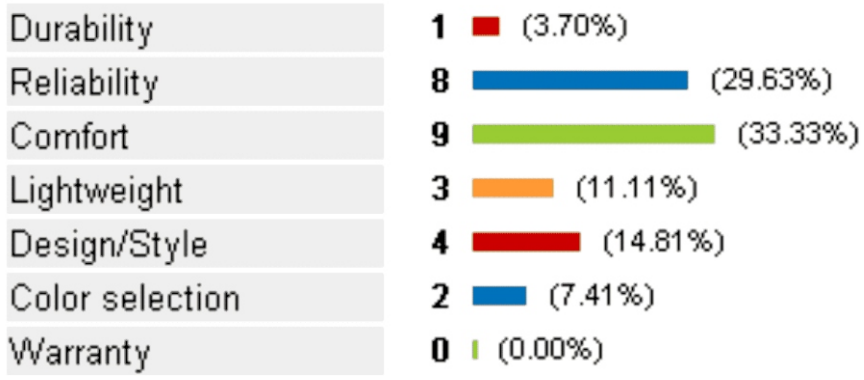
User survey

The company, called "Walk Easy", which manufacture walking aids and ships them all over the world, made a survey and published results of a questionnaire for crutch users. It was to be filled online.

- How long do you expect a pair of forearm crutches to last? (26 votes)

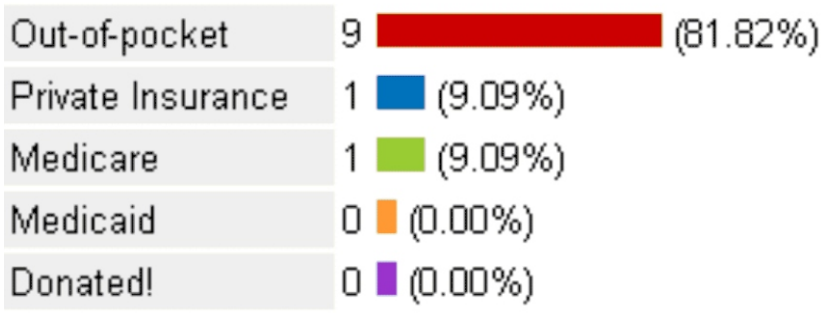


- Which aspect is the most important to you in a walking aid? (27 votes)



- Are you interested in a crutch bag? (44 votes)

- How did you pay for your last purchase of a walking aid? (11 votes)



Overall summary of collected opinions from both studies:

1. Support the weight of the user and provide him/her stability: This is of utmost importance for maintaining safety, whether the user is standing, walking, running or climbing stairs.
2. Employ both shock absorption and energy return: The crutches should have a means of absorbing shock and also have a way to return energy to the user (mostly common to long-term users.
3. Durable: This correlates strongly with the weight-bearing capability of the crutch and also the robustness of the interfaces between parts.
4. Lightweight: The crutch must be lightweight to allow ease of maneuverability and low energy consumption. (The weight of a crutch has to be different according to a user's weight: the heavier user is, the heavier crutch s/he needs.)
5. Maximum mobility: The crutch cannot be bulky, must allow the user to easily move the crutch tip in any direction, and must easily detach from the user in case of a
Fall.
6. Ease of object reach: The crutch must remain attached to the user while he or she is reaching for an object, opening a door, or shaking hands.
7. Comfort: Comfort between the arm and the cuff or cradle, and the hand and the grip are important.
8. Silent operation: One of users' biggest concerns with present crutches is that the pivoting elbow cuff and adjustment holes become loose and produce loud noises (mostly common to long-term users).
9. Support user self-esteem: The crutch should be attractive and stylish so that it is a personal accessory the user is proud of.
10. Foldability: The crutch should be foldable when not in use to give better comfort for a user.
11. Attachable Bag: for storing crutches and carrying personal belongings on the crutch
special bag is preferred by users.
12. Changeable cuffs: for switching from underarm to forearm crutch to let hands and shoulders to rest.
13. Natural Grip should be implemented in the crutches.
14. Larger tip is needed to ensure good touch with the ground.

The crutch is an object that has not kept pace "ergonomically" with the ever-changing world of modern medicine. Static overloading results when muscles, especially those of the hand and the extensor muscles of the wrist, are traumatized or overstressed repeatedly over time. Injuries common to crutch use include carpal tunnel syndrome, wrist tendonitis, medial or lateral elbow epicondylitis, and rotator cuff muscle strains and tears. These injuries result from cumulative stresses on tissues and joints and excessive muscular contraction that impedes blood flow. Other parts of the body, such as the back and the shoulders, are also adversely effected by unnatural stress and increased loads. In addition, use of crutches causes fatigue and discomfort, for its users, when it has to help them in their everyday life.

If crutches are not ergonomically designed, their users run the risk of serious injury. Modern medicine needs an ergonomically designed, comfortable, user-friendly crutch.

The muscle groups most important for crutch walking include:

- The shoulder muscles that stabilize the upper extremity and those that hold the top of the crutch against the chest wall.
- The arm muscles (at the shoulders) must be able to move the crutches forward, backward, and sideways.

Other muscle groups that must be strong enough to support the patient include:

- The forearms , to help prevent flexion or buckling. These muscles are important in raising the body for a swinging gait.
- The wrist muscles, to enable weight-bearing on the hand pieces of the crutches;
- The finger and thumb muscles, to grasp the hand piece.

