Externally Powered Prosthetic Wrist Flexion Device

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BACKGROUND Externally powered prosthetic wrist rotators have been used by individuals with upper limb loss for over 20 years [1, 2]. The recent availability of an externally powered prosthetic wrist flexion device raises these two questions: 1) what are the functional benefits for individuals with upper-limb deficiencies of an externally powered wrist flexion device, and 2) are there advantages to externally powered wrist flexion over externally powered wrist rotation?

AIM
It is the aim of this paper to help physicians and prosthetists to determine when an externally powered wrist flexion device might benefit their patients with upper-limb deficiencies.

METHOD
A wrist flexion device for a remnant limb that has an intact elbow and shoulder was designed and evaluated. Three steps in the process were: 1) kinematic analysis comparing the functionality of powered flexion versus powered rotation 2) development of design objectives, and 3) obtaining of user feedback from individuals using powered flexion prostheses.

A kinematic analysis showed the hand orientations that are possible with different types of wrist. For instance, the analysis showed how well a user could use such objects as a flashlight, a fork, or a personal cleaning device. We compared the use and viability of a Powered Flexion Wrist system, a system with no wrist, a system with a wrist rotator, and a system with both wrist rotator and wrist flexion. The analysis was performed using standard joint space calculations.

Following the kinematic analysis, design objectives for the powered flexion unit were developed based on input from prosthesis users, industry experts, and the literature. These design objectives drove the development of the Powered Flexion Wrist (PFW) unit.

Once designed and developed, two rounds of field trial participants were recruited for PFW evaluation, for a total of eight responses. Participants' evaluation of the PFW was performed through a questionnaire asking the participants to evaluate different aspects of the device on a scale from -2 to 2, which -2 being highly unsatisfied and 2 being very satisfied.

RESULTS

Kinematic analysis
The kinematic analysis of the four wrist systems shows that a flexion wrist enables a different type of workspace from that of a wrist rotator [3]. The analysis also shows that a system with both wrist rotation and wrist flexion enables the most complete workspace (Figure 1). If the user and prosthetist need to choose between either flexion or rotation, they should choose the wrist which aligns most with the individual's desired functional outcomes. However, a wrist with both flexion and rotation will enable more achievable orientations of the hand, and therefore significantly greater and more natural functions.

