CHAPTER 7: TRIALS AND DISCUSSIONS

For the purpose of testing both the manual and powered versions of self-transfer devices, trials were conducted involving potential beneficiaries. The following is the general procedure adopted for the conduct of the trials:

1. A pre-trial survey session, where each participant was asked his/her views on the need of a self-transfer device, in general.
2. Explanation of the working of both manual and powered self-transfer devices
3. Demonstration of transfer process.
4. Guided training sessions, on both the versions, to help the participants operate the transfer devices. During this session, the participants were made to practice the transfer process several times till they became comfortable in using the devices.
5. A testing session in which the participants were asked to transfer from an office chair with handle to a wheelchair and vice versa. A minimum of three such transfers were carried out with a gap of ten minutes between each transfer.
6. Finally, a post-trial survey session with each participant to record their assessment of performance on a five-point ‘likert scale’ with 1 implying ‘poor’ and 5 implying ‘excellent’

7.1. RESULTS OF PRE-TRIAL SURVEY SESSION

A pre-trial survey session was conducted to understand the views of the potential beneficiaries on the requirement of a transfer device. The questions asked to the participants during the pre-trial session and their responses are furnished in Table. 7.1. When asked, whether they need a self-transfer device attached to a wheelchair, all of
them responded with a ‘Yes’. All of them expressed that using a self-transfer device attached to the wheelchair would make their life easier. In response to the third question, five out of six participants did not prefer a caregiver to control the device. Only one participant wanted a caregiver to control the transfer device for him. All the participants replied in negative to the fourth question and were against a fully automated programmed device, without any need for them to control.

Table. 7.1. Responses to the Pre-trial survey questions

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Questions</th>
<th>Responses (n=6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Would you need a self-transfer device attached to a wheelchair?</td>
<td>6 -</td>
</tr>
<tr>
<td>2</td>
<td>Would using such a transfer device make your life easier?</td>
<td>6 -</td>
</tr>
<tr>
<td>3</td>
<td>Would you prefer a caregiver control the transfer device for you?</td>
<td>1 5</td>
</tr>
<tr>
<td>4</td>
<td>Would you prefer a fully automated programmed transfer device?</td>
<td>- 6</td>
</tr>
</tbody>
</table>

7.2. TRIALS USING MANUAL SELF-TRANSFER DEVICE

Five male participants (age: 35±7.9) with 90-95% disability and a female participant (age: 33 years) with 60% disability were involved in the trials using the manual self-transfer device. Four out of the five male participants had flexion contractures at knees. The disability ratings are based on extent of mobility, range of motion in joints, muscle strength, deformity, etc. as certified by the special medical board for disability assessment, Thanjavur Medical College, Tamil Nadu, India. The participants are beneficiaries registered with the District Disabled Rehabilitation Office, Thanjavur, Tamil Nadu, India. The trials were carried out in the presence of a senior physiotherapist and video recorded with consent from the participants. After
explaining the working of the device followed by demonstration of the transfer process and guided training sessions, each participant was asked to transfer from a chair to wheelchair and vice versa using the self-transfer device attached to the wheelchair. All participants could successfully perform the transfer process themselves. The time required for the transfer to one side was less than 45 seconds. In the post-trial survey session, the participants were asked to assess the performance by giving scores to specific features of the manual self-transfer device, such as comfort level of different motions (raise, turn and sit), cushioning of the saddle & under arm support, state of mind without any ‘fear of fall’ and overall comfort perceived in a five point ‘likert’ scale.

![Comfort scores for various features of manual self-transfer device](image)

Fig. 7.1. Comfort scores for various features of manual self-transfer device

The scores for various features given by the participants have been plotted in the column graph shown in Fig. 7.1. From the graph it can be seen that, five participants gave a score of four out of five and participant 2 gave a score of three for the comfort
during raise motion. All the participants provided full score for comfort during turn motion. The participants gave a mixed response for comfort during sit motion, where three participants gave a score of four while the remaining three gave a score of three. This implies that, the participants found the ‘turn’ motion to be the easiest among the three components of the transfer process as the effort required to turn the turntable is very minimal (average score of 5/5). A little effort is required during the ‘raise’ motion in the form of a soft forward push (average score of 3.8/5). ‘Sit’ motion has been rated relatively lower (average score of 3.5/5) by the participants as they had to apply a small additional counter force by pressing the chest against the saddle and a gentle downward force towards the end as explained in section 5.4. Even though one participant had preferred a caregiver to control the device for him, after the training and the trials he has also given a score of four out of five for the overall comfort. This shows that with the training, the transfer device can easily be operated by users. It was heartening to note that the all participants were comfortable with the saddle and did not have any ‘fear of fall’ while using the manual self-transfer and hence they gave full scores for the cushioning of the saddle & under arm support and state of mind without any fear of fall. The overall comfort score as perceived by the potential beneficiaries was four out of five and the individual scores for all the other features were three or above.