From a biomechanics perspective, as a load is applied to the palmar side of the fingers in grasping a tool, lever, or material, load moments result at each of the finger and wrist joints (Chaffin Don B., Andersson Gunnar B.J. "Occupational Biomechanics", 1984)

The mostly stressed body parts using different kinds of crutches

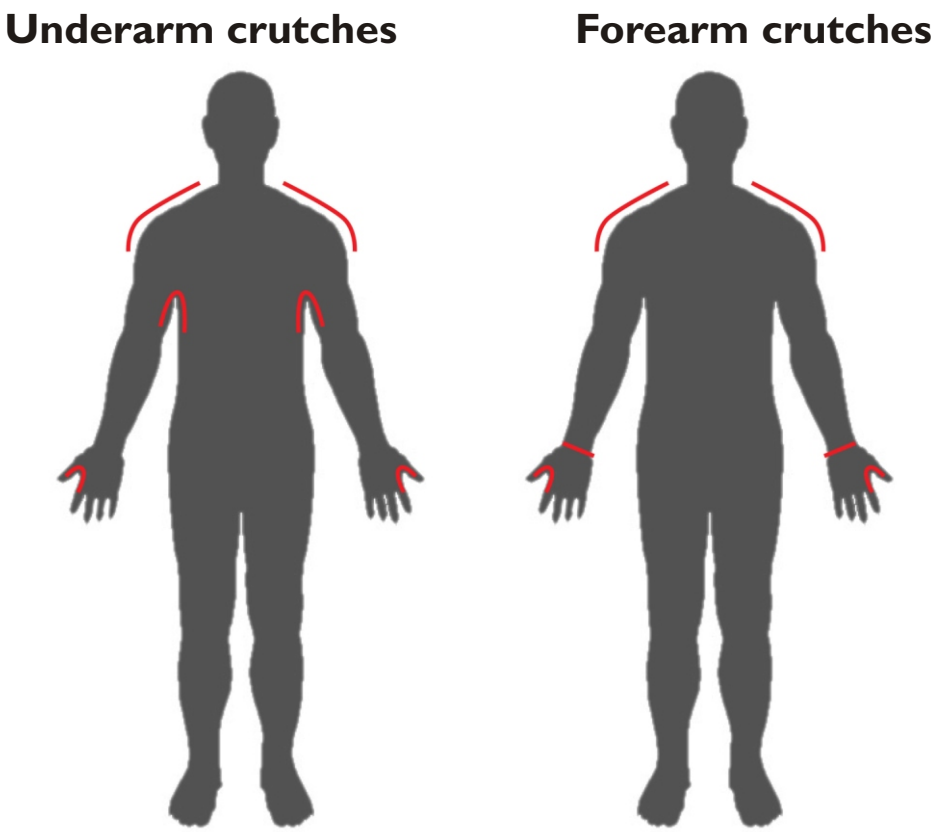


Figure 2.

Different body parts are stressed when using different kind of crutches (Figure 2). So changing a kind of crutch every so often would give user a possibility to rest his/her wrists and elbows (when changing from forearm to underarm crutch), armpits (when changing from underarm to forearm crutch).

Altering the posture of the arm will have a great effect on the moments at the elbow and shoulder, but will have no effect on the external reactive forces since they have remained as a parallel force system (Chaffin Don B., Andersson Gunnar B.J. "Occupational Biomechanics", 1984).

Person's endurance is measured by investigating spontaneous changes in posture. It means, that when a person feels tired (himself in a whole or in specific body part) he wants to change his posture. That gives him relaxation (Daams, 1994).

Moreover, different kind of crutches could be used in different situations. According to physiotherapists and some users, it is much easier to start using underarm crutch, but it is harder to use it for long walks and it is harder to learn how to use forearm crutch correctly, but much easier to use it for a long walks/ longer time. In standing position and using arms, underarm crutch is more comfortable. Also, in the start of using crutches, underarm crutches give better feeling of safety and stability, and, according to some users, it do not stand out as much as forearm crutches. And this is very important for a period of adaptation.

To solve the wrist problems mentioned before, there were some solutions made by researchers and medical engineers.

Figure 3. A cane, created by "Strong Arm Mobility".

Figure 4. Forearm crutch "S_upport" project by Pei-Hua Huang.

The first solution (Figure 3.) to protect a wrist from being stressed - to support it. Users appreciated the first solution of a wrist support on a cane very much, however, it is hard to implement it on a crutch because of it's shape.
The second solution (Figure 4.) was not tested by the users. According to ergonomics it should work, but some of the users were concerned about its appearance.

Fifure 5.

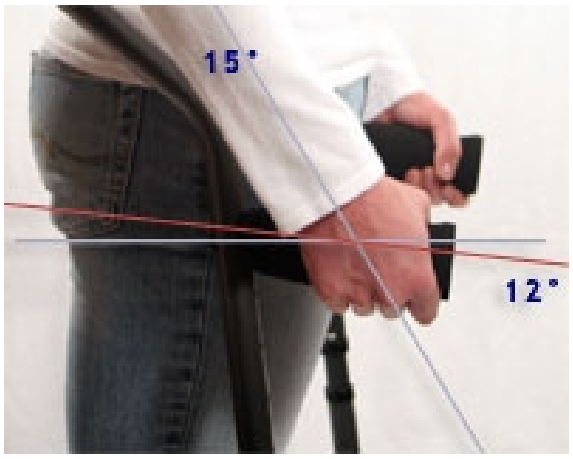


Figure 6.

"Millennial Medical" created this solution of a grip (Figures 5. & 6.) Its main feature - tilted grip, which, according to the company, helps the wrist to be less stressed. Even though it is stable enough, the angle of a grip creates a feeling of instability.

If the wrist is in a neutral posture, the supporting tissues (synovia and flexor retinaculum ligament) and the adjacent median nerve will not be greatly stressed. Such is not the case, however, if the exertion takes place with a deviated wrist. In such case, simple biomechanical concept indicates the need for caution. (Chaffin and Andersson)

The grip itself has many solutions of it's shape and surface too. Here are some examples of offered grips by some crutch producers.