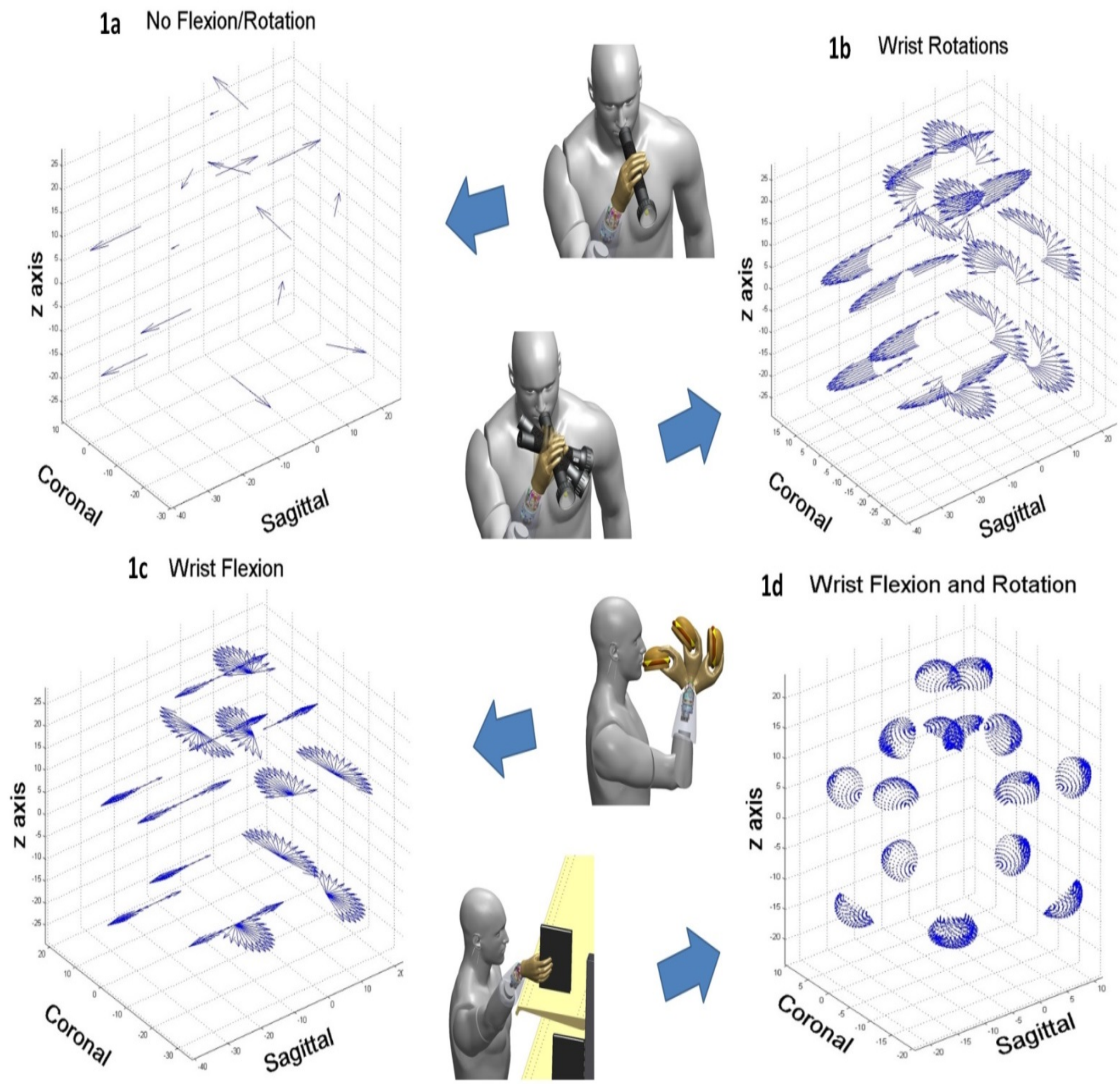

Figure 1: Results of kinematic analysis of 4 different wrist systems. 1a shows the workspace of a system with no wrist. 1b shows the workspace of a system with a wrist rotator. 1c shows the workspace of a system with a wrist flexion device. 1d shows the workspace of a system with both wrist rotation and wrist flexion. Note that the vectors or arrows in 1a, 1b, and 1c show the possible orientation of the axis of a cylindrical object, such as a flashlight, grasped transverse in the hand. However, in figure 1d, which shows that the user can orient a grasped object in virtually any direction, only the end points of the possible vectors are shown for clarity.

Design objectives

The design objectives and achieved results of the PFW are shown in Table 1, along with the specifications of the powered flexion for comparison. Notice that the weight achieved is lower than the target, but still higher than the wrist rotator alone.

	Target	Achieved	PFW+ Wrist Rotator
Length (not including QD) (mm)	57	66	70
Diameter (mm)	48	48	47
Weight (grams)	340	259	259 + 143 = 402
Active Torque Max (Nm)	2.8	2.3	1.7
Passive Torque Max (Nm)	2	2.3 (1.7)	Na
Rotational Travel (Degrees)	145	153	360
Rotational Speed (rev/s)	0.5	0.5	0.533
Bluetooth	yes	yes	yes
IPX7 tested	pass	pass	pass

Table 1: Design objectives and results of the Powered Flexion Wrist. As a reference, the specifications of the PFW + Wrist Rotator, also produced by Motion Control, are also shown.

Field Trial
A total of eight individuals, in two cohorts, evaluated the PFW for at least two months. After the first trial, the wrist was refined before being tested by the second cohort. At the end of the evaluation period, each individual provided feedback through a survey. Figure 2 shows the results of the survey [4,5]. The data shown is the sum of all user responses, separated by cohorts.