7.3. TRIALS USING POWERED SELF-TRANSFER DEVICE

Trials were conducted to test the powered self-transfer device, involving the same six participants. Here also during the testing session all the participants successfully got transferred themselves from a chair to a wheelchair and vice versa. It was observed that the time required for the transfer to one side took less than a minute. The transfer motion is deliberately made slow by employing linear actuators with a slow speed of
10 mm/s and by controlling the motor speed of the turntable to be around 3 rpm, so as to ensure smooth transfer. Like in the trials with manual self-transfer device, in the post-trial survey session, the participants were asked to rate the performance of the powered self-transfer device. The specific features of performance, addressed here are ease of achieving the transfer process, comfort of operating the joysticks, cushioning of the saddle & underarm support, state of mind without any ‘fear of fall’ and overall comfort perceived. A column graph as illustrated in Fig. 7.2 has been plotted using the scores provided by the participants.

From the graph in Fig. 7.2, it can be seen that the scores given by all the participants for ease of achieving the transfer process and overall comfort perceived by the participants were five except the participant 2, who gave a score of four. This can be attributed to his inhibition towards new devices or lack of confidence to operate new gadgets as he was the only person who desired a caregiver to control the transfer device in the pre-trial survey. After the hands on training and practice on the device, this participant gained confidence, was comfortable and hence provided a score of four for both the features. Thus, when more a user practices the transfer procedure, more the device becomes easy to use. Five out of six participants gave a score of four out of five for the comfort of operating the thumb joysticks. This can be understood from the fact that operation of a fist operated joystick is ergonomically more comfortable than the thumb operated joysticks. Due to space constraints of accommodating two joysticks for tilting and raising and also due to the fact that the user needs to hold the curved handle with the fist and simultaneously actuate the two joysticks, thumb joysticks are used in the design. All the participants gave a full score of five for cushioning of the saddle & underarm support and state of mind without any fear of fall. The overall higher ratings provided by the participants suggest that
the device can be used with ease and comfort. Thus, the results of the post-trial survey suggest that the participants are happy to use the device developed.

![Comfort Scores for Various Features](image)

**Fig. 7.2.** Comfort scores for various features of powered self-transfer device

In order to assess the physical strain associated with the handling of the devices for achieving the transfer process, pulse rate of each participant was monitored before and after the testing sessions of both manual and powered self-transfer devices. A pulse rate monitor employing finger plethysmographic sensor is used for this purpose. The average of the pulse rates of each participant measured after the testing session was then compared with the target zone [75] corresponding to that participant to assess the physical strain associated with the handling of the devices. The average pulse rates of all the participants were well within the normal range both before and after the trials. The maximum deviation is found to be less than two beats per minute, which is not significant. Moreover, the average pulse rates of all the participants after the trials were well within their target zones of heart rates pertaining to their age
group. The safest and most effective rate at which the heart beats during physical exertion is between 50% and 85% of maximum heart rate, this range is known as the target zone. This corroborates well with the higher scores provided by the participants for the comfort level perceived by them during the transfer. The working of the pulse rate monitor is briefly explained in Appendix E.

**7.4. COMPARISON WITH EXISTING SELF-TRANSFER AID SYSTEMS**

The performance of the powered self-transfer device developed in this work is compared with the three existing self-transfer systems that serve the purpose of mobility as well as self-transfer, reported in the literature review of chapter 2.

**7.4.1. Comparison with self-transfer aid device by Takahashi et al.**

The transfer aid device developed by Takahashi et al. is yet another locomotion system by itself and not an attachment to the wheelchair unlike the one developed in this work. As discussed in section 2.2.2, once the user is transferred on to the transfer aid device, he/she has to reach the toilet in a standing and bending forward posture itself. This is both physical and mental burden for a disabled person. On the other hand, using more than one locomotion system i.e. wheelchair for normal locomotion and transfer aid device for navigation to the bathroom is also a financial burden and inconvenience for the user. Further, in the design of the transfer device developed in this work, an epicyclic gear train is employed to achieve ‘turn’ motion and to ensure smooth and safe transfer of the user. Takahashi et al. had employed Omni-directional wheels for rotation and locomotion, which have inevitable slip phenomenon during locomotion. This may result in movement in an undesirable direction and to overcome this phenomenon more sophisticated control algorithm needs to be used. The device of Takahashi et al. uses two DOF, one for tilting the arm so as to straighten up the
user and the other for rotation, whereas the device developed in this work employs three DOF, one for tilting the arm to bring the user to a standing and bending forward posture, another for adjusting the height of the arm and the third for rotation. The additional degree of freedom to adjust the height of the arm facilitates reaching a comfortable standing and bending forward posture, which is an additional advantage.

7.4.2. Comparison with HLPR chair

HLPR chair has a complex design and is built on the basis of a fork lift. As mentioned in section 2.2.2, after approaching the toilet commode, the inner L-frame is rotated to orient the user above the toilet seat. Subsequently, the wheelchair seat should move backwards clearing the area beneath the user allowing him/her to be placed onto the toilet seat. For this, the user is lifted up using a torso lift along with a sling that lifts him/her from thighs as shown in Fig. 7.3(a). As it will be inconvenient for the user to remove clothes while the slings are attached, the HLPR chair users are expected to wear special clothes that will expose their bottom. This problem is not applicable to the powered self-transfer device developed in this work. The user can conveniently remove clothes in standing and bending forward posture during the end of stage 4 of the transfer motion as depicted in Fig. 7.3(b).