Figure 7. "Right grip"
Produced by Thomas Fetterman

Figure 8. "Natural Grip"
Produced by "Millenial Medical"

Figure 9. "Contoured Grip"

"Right grip" is shaped according to what the right grip should be. However, it does not fit people with bigger or smaller hands, limits the position of you hand, can cause pain in the palm (Figure 7).
"Naltural Grip" was mentioned earlier. It was created by "Millennial Medical". Users like the shape of it and material (foam). However, the angle of it is arguable (Figure 8).
"Contoured grip" is offered by Swedish company "Swereco". It is called "Contoured grip". Its is simple, matches ergonomic requires, but for a full comfort, it needs extra padding (Figure 9).

Some important research-based guidelines for design of handles were found in literature:

- Handle diamter. A handle for manual materials handling should be at least 115 mm long, be 25 to 38 mm in diameter and have a hand clearance of 30 to 50 mm. (Daams, 1994)
- Handle shape. Eliminating sharp corners, edges, ridges or finger grooves should prevent highly concentrated loads on the skin (Daams, 1994)
- Handle material. The surface material of a handle influences friction, and therefore the amount of force that can be transferred. Bordett et al. (1988) advise to use a non-slip surface for handles. Bullinger and Kern (1979) found that a smooth surface generally has a large friction coefficient in combination with a hand, therefore provides better purchase, than a rough surface.
- Push and pull forces exerted on a slippery handle (treated with engine oil additive) were on average 86% of those exerted on a dry handle (Hallbeck et al., 1990). A foam grip was preferred over a plain wooden handle, with significantly lower ratings of hand tenderness and hand fatigue (Fellows and Freivalds, 1989).

To create a feeling of stability of a crutch for its user, crutch should not only be stable itself, but it must look like it is stable. It is very important to get a user to trust his crutch and feel safe.

Interesting and innovative shape of crutches was developed at Stanford University (Figure 10). Curvy shape is meant for shock absorption and energy return. However, when testing, users complained that it has a lack of stability, even though it was proved that it is ergonomically stable.

To create better stability some crutches have centered lower part of their body with user's body middle axis (Figures 11-13).

Figure 10. Crutches, developed at Stanford University, USA

Figure 11. A crutch developed by "Sprout Design"

Figure12. A cane developed by "Strong Arm Mobility"

Figure 13. A crutch developed by Thomas Fetterman Inc.

Other interesting shapes & forms of crutches and canes

Figure 14.

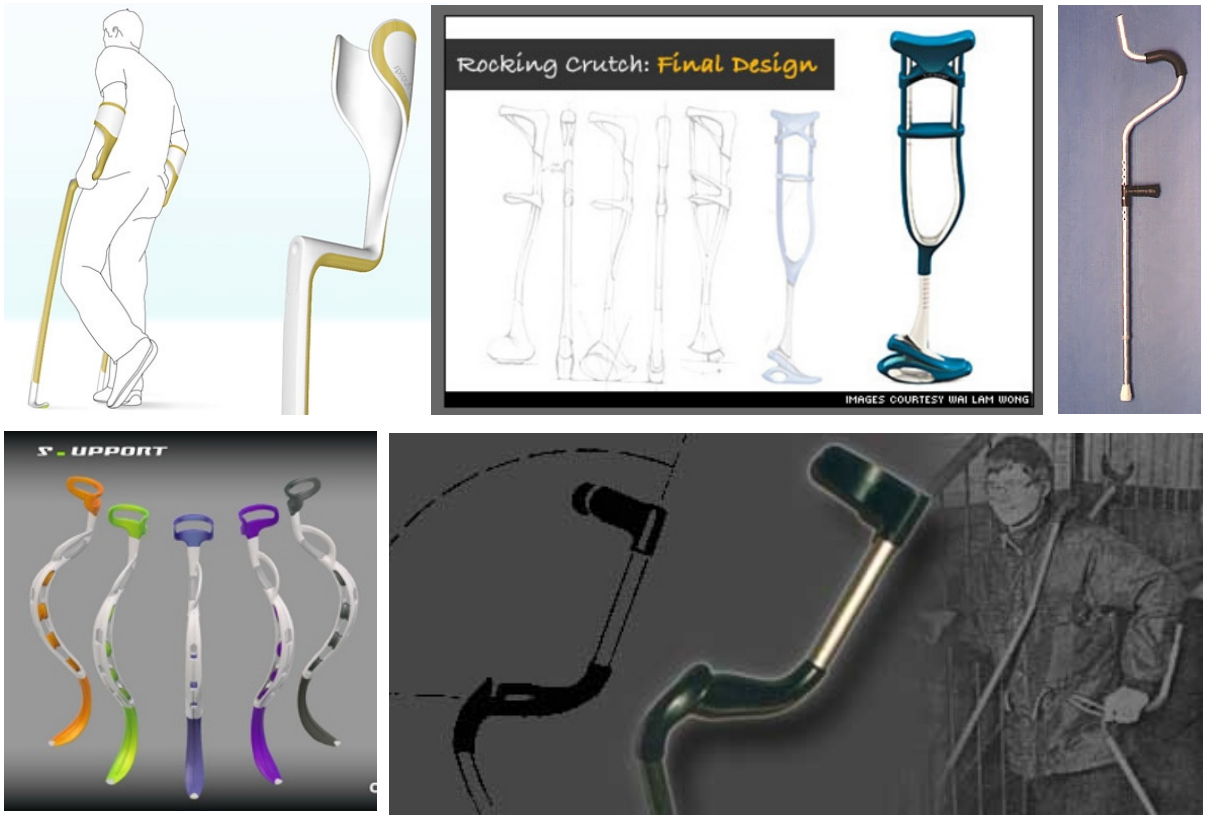


Figure 15.

