A PILOT EVALUATION OF KINEMATIC CHANGES WITH POWERED WRIST FLEXION FOR TRANSRADIAL PROSTHETIC USERS USING THE GAZE AND MOVEMENT ASSESSMENT (GAMA) METRIC

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ABSTRACT

Wrist function is essential for correct positioning of the hand; however, few available prosthetic wrists provide powered flexion/extension. Users must compensate for this lack of function by performing compensatory body movements that may cause injuries and lead to device abandonment. Using the Gaze and Movement Assessment (GaMA) metric, we evaluated task timing, endpoint trajectories and 3D angular joint kinematics when using a 1-DOF wrist compared to a 2-DOF wrist in combination with a 1-DOF hand. We hypothesized that with the 2-DOF wrist, kinematics would be more similar to normative data and that users would perform fewer compensatory movements than when using the 1-DOF wrist.

INTRODUCTION

During the past decade, terminal devices available to upper limb prosthesis users have improved significantly, to the point where several powered multi-degree-of-freedom (DOF) hands that provide individually articulating fingers are commercially available. Such devices have the potential to significantly improve functionality; however, movement of the wrist to correctly position the hand in space is necessary for optimal functional use of the arm and hand [1]. Work by Montagnani et al. highlighted the importance of wrist dexterity [2]. In this work, individuals with intact limbs performed several functional tasks while wearing braces to block use of certain wrist and hand DOFs. Subjects performed poorest using a 1-DOF wrist + 1-DOF hand and best using an intact, unconstrained hand and wrist. Interestingly, performance with a 2-DOF wrist + 1-DOF hand and a 1-DOF wrist + multi-DOF hand were equivalent, indicating the importance of wrist movement in compensating for limited hand function.

Evaluating the benefit of new components and control mechanisms can be challenging, as most validated outcome measures assess the time required to complete various tasks without assessing the quality of the movement or the specific DOF(s) activated to accomplish the task. The Gaze and Movement Assessment (GaMA) metric, developed

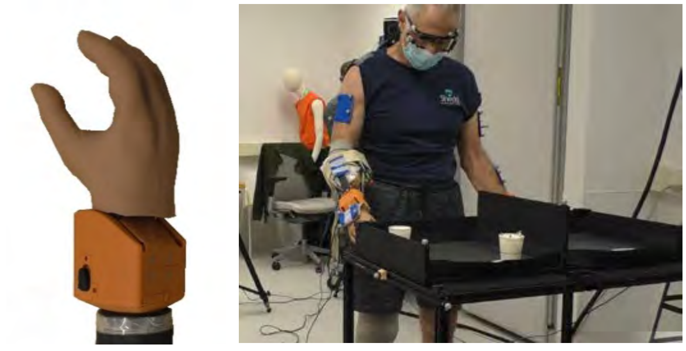

Figure 1: a) Device used for the study. b) Participant wearing the device, in "home" position, ready to begin the Cup Transfer Task.

and validated at the University of Alberta under the DARPA's Hand Proprioception and Touch Interfaces (HAPTIX) program, quantifies motion (three-dimensional angular kinematics and hand movements) and gaze behaviour during simulated real-world tasks [3-6]. The two tasks utilized for the GaMA, the Cup Transfer Task and the Pasta Box Task, require movements representing day-to-day functional requirements, while challenging typical prosthetic limitations such as reaching and transporting objects at varying heights and across the body, with elements of risk and collision avoidance (Fig. 1b). Each task can be subdivided into specific phases of reaching, grasping, transporting and releasing objects. A performance aspect encourages the participant to work efficiently, and tasks are short to allow multiple repetitions within a reasonable testing time frame to assess performance consistency.

A powerful aspect of GaMA data analysis is the ability to assess differences across various phases of each movement and each task. These results provide valuable information not only on proximal joint and body compensatory movements, but on control of the terminal device and motor variability. We hypothesized that the time to complete the task would be slower when the additional wrist flexion/extension degree of freedom was utilized but the compensatory movements, specifically the trunk and shoulder, would be decreased.

