THE EFFECT OF SENSORY FEEDBACK ON THE TEMPORAL ALLOCATION OF GAZE USING A SENSORIZED MYOELECTRIC PROSTHESIS

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ABSTRACT

Myoelectric prosthesis users have altered spatial and temporal allocations of gaze, likely influenced by both control proficiency and sensory feedback. Providing task-relevant and movement feedback can improve spatial visual allocation, but temporal patterns of gaze shift have not been reported for prosthesis users with sensory feedback systems. We present data from two prosthesis users with integrated touch and kinesthetic feedback in a myoelectric prosthesis performing a functional cup movement task while tracking eye and hand movements. Despite different skill levels and task performance, both participants showed improved ability to disengage eye fixation from the object and transition to the next movement plan when provided kinesthesia and touch feedback together. Temporal allocation of gaze, specifically, the ability for the eye to disengage after interacting with objects, seemed impervious to skill level and maybe a valuable measure of the ability to trust the sensory feedback, disengage vision, and motor plan forward in a sensorized prosthesis. Eye latency measures could be a valuable marker of control skill and feedback efficacy in prosthesis users.

INTRODUCTION

Myoelectric prosthesis users have disruptions to normal hand-eye coordination when interacting with objects. Generally, prosthesis users will fixate their gaze on the prosthetic hand and cannot look forward to the next target location of action [1], [2]. This behaviour is quite different from normal eye-hand coordination, where the eyes lead the hand and fixate on task-relevant areas to efficiently motor plan the next movement [3], [4] and may contribute to less use of the prosthesis for functional activities.

We have shown in a prior study that providing relevant touch and kinesthetic feedback in a sensory integrated myoelectric prosthesis can reduce the spatial allocation of vision, with reduced fixation to the hand and increased fixation to the next target in an object interaction task [5]. However, sensation is only one aspect of prosthetic performance that may influence visual behaviour; accurate control may also provide the confidence to look away from the hand once the object is firmly grasped and look ahead to the next target [6]. The transition of the gaze fixation may therefore be affected by both movement control and the type of sensory feedback provided.

Using a simulated transradial myoelectric prosthesis with non-disabled participants [7], we explored eye latency measures [3] for further insight into eye fixation and hand movements. The ability of the eye to precede the grasp of an object significantly correlated with hand trajectory variability and grasp time. Similarly, the ability to disengage the eye after pickup of the object to transition the gaze to the next dropoff location significantly correlated to hand trajectory variability, distance travelled, and transport time. Lastly, the ability of the eye to disengage after dropping off the object was related to release time. Similar to the findings of [8], control issues with opening and closing the prosthetic hand and controlling movement through space influenced the ability to temporally and spatially allocate visual fixation. Therefore, the temporal allocation of vision may be of value to explore in prosthesis users with sensory feedback, as presumably providing channels of real-time feedback should release vision to be more effectively used for motor planning.

This paper explores the changes to eye gaze transitions when picking up and dropping off objects in two participants with sensory integrated prostheses providing matched touch feedback (to the digits) and kinesthesia (sensation of hand grasp movement). Whereas touch sensation provides task-specific feedback on object contact during grasp, kinesthesia should improve the ability to reallocate vision for motor planning of the next movement. We also hypothesized that measures of hand function, used as a proxy of control skill [9], may affect the eye gaze adaptations seen with sensory feedback. If eye gaze metrics are responsive to changes with sensory feedback, this could be a valuable method of assessing both sensory feedback and control strategies from the perspective of movement planning.

METHODS

As described in [5], two participants that had undergone targeted motor and sensory reinnervation at shoulder disarticulation level (participant SD) and transhumeral level (participant TH) were fit with a bidirectional myoelectric prosthesis with touch feedback related to the prosthetic digits, and kinesthetic sensation of hand close. They performed trials in 3 conditions: *motor* (no feedback), *touch* (touch tactors activated), and *kinesthesia* (both touch and kinesthetic tactors activated). SD had control of 3 prosthetic movements (hand open/close, elbow flexion/extension, pronation/supination). TH only had control of hand open/close, due to technical difficulties with the prosthetic elbow. Both participants gave written informed consent for the study, which was approved by the ethics review board.

Participants performed the Cup Transfer Task of the Gaze and Movement Assessment protocol [10] which records eye gaze and hand movements as they pick up and transfer 2 compliant cups full of beads over a barrier on a table in front of them and then back to the starting location, for a total of 4 cup movements. SD performed 13 trials for motor and touch conditions and 9 trials for the kinesthesia condition. TH performed 20 trials for motor and 19 trials for touch and kinesthesia conditions. Data processing steps to attain metrics of interest for this analysis (eye latencies and hand function metrics) are described in [11].

