# UNDERSTANDING HOW HARNESSING AFFECTS A USER'S WORKSPACE

Alix Chadwell[1], Laurence Kenney[1], Dave Howard[1], Robert Ssekitoleko[2], Brenda Nakandi[2], John Head[1]
[1]*University of Salford, UK,* [2]*Makerere University, Uganda*

## ABSTRACT

Despite the fundamental importance of reachable workspace in upper-limb prosthetics, to date there have been no studies on this aspect. We have developed a methodology to quantify the reduction in the reachable volume of body-powered prosthesis users due to harness setup, and to record the range-of-motion of the prehensor at a series of locations within the workspace. For this proof-of-concept study ten anatomically intact participants were assessed using a prosthesis simulator. Data was collected using a 3D motion capture system and an electronic goniometer. The harness/cable reduced the reachable workspace by 15-62% with participants struggling to reach across the body and above the head. Across all arm postures assessed, participants were only able to achieve full prehensor range-of-motion in 9%. The methodologies could be useful in guiding the setup of body powered prostheses and in the evaluation of future designs of both body-powered and myoelectric prostheses.

## INTRODUCTION

Reachable workspace is a key measure within the fields of upper-limb rehabilitation [1], [2] and robotics [3], with reduced workspace being shown to have a negative correlation with quality of life [4]. For upper-limb prosthesis users, the reachable workspace may be reduced due to a reduction in the degrees of freedom available in each of the joints (e.g. a prosthetic socket restricting full flexion of the elbow).

For a user of a body-powered prosthesis, the cable routing of the control harness can cause further restrictions, sometimes preventing the user from reaching certain parts of the workspace. Additionally, the ability of the user to fully exploit the 'Mechanical aperture RoM' of the prehensor may also be affected by the harness setup. Increasing the length of the cable during setup to increase the size of the reachable workspace, could negatively impact on the achievable aperture Range of Motion (RoM) so that the user cannot fully close a voluntary closing (VC) terminal device in some arm postures. Conversely, decreasing the length during setup, to ensure full closure is always possible, could prevent the user from fully opening the device in some arm postures, and from reaching certain parts of the workspace.

To reflect the need to find a compromise, various clinical guidelines have been developed; however, these vary and are somewhat vaguely worded. Further, whether any of the resulting setups are optimal in any formal sense is not known. Many prosthetists will rely on their own experience when setting up the harness system, and it is not known what the most common setups are.

The extent of the workspace limitations and the implications on function have not been explored. Until we have methods to quantify these limitations, design and setup decisions will be difficult to justify. Therefore, the aims of this proof-of-concept study were to develop suitable methods with which to quantify the limitations on both reachable workspace and the ability to fully exploit the 'Mechanical aperture RoM' of the prehensor within this space.

## METHODOLOGY

Ten healthy anatomically intact adults were recruited. Ethical approval for the study was granted by the University of Salford Health Research Ethics committee (REF: HSR1819-050) and informed consent was gained from all participants. Participants were assessed using a TRS body-powered prosthesis simulator, consisting of a right-handed wrist brace, a figure-of-9 (P-loop) harness, and a TRS Voluntary Closing GRIP3 prehensor. Motion data from body-worn and prosthesis-mounted reflective markers were captured at 100Hz using a 13 Oqus camera system (Qualisys, Gothenburg, Sweden), and an electronic goniometer (SG75, Biometrics Ltd) was attached across the mobile 'thumb' of the prehensor to measure prehensor aperture (opening and closing).

To assess the impact of the harness on the reachable workspace, participants attempted a series of arm sweeps around the body under two conditions: unharnessed and harnessed. To capture the reachable workspace, participants were asked to sweep their hand through 9 arcs with the elbow fully extended (note that the contralateral (left) shoulder remained in a neutral position throughout). These arcs were parallel to the frontal, sagittal, and transverse planes as shown in Figure 1.

The next part of the experiment was to evaluate the extent to which the participant could open and close the prehensor within their reachable workspace. Whilst holding the prehensor in a range of pre-specified locations around the body, participants were asked to open and close it as far as possible by only abducting and adducting the contralateral (left) shoulder.