METHODS

One individual, a 73-year-old male individual with a transradial level amputation, was fit with a 2DOF wrist and OttoBock Transcarpal hand (Figure 1a). The wrist allows for 351 degrees of rotation and 100.5 total degrees of flexion (58 degrees) and extension (42.5 degrees). The prosthetic components were connected to a test socket, which was fit with an Ossur upper limb silicone liner and a lanyard suspension (Figure 1b).

Marker plates were placed on the upper arm, forearm, dorsal hand, trunk, and pelvis and individual markers were placed on the index finger and thumb. The participant wore Pupil Labs Core eye-tracking system, with 4 additional markers connected to the frame for tracking of head movements. Markers were placed on the wrist, epicondyles and torso for calibration. After calibration, the participant was instructed how to perform the task and was able to practice, with guidance from an Occupational Therapist, prior to data collection. The task, performed standing, was the Cup Transfer Task of the Gaze and Movement Assessment (GaMA) [3]. During the Cup Transfer Task, a cup close to the participant was first picked up from the top and moved across a divider (M1). Then a second cup, further from the participant, was picked up from the side and moved across the divider (M2). The two cups were then returned to the original position, in the reverse order (M3 and M4). In between moving the cups from one side of the divider to the other, the hand returned to a "home" position on the side of the table. During the practice and data collection session, the device was controlled by an engineer connected to the system via a bluetooth connection. As the user practiced and performed the task, he verbally indicated to the engineer his desired movements. This strategy reduced the impact of inadvertent movements and fatigue, while allowing the evaluation of the impact of the wrist movement on the timing and joint kinematics. Each cup movement was divided into 4 phases: Reach, Grasp, Transport and Release.

Two sets of data were recorded. For the first set, the participant was able to request hand open and close and wrist rotation movements; the wrist flexion was kept in a neutral position. For the second set, the participant was also able to request wrist flexion and extension movements. Data were collected until six trials were completed without errors for each configuration set. The data compared between the two configurations included the timing for the reach, grasp, transport and release phases of each movement, the endpoint trajectory, and the joint kinematics. The study was approved by the Northwestern University IRB.

RESULTS

As expected, trials in which the participant utilized the wrist flexion and extension (FE On) took longer than those when only the wrist rotator was used (41.69s$\pm$4.75 vs 28.43s$\pm$4.57). The additional time was primarily in the "Reach" phase of the movements, as the individual was prepositioning the device. (Figure 2).

Though the mean distance travelled of the hand endpoint for the various movements was not notably different between conditions, except for M2, the path travelled was visually different, especially for M2 and M3, with wider trajectories for the movement of the cup further away from the participant back to the original position with FE off.

Joint kinematics were calculated for the 2 conditions and compared to normative data (n=14). Though the prosthetic user did include wrist flexion and extension movements during the task with FE on, the average range of motion used was less than that of the normative population (34 degrees vs 92 degrees).

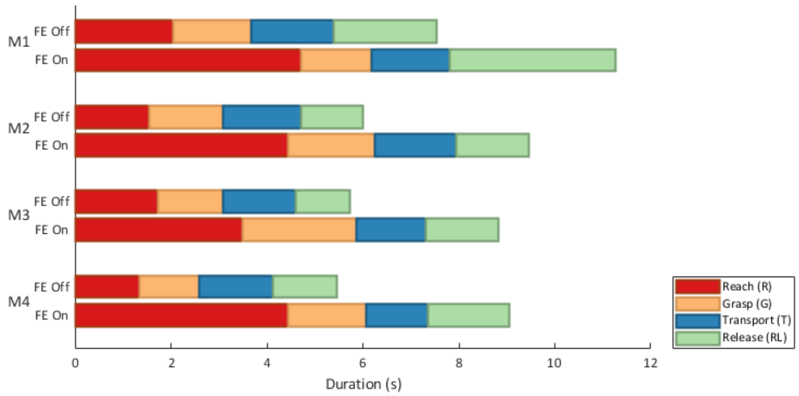

Figure 2: Breakdown of the timing of the 4 different cup movements, M1-M4.