As detailed in [3], eye arrival latency (EAL) was defined as the time the eye first fixates to the target location relative to the end of grasp for "pickup", and to the end of transport for "dropoff" of the object. Eye leaving latency (ELL) was defined as the time the eye first leaves the pickup location relative to the start of transport; and leaves the dropoff location relative to the end of transport. A shorter ELL is a more positive number, whereas a longer ELL is more negative (see: [3]). Target locking strategy (TLS) [8] was calculated as the ratio of percent (%) fixation to current minus % fixation to hand for the phases of reach and transport initially for each movement based on the average % fixation values, and then across movements as a summary metric of spatial gaze fixation. For EAL and ELL metrics, all trial values across the 4 movements were averaged per condition. Values are reported as mean (standard error of the mean).

RESULTS

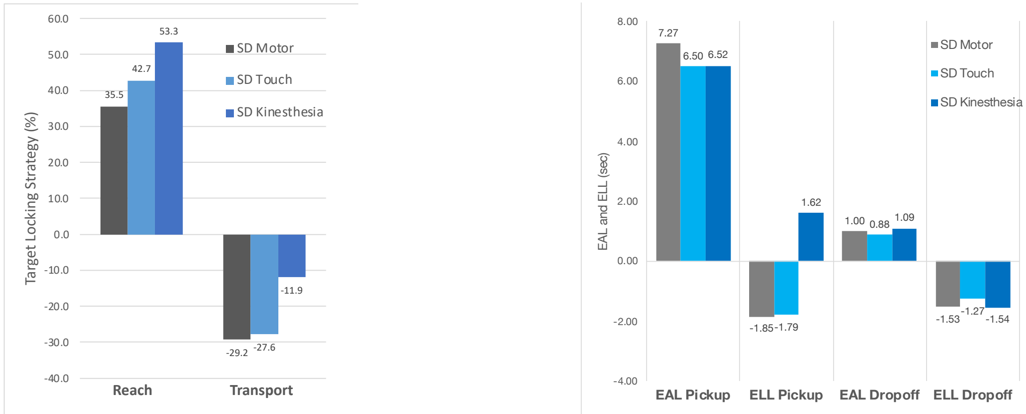
The two participants were different in skill level and control (Table 1). SD had longer task durations and spent more relative time in prolonged grasp phases (grasp SD 31.1(2.0)%; TH 23.4(2.2)%), compared to TH who had more prolonged transport phases (transport SD 24.0(0.6)%; TH 35.5(2.2)%). SD also showed longer hand distance travelled and greater hand trajectory variability in both reach and transport compared to TH, indicating a less efficient movement path. The hand movement metrics were substantially unchanged across conditions, except for slightly lower hand trajectory variability in reach for SD in the kinesthesia condition. SD showed an improved TLS for the kinesthesia condition in both reach and transport (Figure 1a), reflecting less fixation to hand and greater fixation to the next target. For reach, the value improved closer to normative, and for transport, the TLS became less negative (indicating greater target fixations, but still not greater than fixations to hand).

Regarding eye latencies of SD (Figure 1b), when transitioning from picking up the cup to transporting, in the motor and touch conditions the eyes lingered on the cup well into the transport phase (ELL pickup motor -1.85(0.13) sec; touch -1.79(0.15) sec). However, for the kinesthesia condition, the ELL became positive at +1.62(0.19) sec, indicating the eyes disengaged from the cup and shifted to the next target location while still in grasp phase. The other latency measures were not notably different between conditions for SD; in general, the EAL pickup values were very high (6.50-7.27 sec), reflecting the long reach and grasp times.

Table 1: Hand movement values across conditions

Metric average values across all movements	Normative Reference	Participant SD			Participant TH		
		Motor	*Touch*	*Kinesthesia*	*Motor*	*Touch*	*Kinesthesia*
Total task duration (sec)*	8.9 (0.1)	58.6 (3.4)	55.3 (1.9)	51.9 (1.5)	18.7 (0.2)	20.3 (0.3)	18 (0.2)
Hand distance travelled (mm)	4864 (47)	6497 (237)	6896 (153)	6998 (176)	5574 (24)	5497 (25)	5523 (18)
Hand trajectory variability Reach; Transport (mm)	18 (4); 19 (4)	71 (8.0); 50 (3.3)	75(9.2); 38(2.2)	58 (6.3); 52(5.7)	32(2.2); 25(0.7)	52(6.9); 30(2.1)	32(3.2); 21 (1.1)

*Calculated as sum of all phase durations



a b

Figure 1: Participant SD a) Target Locking Strategy (% fixation to current - % fixation to hand) averaged across movements for Reach and Transport phases. Normative value 79% for Reach and 67% Transport. b) EAL and ELL values at pickup and dropoff averaged for all trials per condition.