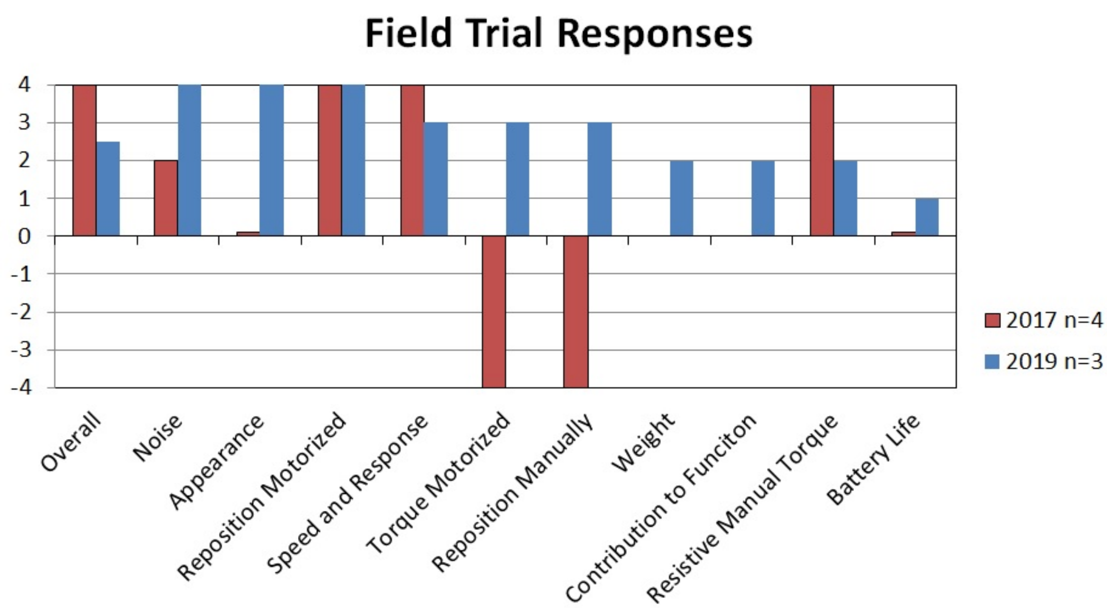

Figure 2: Field Trial responses of the two cohorts.

The first cohort was dissatisfied with the motorized torque and the manual repositionability of the PFW. Between the two field trials, the motor torque and the manual repositionability were improved, as can be seen by the second cohort evaluation data. Overall, prosthesis users evaluated the PFW favourably.

In the process of administering the final prosthesis user survey, other factors were discussed by individuals which are important to note. Two of the final prosthesis users desired the PFW to be shorter. Two of three individuals also mentioned a decrease in system battery life when using the PFW, especially with a pattern recognition system.

DISCUSSION

From the kinematic analysis, it is clear that one type of wrist does not fully define the workspace. The data shows that the PFW is beneficial for tasks requiring access to the midline of the body, such as eating and dressing, or picking things off the floor or table (Figures 3). Other tasks, such as unscrewing a bottle or turning a key, are more easily accomplished using a wrist rotator. An ideal solution would be to have both a rotator and a PFW, since the workspace is greater. However, length, weight, battery life, and the need to control so many degrees of freedom must be taken into consideration for different individuals.

Figure 3: Individual executing tasks using the Powered Flexion Wrist.

If only one wrist function can be integrated into a prosthetic system, the prosthetist should recommend the wrist which best matches the desired functional outcomes of the individual.

Although the weight of the PFW is heavier than the wrist rotator alone, it is interesting that the field trial participants did not rate the wrist as being too heavy. One respondent made the point that if the device is functional, the weight is secondary.

The first set of feedback motivated a design change in the transmission, which increased both the passive positionability and the active torque of the system. The second set of feedback indicates that the current design is acceptable.

CONCLUSION

The kinematic analysis and the results from user questionnaires clearly show that a Powered Flexion Wrist offers potentially significant functional benefits for individuals with upper-limb loss. When choosing an appropriate wrist, one must consider the types of tasks desired to be performed and the person's functional workspace.

DISCLOSURE

Fillauer manufactures externally powered and passive flexion and rotation devices.

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ACKNOWLEDGEMENTS

This work was financed by the Fillauer Corporation (Fillauer makes externally powered and passive flexion and rotation devices) and United States Congressionally Directed Medical Research Program (CDMRP).