Various positions of crutches

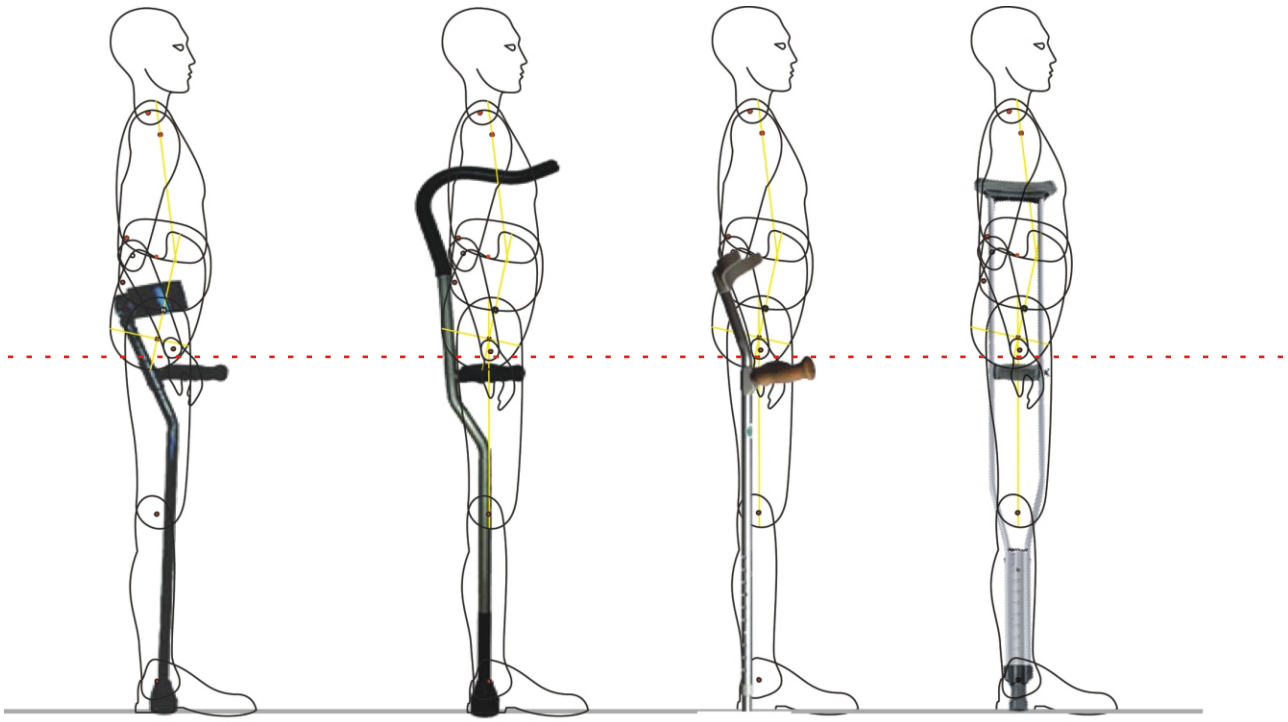


Figure 16.

The position of handle and lower part of different types of crutches is almost identical (Figure 16). Only upper part differs. It means, that it could be possible to implement a function of changeable upper part in a crutch. And give possibility for a user to have two-in-one crutch.

Cuffs & Cradles

There are many good solutions of cuffs and cradles.
There are usually two types of cuffs (armbands) closed/full and open (Figure 17.).
The choice depends on an individual user needs, size of his/her arm, comfort. It must be possible to choose them individually.
The removable padding (Figure 18.) is sometimes needed to make it more comfortable.

Figure 17.

Figuree 18.

When designing, external factors which should be taken into account include clothing, footwear and the weather (Daams,1994).

Hygiene issues are very important when designing both - cradles and cuffs, the same as grips. Cradle has to be solved very well ergonomically too. Wrong ergonomics will cause a armpits problems for a user , like damaging the nerve of an armpit.

Figure 19. Examples of not very comfortable cradles that causes pain in an armpit

Figure 20. Examples of more comfortable cradles.

Tips

The Tips of crutches are quite developed nowadays. They protect crutches from slipping, absorb shock and make them more energy efficient.

Figure 21.