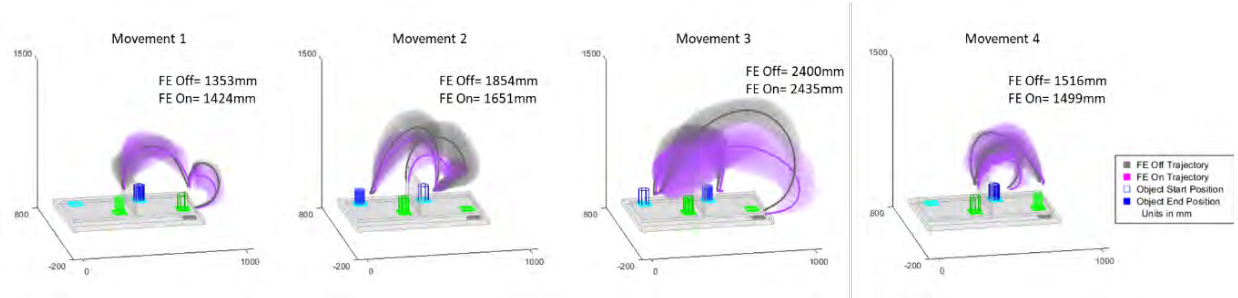

Figure 3: Trajectory of the prosthetic hand during the 4 movements: average with + 1 standard deviation (SD) shaded. The mean overall distance of each curve (in mm) is shown for both conditions.

Table 1: Total range of motion (in degrees) at each DOF. Prosthesis user data indicates mean across trials [between-trial SD]. Normative data indicates mean of participant means [between-participant SD].

	Wrist FE OFF	***Wrist FE ON***	***Normative***
Trunk Flexion/Extension	21.1 [1.6]	17.3 [0.8]	18.7 [5.9]
Trunk Lateral Bend	24.5 [3.0]	18.1 [2.2]	11.6 [2.8]
Trunk Axial Rotation	25.3 [1.0]	21.9 [2.3]	17.5 [4.3]
Shoulder Flexion/Extension	59.3 [5.4]	60.5 [3.4]	73.3 [8.6]
Shoulder Abduction/Adduction	42.3 [5.1]	44.1 [7.2]	35.9 [5.4]
Shoulder Internal/External Rotation	60.0 [6.4]	55.2 [8.8]	59.9 [8.4]
Elbow Flexion/Extension	64.3 [5.4]	68.5 [7.5]	96.4 [7.9]
Pronation/Supination	20.3 [1.6] *	20.9 [2.9] *	78.5 [9.0]
Wrist Rotation	6.6 [2.4]	65.1 [30.2]	
Wrist Flexion/Extension	10.1 [2.1] *	33.8 [6.7]	91.8 [10.4]
Wrist Ulnar/Radial Deviation	8.8 [1.4] *	10.0[1.6] *	32.1[7.1]

* Participant did not have access to these DOFs. Non-zero values are the result of error in the system, or inadvertent marker movement/socket movement

Lateral trunk bend and axial rotation showed an increased total range of motion when comparing normative values to Flexion On and Flexion Off conditions (Table 1). The prosthetic user also used less shoulder flexion/extension and elbow flexion/extension compared to normative. The prosthetic user held his arm in a more adducted position early in the task in both conditions compared to normative data with a slight increase in total ROM for shoulder abduction/adduction for both conditions.