The device developed in this work, when attached to a wheelchair measures a length of 1.07 m and the maximum extended length after 180° rotation measures 1.20 m whereas the corresponding dimensions of the HLPR chair are 1.09 m and 1.45 m respectively. Hence the device could be accommodated inside a smaller bathroom of size 1.7 m long x 0.9 m wide as against 2 m x 0.9 m, required for accommodating HLPR chair.
Further, the transfer device can be easily detached from the wheelchair and hence during normal locomotion, the device need not be carried along with the wheelchair, whereas, HLPR chair carries the mechanisms and actuators required for lift and transfer operation along with it even during locomotion.

In addition, HLPR chair employs seven motors, one for lift operation and two each for steering & driving, seat & foot rest actuation and torso lift operations, making the device complex. The design of the powered self-transfer device developed in this work is economical and cost effective as it needs only three motors.

![Fig. 7.3. (a) User in the sling of HLPR chair above a seat (b) User in the standing and bending forward posture on the powered device developed](image)

**7.4.3. Comparison with TEK RMD**

TEK RMD is a mobility device that may be used as an alternative to a powered wheelchair specifically designed for paraplegic people, which the user needs to navigate in upright standing posture as shown in Fig. 7.4. The device is not recommended for all lower limb disabled individuals due to various reasons. As discussed in section 2.2.2, due to psychological and physical health factors, not all
wheelchair users can navigate in standing position. Further, TEK RMD is not suggested for disabled people with leg length discrepancy of more than 5 cm and individuals suffering from flexion contractures [76]. Many lower limb disabled people, especially individuals affected by polio suffer from leg length discrepancy and flexion contractures at hip, knees or ankles preventing them to stand in upright posture. In powered self-transfer device developed in this work, the user can navigate in the wheelchair with transfer device attached to it, in the sitting posture itself. Thus the device can be used by the people who even suffer from autonomic dysreflexia and hypotension while in an upright standing posture. Most of the participants involved in the trials of this work are affected by polio and have leg length discrepancy and flexion contractures at hip, knees or ankles. The device successfully transferred them with ease and comfort, proving that it can be suggested for individuals with such disorders. In TEK RMD also, as the fixing belts or the slings hold the user onto the device they cause hindrance to remove pants, so as to use the toilet.

Fig. 7.4. User in upright standing posture after being transferred to TEK RMD (Courtesy: M/s. Matia Robotics, USA)
The limitations/disadvantages of the above transfer systems when compared to the device developed in this work are compiled and furnished in Table. 7.2.

Table. 7.2. Limitations/disadvantages of the existing self-transfer devices

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Devices</th>
<th>Limitations/Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Transfer device by Takahashi et al.</td>
<td>• User needs to approach the toilet in standing and bending forward posture</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Omni-directional wheels require proper control to avoid slip</td>
</tr>
<tr>
<td>2</td>
<td>HLPR Chair</td>
<td>• Inconvenient to remove normal clothes so as to use toilet</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Complex design involving more actuators and sophisticated electronics making the system costly</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Requires a larger bathroom.</td>
</tr>
<tr>
<td>3</td>
<td>TEK RMD</td>
<td>• User needs to navigate only in upright standing posture</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Not suitable for individuals with:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>➢ Leg length discrepancy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>➢ Flexion contractures at hip, knees or ankles</td>
</tr>
<tr>
<td></td>
<td></td>
<td>➢ Autonomic dysreflexia</td>
</tr>
<tr>
<td></td>
<td></td>
<td>➢ Hypotension while being standing in upright posture</td>
</tr>
</tbody>
</table>

Based on the comparisons, it can be inferred that the transfer device developed in this work is more comfortable and economical than the other existing transfer devices.

Trials were also conducted using the manual and powered devices to transfer to a toilet commode and to a short stool, during which, the participants performed the transfer successfully by themselves. The transfer device is suitable for domestic as well as public environments without any structural modifications. The device requires a bathroom size of 1.70 m x 0.9 m with a doorway of width 0.7 m. The device can easily be accommodated inside the wheelchair accessible toilets in public places like
airports, railway stations, etc. which have dimensions of 2.415 m long x 1.525 m wide and having doorway of minimum width 0.815 m as per ICC A117.1-2009 standards for accessible and usable buildings and facilities [57], given in Appendix F.

7.5. SUMMARY
In this chapter, experimental trials that were carried out for testing the manual as well as the powered versions of self-transfer device have been presented. The trials validated the working of the design and the participants were able to use the transfer devices with ease. In addition to the opinion survey carried out on comfort and convenience of using the devices, the physical strain experienced by the participants were measured using a pulse rate sensor. As the variations in pulse rates before and after using the device were insignificant and also were within the target zones of the participants, the positive feedback given by the users is cross validated. Further the powered self-transfer device has been compared with the closest competing devices on various attributes to highlight the advantages.