IMPACT OF UNILATERAL TRANSRADIAL PROSTHESIS IN UPPER LIMB UTILIZATION RELATIVE TO ABLE-BODIED CONTROLS: INSIGHTS FROM WIRELESS ACCELEROMETER DATA

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ABSTRACT

Hand loss profoundly impacts daily functioning. The use of an upper limb prosthesis can restore a measure of both unimanual and bimanual upper limb function for this population. We asked unilateral, transradial amputees (N=22) and healthy controls (N=20) to wear wireless accelerometers on their forearms and distal prostheses, as well as on their upper arms bilaterally to capture data over 3 days while the subjects were in their natural environments. Prosthesis users wore their devices an average of 11 hours/day. They exhibited heavier reliance on their sound side upper limb than on their affected limb. However, they were observed to engage in unimanual activity with their prostheses an average of 20 minutes/day compared to the 60 minutes of mean unimanual activity observed in the non-dominant extremity of control subjects. Bimanual activity among prosthesis users was recorded for an average of 4 hours/day compared to an average of 5 hours/day in the control population. While participants generally exhibited 70% reliance on their lower arm segment relative to their upper arm segment, on the affected extremity of the amputee participants, this reliance dropped to 50%, suggesting a need for greater upper arm activity to preposition the prosthesis in space. Upper arm accelerometers confirmed that engagement of the upper arm segment in upper limb amputees diminish when the prosthesis is removed. Collectively, this data begins to demonstrate the ability of transradial prostheses to preserve both unimanual and bimanual functionality. (This abstract focuses on a subset of previously published data from Frey S, Motawar B, Buchanan K, et al. Greater and more natural use of upper limbs during everyday life by former amputees versus prosthesis users. *Neurorehabil Neur Rep.* 2022;36(3):227-38).

INTRODUCTION

Upper limb amputation has a profound impact on both function and quality of life.[1-4] Prostheses can improve outcomes, but disuse occurs among a minority of patients[5] and those that use a prosthesis often rely heavily on their intact limbs during everyday life.[6] This tendency towards one-handedness has been associated with greater disability and overuse injury.[7]

Recent literature has attempted to quantify the engagement of upper limb prostheses through wrist-worn accelerometers.[6] These efforts have observed that prosthesis users demonstrate a preference towards their intact side, a lack of correlation between prosthesis wear and prosthesis use and a lack of correlation between prosthetic skill and prosthetic engagement.[6]

We implemented a wireless accelerometry protocol to record upper extremity movements during 3 days of normal activity in transradial amputees and healthy age-matched controls. Prior studies only implemented the forearms and prostheses at the distal wrist levels to capture hand and terminal device movements.[6] In contrast, in addition to bilateral distal sensors we placed sensors proximally above the elbows. This allowed us to evaluate between-group differences in both upper arm and residual limb movements and the use of the upper arm by amputees when not wearing their prosthesis. We sought to better define the extent to which transradial prostheses were able to enable the unimanual and bimanual upper limb engagement observed in able-bodied controls. This effort was part of a larger trial that additionally enlisted both hand transplant and hand replant patients which has been published elsewhere.[8]

METHODS

Ethics

The protocols was approved by the University of Missouri Office of Human Protections and the Human Research Protection Office at the Department of Defense and was performed in accordance with the Declaration of Helskinki. All participants provided informed consent.

Participants

With respect to the data reported in this abstract, we used wireless accelerometers to capture data on limb use across 3 consecutive days in 2 groups of interest. Group 1) users of unilateral transradial prostheses (N=22, aged 56.4 ± 17.1 years, 1 female, 30.2 ± 21.6 years after traumatic amputation). Half of the limb loss group had dominant hand affected; and Group 2) healthy age-matched controls (N=20, aged 53.4 ± 15.8 years, 3 females, 18 right handed. Current amputees used a variety of prostheses: exclusively body-powered (n=8), exclusively myoelectric (n=7), both body-powered and myoelectric (n=5), passive (n=1) and unknown (n=1). On average, the amputee group had used a prosthesis for 26.09 ± 20.93 years, with their current prosthesis being in use for an average of 7.11 ± 14.46 years. Prosthesis users were recruited through Hanger Clinic and local and national advertising, resulting in a convienence sample of individuals who responded to recruitment materials.

Data Collection

Data collection on this trial has been reported in detail elsewhere[8] but is described briefly as follows. Four accelerometer sensors (GT9X Link, ActiGraph Corp, Pensacola, FL) were shipped to subjects. Subjects wore these accelerometers for 3 consecutive days. The data collection included 2 weekdays and 1 weekend-day to sample both occupational and leisure activities. Two accelerometers were worn on the anatomical or prosthetic forearm to capture hand or prosthesis movements, and two accelerometers were placed above the elbows to capture upper arm movements.

Data Analysis

Data Analysis on this trial has been reported in detail elsewhere,[8] but is described briefly as follows. Activity counts were counted in 1-second epochs and downloaded from the accelerometer. Variables of interest were computed during awake time. For prosthesis users, we also identified prosthesis non-wear time.

Table 1: Variables of interest including measured unilateral and bilateral forearm activity and median reliance on the upper arm. (In general, the metrics of the affected limb of prosthesis users are compared against the nondominant limb of the control group, while the metrics of the unaffected or sound limb of prosthesis users are compared against the dominant limb of the control group).