3D marker co-ordinates from the prosthetic 'finger', right shoulder, and a cluster of three markers on the sternum were exported from Qualisys, and data processing and analysis was undertaken using Matlab (Mathworks Ltd). This included:

- Filtering of 3D co-ordinates and goniometer data.
- Rotation of 3D co-ordinates from the lab frame into a co-ordinate frame based on the sternum.
- *Reachable Workspace:* Calculation of the convex hull surrounding the 3D co-ordinates from the 'finger' marker and the sternum origin marker using the Matlab alpha shape function.
- *Reachable Workspace:* Removal of the surface of the convex hull behind the person's back which joined the extremes of the arc sweeps. This was replaced by a surface joining these perimeter points to the sternum (Figure 2). The removed space corresponds to an area of the volume which the participant was unable to reach, thus overestimating the reachable volume.
- *Reachable Workspace:* Volume calculated.
- *Control Over Prehensor Aperture:* Grouping of hand positions into segments around the body.
- *Control Over Prehensor Aperture:* Mean Achievable aperture Range of Motion calculated for each segment.
- *Control Over Prehensor Aperture:* Results presented according to 8 segments around the body, 5 segments up/down the body, and 3 segments radially away from the body. All segments centered on the right shoulder.

## RESULTS

Across all ten subjects, the harnessed reachable volume was approximately 70% of the unharnessed volume. At best there was a 15% reduction in the reachable volume when wearing the harness, and at worst a 62% reduction. Figure 3 shows example data from a participant with a large reduction in their reachable workspace (unharnessed volume = 1.25 $m^3$, harnessed volume = 0.49 $m^3$) as viewed from the front. When the control harness was connected, this participant struggled to reach their arm above the horizontal and across the body to the left-hand side.

All participants found it harder to open the prehensor in postures where the arm was crossed over to the left side of the body or when the arm was higher than the sternum as the harness was too tight to achieve full opening. Some participants also struggled to close the prehensor when the arm was on the right-hand side of the body as the harness became too slack. For most participants, as the arm moved down the body, the achievable aperture RoM increased. However, for some the increased slack in the system meant that the cable length increased to a level where they struggled to close the prehensor in the lower segments. When participants operated the prehensor near to their chest, very few were able to open the prehensor beyond 50% aperture. As they extended their arm away from the body, the achievable aperture RoM generally increased.

Participants were only able to achieve the full 'Mechanical aperture RoM' in 9% of postures assessed. In 38% the achievable aperture RoM was <=50% of the 'Mechanical aperture RoM'; in ~2/3 of these the participant struggled to open the prehensor and in the other ~1/3 they struggled to close the prehensor.

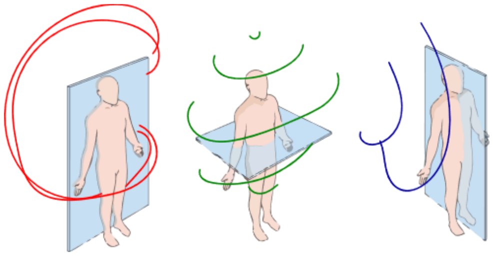

*Figure 1: To calculate the reachable volume, the arm was swept through 9 predefined arcs in the frontal, transverse, and sagittal planes. These data were later combined to generate a 3D point cloud of fingertip positions.*

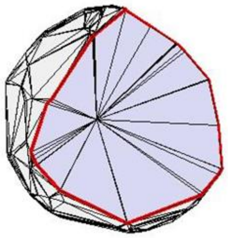

*Figure 2: A convex hull surrounding all the 'finger' marker locations and the sternum marker was generated. The area connecting the extremes of the movement arcs behind the person's back was removed and replaced by a surface joining these extremes to the sternum to avoid overestimation of the workspace volume.*