For TH, the movement profile was quite different. He moved faster, with less variability, as expected given the intact shoulder and only having to control one degree of freedom. He also had positive TLS values for all conditions in reach and transport, reflecting that he did not have high hand fixations (reported in: [5]), and TLS did not improve with kinesthesia. However, ELL at pickup had similar improvements as with SD; in motor and touch conditions ELL pickup was negative (ELL pickup motor -0.26(0.04) sec; touch -0.29(0.05) sec) and improved to positive for the kinesthesia condition at +0.22(0.09) sec (Figure 2), indicating he could disengage his eye fixation away from the object just before the end of grasp. The other latency measures also showed a trend to be closer to zero for the kinesthesia condition, specifically ELL at dropoff also showing earlier disengagement from the cup during release.

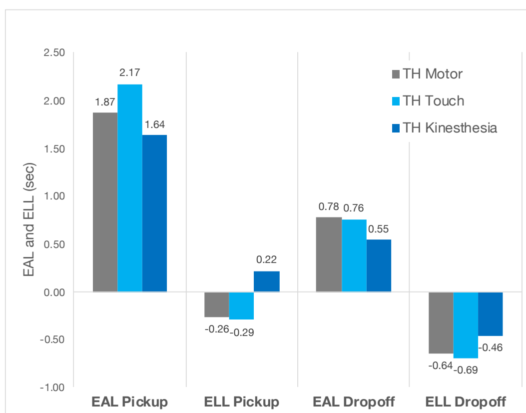


Figure 2: Participant TH EAL and ELL values at pickup and dropoff averaged for all trials per condition.

DISCUSSION

Touch and kinesthetic sensory feedback within a prosthesis system has been shown to improve spatial allocation of gaze fixation behaviour [5]. Spatial and temporal gaze transitions have also been shown to reflect control stability and performance and influence the interpretation of visual allocation [8]. Specifically, the impact of sensory feedback on eye behaviour might be determinant on control proficiency. In this analysis, both kinematic hand function measures and eye behaviours reflected the individual differences in skill and control performance. SD, at a shoulder disarticulation level using 3 degrees of freedom, had lower baseline motor function as reflected in slower movements, longer hand trajectory and higher variability. Providing positional awareness (kinesthesia) related to grasp function in addition to touch feedback had an impressive impact on spatial visual allocation, with improved target locking strategy. At pickup of the object, with kinesthesia and touch, SD was also remarkably able to temporally reallocate the gaze fixation forward when *still in the grasp phase*, thereby impacting both spatial and temporal gaze allocation behaviour.

TH, with an intact shoulder and controlling hand open/close, had a more confident reach and overall performance at baseline than SD. The addition of kinesthetic grasp and touch feedback did not change movement function or target locking, although he did show reduced fixations to hand [5]. TH's spatial allocation of vision was likely already positively influenced by his proficient motor control. However, the addition of kinesthetic feedback to touch improved the ability to transition the gaze more normally at the end of grasp and when releasing the object. The improvement in eye latency measures suggests kinesthesia increased confidence in disengaging vision from the object for motor planning of the following action.

Limitations of this study include only 2 participants representing different amputation levels and skill proficiency. With higher participant numbers, we could more thoroughly investigate the consistency of these trends and the statistical generalizability. There was no "only kinesthesia" condition due to the intense testing schedule and need to limit conditions, so the results do not directly tease out the differences between touch and kinesthesia, other than to note that touch alone did not provide the same improvements. We believe this underscores the importance of proprioception and kinaesthesia in releasing vision for motor planning in prosthesis users.

CONCLUSION

Temporal allocation of gaze, specifically, the ability for the eye to disengage after interacting with objects, seemed impervious to skill level and maybe a valuable measure of the ability to trust the sensory feedback, disengage vision, and motor plan forward in a sensorized prosthesis. Eye latency measures could be a valuable marker of both control skill and feedback efficacy in prosthesis users and should be further investigated.

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