Figure 22. Ordinary crutch tips

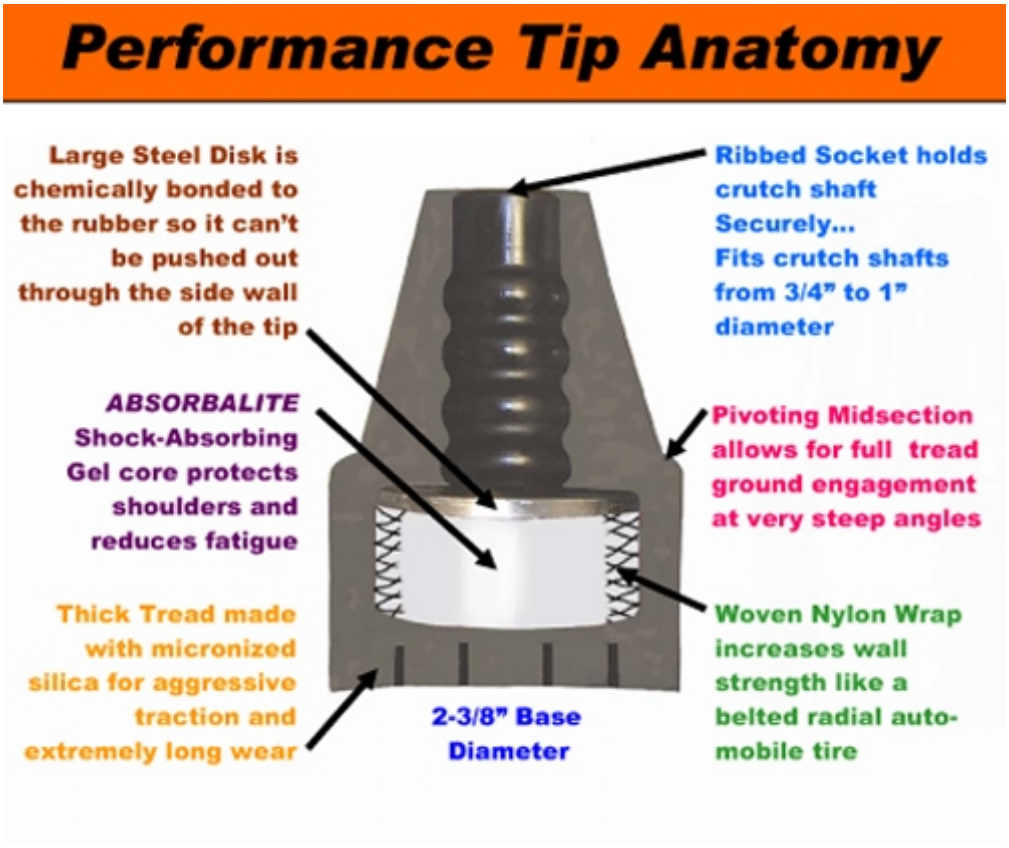


Figure 23. Performance Tip invented by Thomas Fetterman Inc.

Ice pick

Figure 24. Foldable ice pick with hardened tip or barbed ring. (”Swereco”)

Figure 25. Ice pick with 4 spikes is a complete ice pick with built-in spikes easy to fold in and out with the foot or the hand. Plastic inserts are included for adjustment to the most frequent tube diameters. (”Swereco”)

Construction parts of crutches:

Body:

- Unibody vs. body from several parts
- Air-tight
- seamless aerospace grade titanium tubing
- with/without internal elastic cord

Grips:

- Shock-absorbing
- Gel-filled
- Tapered

Tips:

- Shock-absorbing
- Pivoting
- Larger than conventional
- Round vs. angular (square, hexagonal)

Underarm Cradle:

- Curved vs. Streight
- Stabilized behind the user

Cuffs:

- with armature inside vs. without armature inside
- rotatable vs. Fixed
- with/without padded inserts
- closed (full) vs. open (half full) armband

Possible materials

Body:

- Wood (rosewood, oak, rock maple)
- Aluminum Alloys
- Steel
- Titanium
- End-plugs from solid brass
- Iron- tube
- Carbon Fiber
- IMD Plastic
- IMR Plastic

Grips & Underarm Cradle:

- Rubber (latex free)
- Leather Saddle
- PVC vinyl
- closed cell polyurethane pad covered with leather
- Urethane foam
- Neoprene Foam (with a nylon skin)
- Wood
- PP
- TPE

Tips:

- Rubber (latex free)

Cuffs:

- Stiff metal armature (inside)
- Nylon
- PA
- PP

Finish:

- natural luster
- black powder coating

Adjustable constructions

Figure 26. Rotating cuff for walking (left) and standing (right)

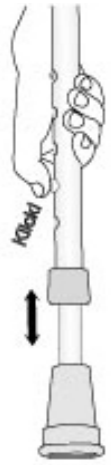


Figure 27. Height is adjusted by pressing a button.

Folding constructions

Figure 28.

There are different kinds of folding constructions of crutches (Figure 28). Sometimes internal elastic cord is used to prevent parts of a crutch from parting.

The folded crutch should be small enough to fit into a luggage or a bag

Sizing a forearm crutch

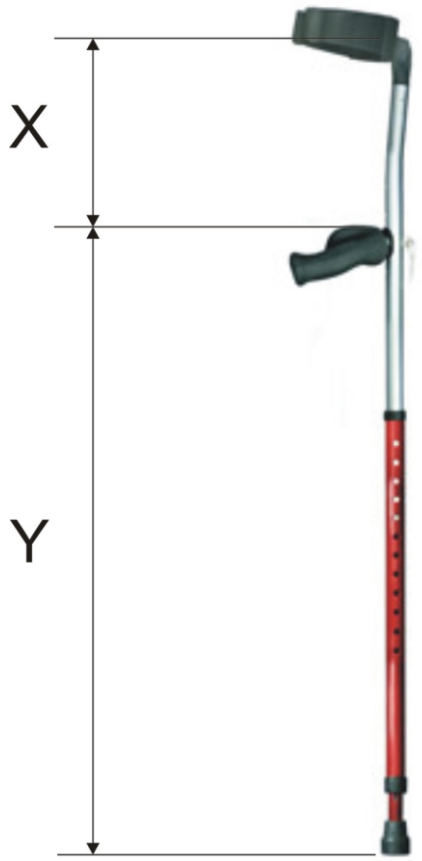


Figure 29.

Figure 30.

The "X" measurement will determine the position of the underarm piece in relation to the handgrip on the final crutch or crutches. It is the distance from your elbow, leaving ~ 8 cm, and your handgrip.

The "Y" measurement will determine the distance between your handgrip and the bottom of the crutch tip. The measurement must be taken when the elbow is flexed not more than 30 degrees.