	Amputees		Control Dominant		Control Nondominant	
	Mean	SD	Mean	SD	Mean	SD
Unilateral forearm activity (hours/day)	4.8	1.6	2.72	.89	N/A	N/A
Unilateral affected forearm activity (hours/day)	.33	.19	N/A	N/A	1.06	.46
Unilateral unaffected forearm activity (hours/day)	4.47	1.61	1.65	.54	N/A	N/A
Bilateral forearm activity (hours/day)	4.02	1.35	5.04	1.33	N/A	N/A
Median reliance on forearm, affected limb (%)	49.41	3.37	N/A	N/A	70.33	7.66
Median reliance on forearm, unaffected limb (%)	69.98	3.61	68.56	7.46	N/A	N/A
Median reliance on affected upper arm, prosthesis off (%)	25.37	12.44	53.58	5.35	46.42	5.35
Median reliance on affected upper arm, prosthesis on (%)	30.62	7.07	N/A	N/A	N/A	N/A

RESULTS

Our data found that prostheses were used an average of 79% of waking hours with a mean recorded utilization of 11.1 ± 1.8 hours/day. Additional variables of interest are shown in Table 1. Unilateral engagement of the prosthesis was recorded an average of 20 minutes per day. Unilateral engagement of the sound side extremity was recorded for an average of 4.5 hours per day. By contrast, unilateral activity in the dominant and non-dominant extremity of the control subjects were reported an average of 100 minutes and 60 minutes respectively per day. Among prosthesis users, an average of 4 hours of bimanual activity was recorded. By comparison, control subjects recorded an average of 5 hours of bimanual activity per day.

Reliance upon the forearm relative to the upper arm was recorded in four conditions; that of the dominant limb in controls, the non-dominant limb of controls, the sound side limb of the prosthesis users and the affected extremity of the prosthesis users. That mean forearm reliance ratios were reported at 69%, 70% and 70% respectively among the first three scenarios. In the last scenario a forearm ration of 50% was recorded.

Upper limb reliance among the non-dominant limbs of control subjects was observed at 46%. When the prosthesis was not worn, this ratio decreased to 25%. When the prosthesis was worn this variable increased to 31%.

DISCUSSION

While a minority of those with upper limb amputation eventually choose to abandon the use of a prosthesis, the subjects enrolled in our trial were found to wear their devices for more than 11 hours per day. During this period, prosthesis users engaged in both unimanual and bimanual tasks. Viewed collectively, prosthesis users engage in an average of 8.82 hours of upper limb activity. This is roughly one more hour of upper limb activity than that recorded on average for healthy controls (7.76 hours). This relative parity may reflect the similarities associated with activities of daily living (ADLs) in both groups, with upper limb amputees requiring additional time to complete upper limb tasks.

As observed by Chadwell et al,[6] the disparity between unimanual engagement of the prosthesis and unimanual engagement of the sound side limb is stark, observed at 20 minutes and nearly 4.5 hours respectively. However, the disparity between unimanual engagement of the prosthesis and unimanual engagement of the non-dominant extremity of the controls was much less pronounced at 20 and 60 minutes respectively. Our data suggest that transradial prostheses are able to preserve roughly 1/3rd of the unimanual activity duration typically associated with a non-dominant extremity.

Ostlie et al[9] observed a tendency for upper limb prostheses users to report preferentially engaging the use of their devices in bimanual tasks. Our data support this tendency, with engagement of transradial prostheses during bimanual tasks occurring an average of 4 hours daily. This value begins to approximate the 5 hours of bimanual tasks recorded among health controls, suggesting that transradial prostheses are able to facilitate approximately 80% of the bimanual activity duration observed in able-bodied controls.

The relative reliance upon the forearm relative to the upper arm was assessed in four conditions. Specifically, the ratio of forearm movement to upper arm movement was recorded in the dominant control limbs, the non-dominant control limbs, the sound side extremities of the unilateral amputees and the amputee's affected extremities. The mean values in the first three conditions were comparable at approximately 70%, suggesting that upper limb activity was predominantly executed distal to the elbow. By contrast, this ratio was observed to be much lower for the affected group at 50%. This may suggest a greater need for proximal joint motions to effectively preposition the terminal device in space for task execution. Pilot efforts to understand such proximal joint compensations have been reported.[10]

Interlimb reliance among the upper arms of the non-dominant limbs of control subjects averaged 46%. When prostheses were not being used, our amputee subjects demonstrated an even greater reliance on the upper arm segment of the unaffected limb, suggesting decreased engagement of the affected extremity (upper arm reliance of the affected extremity = 25%). When the prostheses were worn, the engagement of the affected extremity increased (upper arm reliance of the affected extremity=30%). This shift suggests increased engagement of the affected extremity with the prostheses on, better approximating the valued observed in the non-dominant extremities of control subjects.

This initial analysis was confined to users of unilateral transradial prostheses. Additional insights may be gathered when this data is compared against that collected from users of bilateral prostheses or among prosthesis users with more proximal amputation levels.

CONCLUSION

Upper limb prostheses are characterized by several limitations. These include their weight, limited dexterity and lack of sensory restoration. Yet, for all of these limitations, our findings suggest that transradial prostheses are able to facilitate roughly 1/3rd of the unimanual activity duration recorded upon the non-dominant extremities of able bodied controls. Similarly, transradial prostheses facilitate the performance of approximately 80% duration of the bimanual activity recorded among able bodied controls. Limitations in prosthetic dexterity is such that the proximal joint segments of the affected extremity appear to experience greater compensatory motion to facilitate upper limb function. Amputees appear to engage their residual limbs more frequently while wearing their prostheses than when prostheses are not being worn.

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