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A Novel Electro-prosthetic Proprioception by Distance-based Electrical Stimulation for Finger Aperture Control

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***Abstract*— Planning and execution of a finger reaching task to control finger aperture depends on proprioceptive feedback, especially when vision is occupied by other tasks or occluded. To address this visual-proprioceptive mismatch and improve finger control, we introduce electro-prosthetic proprioception (EPP) that provides a more accurate sensory reference. EPP was rendered by electrical stimulation applied to the fingertip with a frequency inversely proportional to finger aperture. We measured how EPP could enhance accuracy without vision, and found it to significantly improve, even after EPP was removed. This effect was retained 24-hours post training, while the visuomotor training control group showed no retention. This new type of proprioception offers a new pathway for feedback in any tasks that require accuracy enhancement.**

***Clinical Relevance*— EPP may have broad applications in motor training paradigms, such as hand skill training for novice surgeons and in neurorehabilitation.**

I. INTRODUCTION

Finger motor tasks often need high manipulation accuracy because the fingers are often used in sophisticated tasks. Finger aperture control between a pair of fingers during interactive reaching is one of the critical maneuvers for applications where it is important to apply the right amount of force to a target object. The planning and execution of a finger reaching are based on the weighted averages of the visual and proprioceptive estimates of the fingers where the weights are proportional to the precision of the estimates [1].

As visual and proprioceptive perceptions are based on different dynamics, visual and proprioceptive distance estimates have a mismatch. We often consider the visual system to provide the ground-truth, or most accurate position sense, which means proprioception is untrue for some positions if it does not have vision to assist, override, or recalibrate proprioception. Visual-proprioceptive mismatch intrinsically causes an error in replicating the visual distance by the fingers, especially when the fingers are out of sight. Unless there is a continuous effort to reduce the visual-proprioceptive mismatch with visual feedback on the fingers, the fingers cannot replicate the visual distance in a high accuracy. To compensate for the visual-proprioceptive mismatch, we selected a form of electrotactile feedback with a frequency modulation, which we call as electro-prosthetic proprioception (EPP), to deliver finger aperture distance information. EPP was applied with a frequency inversely proportional to the distance between the fingertips. In this study, we tested the efficacy of EPP against conventional visual sensory feedback method, on enhancing the visual-proprioceptive matching accuracy.

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II. METHODS

Sixteen subjects participated in the experiment. Group 1 (n=8) received conventional visuomotor training with the target distance and the finger aperture displayed together on a screen (visual training), while group 2 (n=8) received visuomotor training with EPP (EPP training). The experiment was conducted for two days with a series of trials where subjects were asked to reproduce a target line displayed on a screen by a finger aperture. The experiment done at 24-hours post training tested the lasting effect.

III. RESULTS

We observed that finger aperture control accuracy significantly improved with the EPP training ($p<0.001$), compared to the conventional visual training. More importantly, the effect of the EPP training was retained at 24-hour post training ($p<0.001$) where visual training showed no lasting effect at 24-hour post training ($p=0.655$).

IV. DISCUSSION & CONCLUSION

We found that EPP indeed compensates for visual-proprioceptive mismatch, perhaps because it directly delivers the distance information via stimulation frequency. In contrast, natural proprioception indirectly delivers the distance information through muscle and tendon sensors that are known to detect force or velocity, leaving position to be inferred through sensorimotor integration. Further, the effect of the EPP training persists 24-hours post training, which suggest that EPP shaped a long-term memory that may recalibrate the proprioception. EPP has promise in improving surgeons' position accuracy which will potentially improve surgeon's hand skills and reduce critical damage during the high-risk surgeries. This also provides enhanced feedback for tasks that require repetitive practice, such as sports, music performance, piloting, and neurorehabilitation.

REFERENCES

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