Sizing an underarm crutch

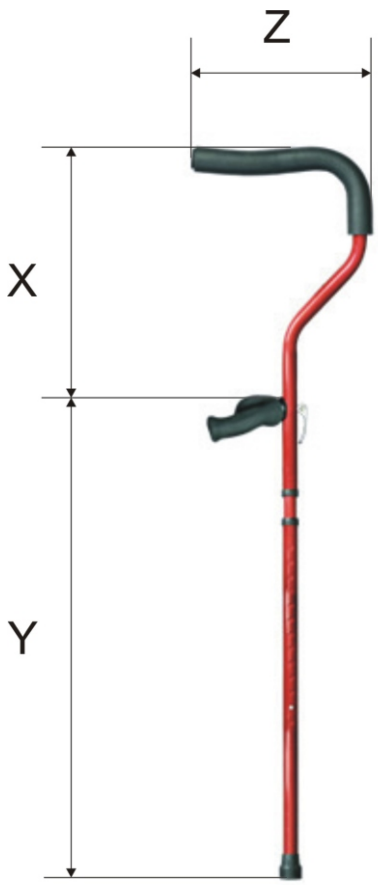


Figure 31.

Figure 32.

The "X" measurement will determine the position of the underarm piece in relation to the handgrip on the final crutch or crutches. It is the distance from your underarm to your handgrip when elbow is flexed not more than 30 degrees.

The "Y" measurement will determine the distance between your handgrip and the bottom of the crutch tip (the same distance as measuring the forearm crutch).

The "Z" measurement will determine the length of the cradle. This measurement depends on the thickness of users arm, but practically it is always a standard.

People's body heights in Sweden

- The dimensioning body height (5th to 95th percentiles) of women in Sweden varies between 156,2 and 178,9 cm. The lowest woman's height is 147,5 cm and the highest - 186,0 cm ((Sperling et al, 2007).
- The dimensioning body height (5th to 95th percentiles) of men in Sweden varies between 166,9 cm and 190,2 cm. The lowest man's height is 156,8 cm and the highest - 1970 cm (Sperling et al, 2007).

The shoe height (+2,5 cm) must be taken into account.

Sizes of adjustable crutches In the Swedish market:

Forearm crutches:

- Weight ~ 800 g
- Adjust. height ~ 75-98 cm
- Adjust. Upper part ~ 21-26 cm
- Max user weight ~ 120 kg

Underarm crutches:

- Weight ~ 880 g
- Adjust. Height ~ 110-130 cm
- Max user weight ~ 150 kg

This data shows that the offered production does not cover the whole range of people's heights due to products height adjustability limitations.
So it has to be different sizes of crutches offered for users.

The weight of a crutch is also very important as it has to support user's weight. The heavier user is, the heavier crutch s/he needs.

According to the survey, done by "Walk Easy", and user opinions review, many crutch users express a wish to be able to carry something like their personal belongings when using crutches.

The main issue with a bag on a crutch is to keep the weight balance. If there is a big difference in a weight of two crutches, it becomes harder to ensure stability. It is mostly relevant for weaker crutch-users. The weaker users prefer having a comfortable easy-to-reach bag on their bodies.

Moreover, ordinary bag is attached to a crutch only by handles and it swings during the walk (Figure 33). That is why it is better to use special crutch bag that is attached to a crutch in different places and do not swing during a walk (Figure 34).

Figure 33.

Figure 34.

The bag for storing crutches is also preferred by crutch users. There are some solutions of the bags for carring and/or storing foldable and not foldable crutches (Figure 35)

Having two bags at the same time is not very efficient, so the solution for this could be having two-in-one bag for carrying belongings and storing crutches.

Figure 35.

As it is seen from this research, the market of crutches has not evolved much during the time. There are plenty of problems that should be solved by industrial designers.

Both - physiotherapists and users are arguing which kind of crutches is better. There are many advantages and disadvantages of both of them and both kinds are still being used. Users, who like them both, have to have several pairs of crutches at home to be able to switch. The purpose of this project is to find a solution how to make such kind of crutch, which could give users possibility to change its type by not having to buy another pair and still keeping its mobility and good self-esteem.

Moreover, when traveling, it is more comfortable to have foldable crutches - to fit them into a bag, car's/train's/plain's compartments.