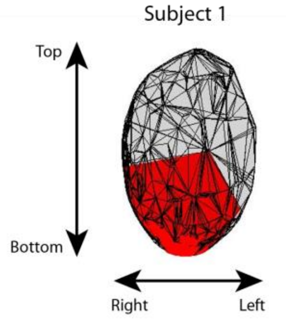

*Figure 3: 3D reachable volume as viewed from the front. The combined volume shown in both grey and red is the unharnessed reachable volume, and the smaller red sub-volume is the harnessed reachable volume.*

## DISCUSSION

This study has introduced novel methods for evaluating reachable workspace and user control over prehensor aperture for a body-powered prosthesis. Clearly, an 'ideal' prosthesis would offer the user the ability to position and orient the prehensor at will within his/her unrestricted workspace, and to fully exploit the 'Mechanical aperture RoM' anywhere within this volume. The methods introduced here provide an objective approach to evaluating how far a given design is from this ideal.

Participants encountered major restrictions to both their reachable workspace and their ability to fully exploit the 'Mechanical aperture RoM' with their arm in different postures throughout the workspace. This is perhaps unsurprising and already recognized as an issue by clinicians who recommend a few different approaches to setting the cable length [5]-[7]. It is worth noting that the setup procedure used in this study (which was non-standard due to pilot work highlighting the infeasibility of employing standard approaches) resulted in a longer cable setups than the traditional approaches, and as such, these traditional approaches could result in an even greater reduction in reachable workspace and a greater number of positions where the user achieves <=50% of the full 'Mechanical aperture RoM'. These methods could be used to objectively evaluate alternative setups.

This proof-of-concept study offered a novel approach to the quantification of a body-powered prosthesis user's reachable workspace and their ability to exploit the 'mechanical aperture RoM' of the prehensor within that workspace. To interpret the results of our study and similar future studies there is a need to better understand the implications of a reduced reachable workspace and aperture control limitations for the user's daily life. The emerging field of real-world monitoring of prosthesis use [8], [9] may offer useful approaches which could be exploited here.

## ACKNOWLEDGEMENTS

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## REFERENCES

[1] R. Matthew, G. Kurillo, J. Han & R. Bajcsy. "Calculating reachable workspace volume for use in quantitative medicine." *European Conference on Computer Vision Workshops*, pp 570-583, 2014.

[2] G. Kurillo, A. Chen, R. Bajcsy & J. Han. "Evaluation of upper extremity reachable workspace using Kinect camera." *Technology and Health Care*, vol 21 (6), pp 641-656, 2013.

[3] J. Zhao, Z. Feng, F. Chu & N. Ma. "Chapter 5 - Workspace of the End Effector of a Robot Mechanism" *Advanced theory of constraint and motion analysis for robot mechanisms.* pp 159-200, 2014.

[4] A. Ngan et al., "Functional workspace and patient-reported outcomes improve after reverse and total shoulder arthroplasty," *J. Shoulder Elb. Surg.*, vol. 28 (11), pp 2121–2127, 2019.

[5] "Checkout of below-elbow prostheses." in *Upper-limb prosthetics*, 1979 Revis., New York University Post-Graduate Medical School Prosthetics and Orthotics. ISSN 0309-3646

[6] "TRS prosthetic simulator instructions." [Online]. Available: www.trsprosthetics.com/wp-content/uploads/2018/02/Simulator-Instructions.pdf [Accessed. 09-Dec-2019]

[7] "Adjustments of Transradial Body Harness - YouTube." [Online]. Available: https://www.youtube.com/watch?v=uaXP7A2DLik. [Accessed: 09-Dec-2019].

[8] A. Chadwell, L. Kenney, M. Granat, S. Thies, J. S. Head, and A. Galpin, "Visualisation of upper limb activity using spirals: A new approach to the assessment of daily prosthesis usage." *Prosthet. Orthot. Int.*, vol. 42 (1), pp 37–44, 2018.

[9] A. Chadwell et al., "Upper limb activity in myoelectric prosthesis users is biased towards the intact limb and appears unrelated to goal-directed task performance," *Sci. Rep.*, vol. 8 (1), pp 1–12, 2018.