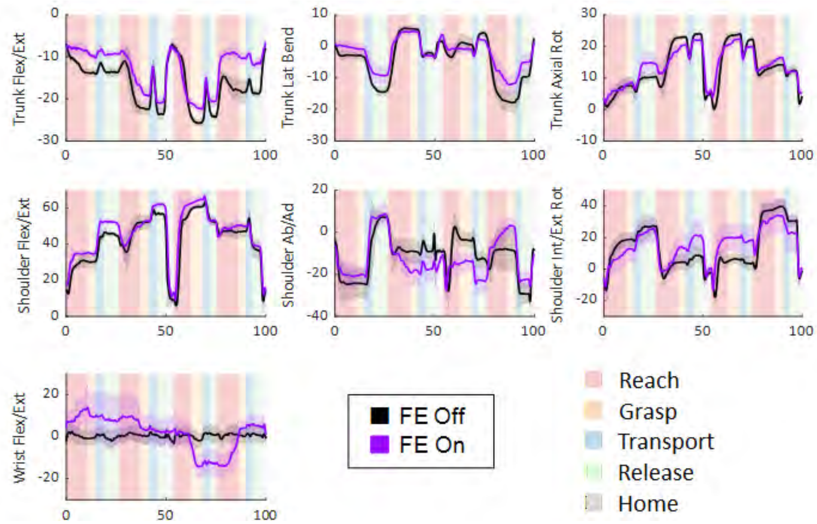

Figure 4: Time Normalized Joint Kinematics. Top row (L-R) Trunk: Flexion/Extension, Lateral Bend, Axial Rotation. 2nd Row (L-R) Shoulder: Flexion/Extension, Ab/Adduction, Internal/External Rotation; Bottom Row: Wrist Flexion/Extension. Vertical shading behind the plots represents the phases of the task.

DISCUSSION

As hypothesized, utilization of the additional degree-of-freedom (wrist flexion and extension) did increase the time required to do the task. The range of motion utilized at the wrist was much less than normative data. However, there were changes in the hand trajectory as well as the joint kinematics. In both conditions, the prosthesis user employed more trunk lateral bending and axial rotation compared to the normative population. However, the addition of wrist flexion and extension did appear to reduce the overall peak-to-peak to values closer to the normative values. The shoulder motion was different from normative, with less flexion and more abduction/adduction range utilized in both conditions.

There are limitations to this pilot study. In order to ensure that the device was moving as desired without any inadvertent movements from poor control or fatigue, the user orally indicated his desired movements. An engineer then drove the device as instructed. Though the participant had used a multifunction wrist system in the past as part of other research studies, the individual evaluated did not have the opportunity to control the prosthesis in a home environment. It is expected that additional training and usage will allow future users to more naturally include the additional degrees of freedom into various tasks. This may continue to improve how the users coordinate trunk and shoulder movements to perform the task. Based on this initial study, with the addition of wrist flexion and extension, we continue to expect improvements in trunk and shoulder compensatory movements.

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REFERENCES

[1] B. D. Adams, N. M. Grosland, D. M. Murphy, and M. McCullough, "Impact of impaired wrist motion on hand and upper-extremity performance," *J Hand Surg Am,* vol. 28, no. 6, pp. 898-903, Nov 2003.

[2] F. Montagnani, M. Controzzi, and C. Cipriani, "Is it Finger or Wrist Dexterity That is Missing in Current Hand Prostheses?," *IEEE Transactions on Neural Systems and Rehabilitation Engineering,* vol. 23, no. 4, pp. 600-609, 2015.

[3] A. M. Valevicius *et al.*, "Characterization of normative hand movements during two functional upper limb tasks," *PLOS ONE,* vol. 13, no. 6, p. e0199549, 2018.

[4] A. M. Valevicius *et al.*, "Characterization of normative angular joint kinematics during two functional upper limb tasks," (in eng), *Gait Posture,* vol. 69, pp. 176-186, Mar 2019.

[5] H. E. Williams, C. S. Chapman, P. M. Pilarski, A. H. Vette, and J. S. Hebert, "Gaze and Movement Assessment (GaMA): Inter-site validation of a visuomotor upper limb functional protocol," (in eng), *PLoS One,* vol. 14, no. 12, p. e0219333, 2019.

[6] E. B. Lavoie *et al.*, "Using synchronized eye and motion tracking to determine high-precision eye-movement patterns during object-interaction tasks," (in eng), *J Vis,* vol. 18, no. 6, p. 18, Jun 1 2018.