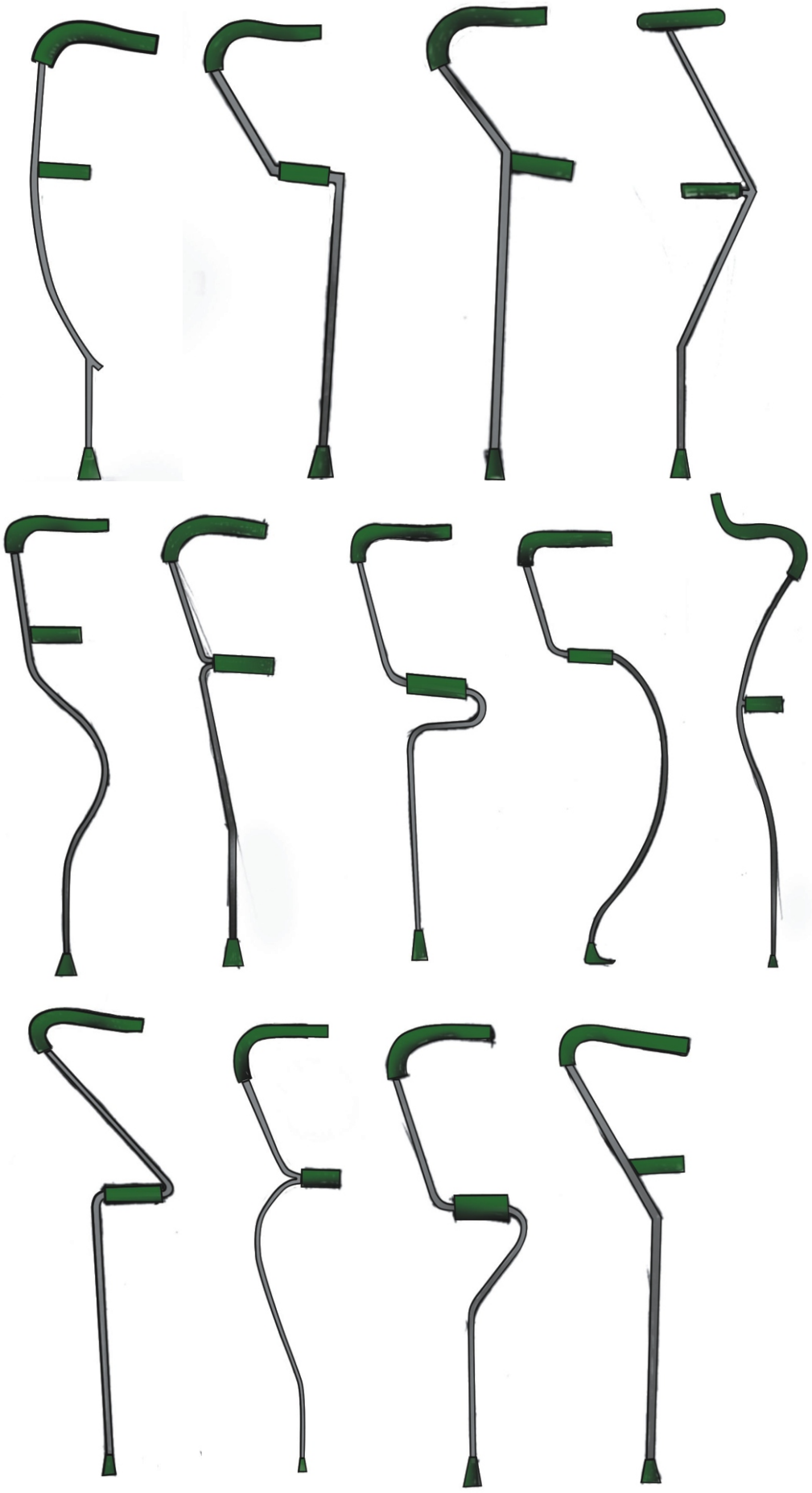
Design criteria

A crutch should:
- Give possibility to change a type of a crutch;
- Be foldable;
- Provide stability;
- Support user's weight;
- Provide mobility and comfort;
- Support user's self-esteem;
- Provide possibility to carry things when using crutches;
- Have possibility of being stored when not in use.

design phase

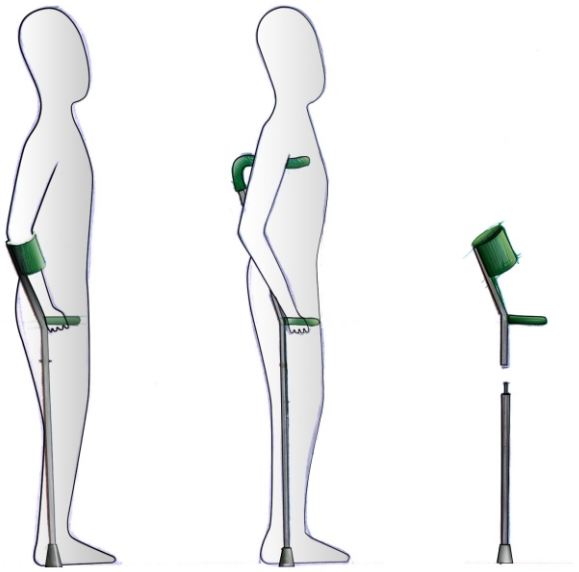
Shape of a crutch

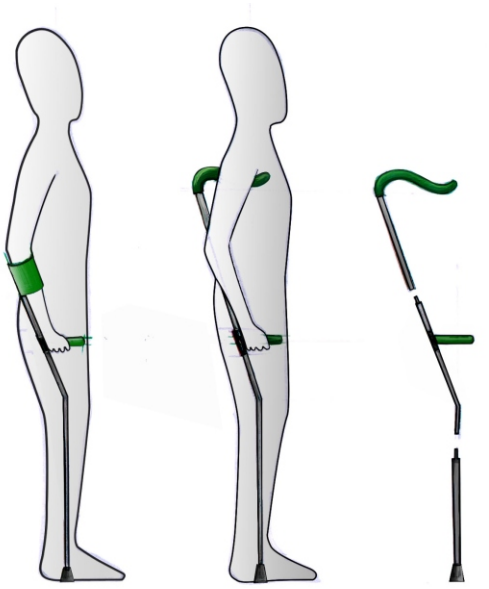
The first step of design phase was to find a shape of a crutch. Here are some examples of the brainstorming.



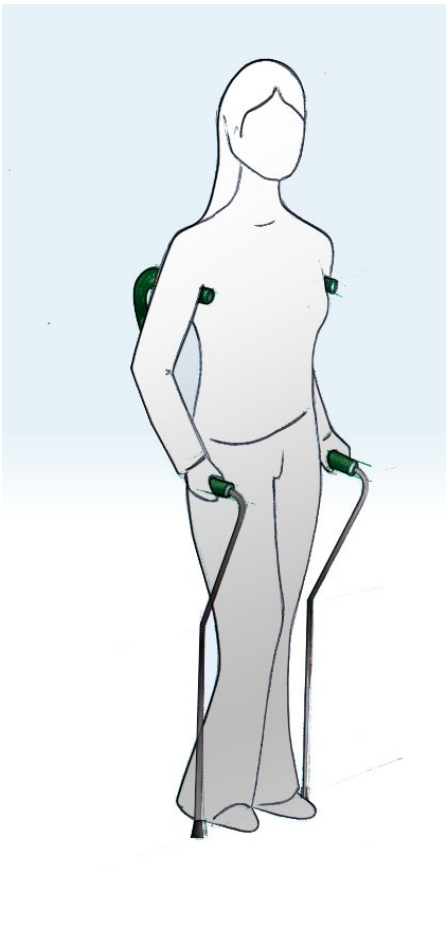
Construction of a crutch

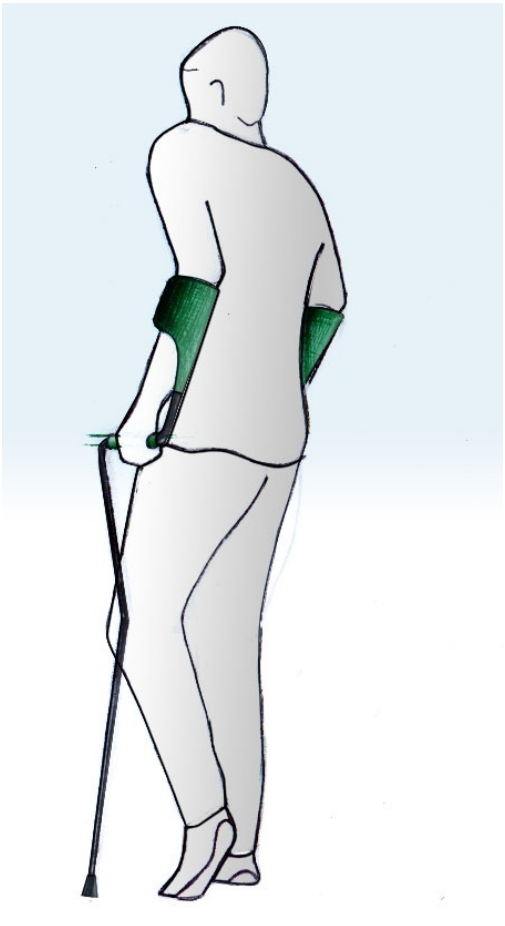
Four different shapes of a crutch were selected. The shape should allow a crutch to be foldable with changeable upper-part.



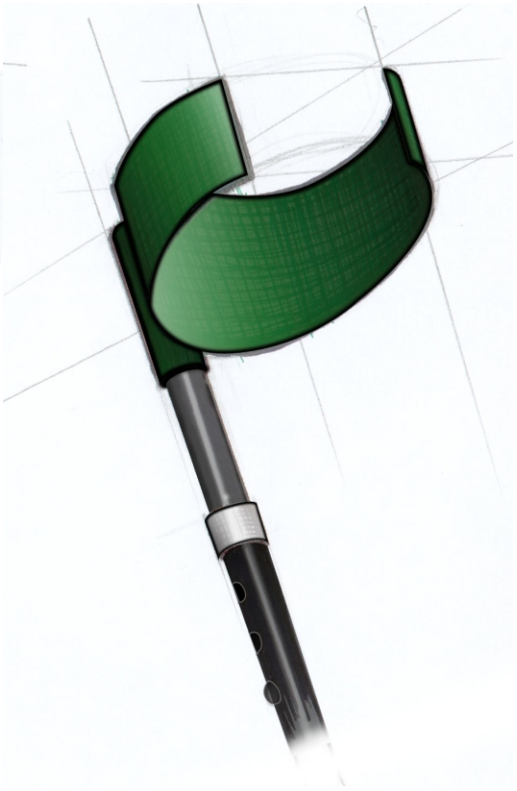


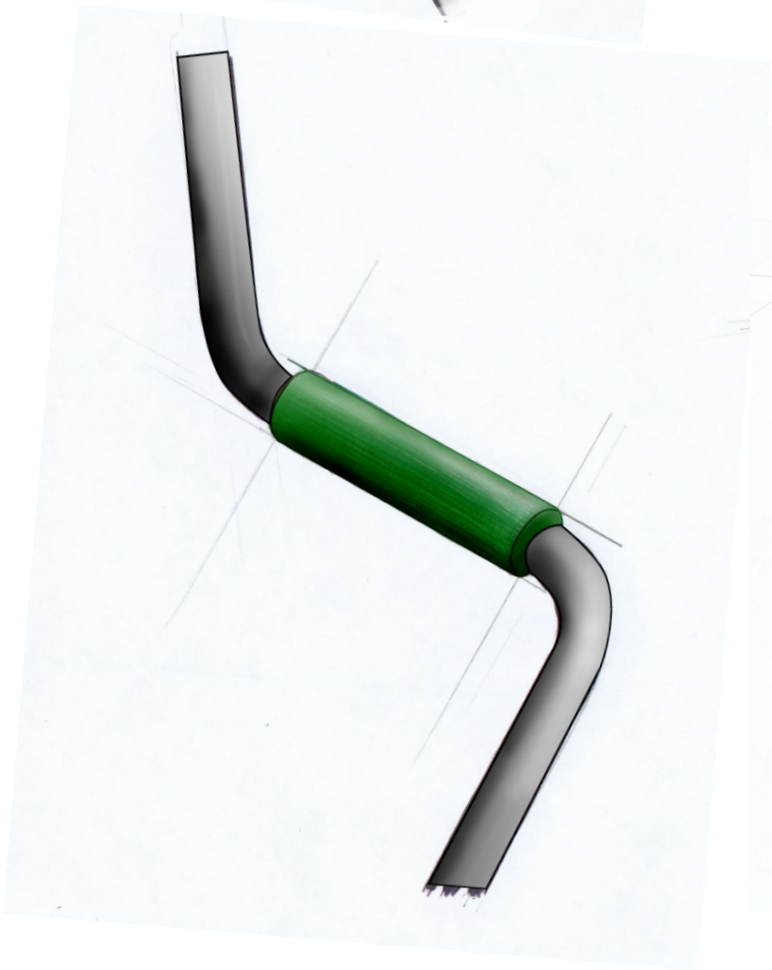
Chosen concept





Detailing





Detailing