HANDWRITING MECHANICS: 3-D KINETIC SYNERGIES IN CIRCLE DRAWING MOVEMENTS

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INTRODUCTION

The purpose of this study was to investigate central nervous system (CNS) strategies for controlling multi-finger forces in 3D space during circle-drawing tasks using Kinetic Pen recently developed [1].

METHODS

Twenty-four subjects drew 30 discrete concentric circles using Kinetic Pen for each experimental condition, which included two directions (clockwise, CW vs. counter-clockwise, CCW) and two pacing (self-paced vs. external-paced) (Fig 1). For the external-paced condition, subjects drew circles while following metronome beeps. The 3D contact forces and moments of force between the hand and the pen were calculated from recordings of the miniature 3D force/moment sensors (Nano-17, ATI) embedded in the barrel of the pen. The pen-hand contacts included thumb, index finger, middle finger, and webbing between thumb and index finger. The 3D position of the pen was also recorded using a Vicon motion capture system. The synergistic action of the contact forces, defined as kinetic synergy [2], was compared in three orthogonal dimensions: a *radial* component that dictates the pen's motion from the circle edge towards its center, a *tangential* component that dictates the pen's motion tangent to the curvature of the circle, and *vertical* component that dictates the pen's motion perpendicular the writing surface. Uncontrolled Manifold Analysis [3] was used to quantify the kinetic synergy (ΔV; the greater ΔV the greater the synergy) between contact forces in each dimension. Four hypotheses were tested. 1) Kinetic synergies between the pen-hand contact forces exist in all three dimensions. 2) The radial and tangential components yield stronger synergies than the vertical component. 3) Synergies exist in both CW and CCW directions and the synergy strengths do not differ between them. 4) The self-pacing yields stronger synergies than the external pacing.

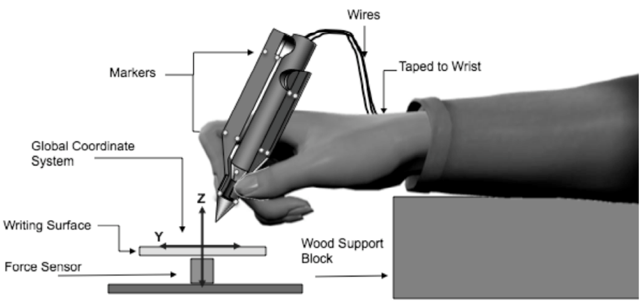

Figure 1: Schematic of experimental setting showing a subject holding the Kinetic Pen with reflective markers attached during circle drawing.

ANOVA with the factors of Pace [2 levels: self and external], Direction [2 levels: clockwise and counter-clockwise], and Component [3 levels: radial, tangential, and vertical] were used for statistical analysis.

RESULTS AND DISCUSSION

Kinetic synergies existed across all components and were significantly stronger in the radial and tangential components than vertical component (Fig 2). This suggests that the CNS utilizes kinetic synergies that are not only task dependent but also able to prioritize components within a task to optimize the handwriting performance. The kinetic synergies of radial and tangential forces were much stronger than those found during simple grasping tasks used in previous studies (i.e., usually $\Delta V<1$) [4]. This may have caused by the high precision of the manual dexterity necessary to write words, where errors on the scale of millimeters can render script illegible [4]. It is also to be noted that high kinetic synergy existed also in vertical component ($\Delta V>0$) although precise control of vertical forces is not required for the optimally drawn shape of circles. The findings were supported by the repeated-measures ANOVA with significant effects of Direction, Component, Direction x Component, Direction x Component x Pace ($p<.05$).

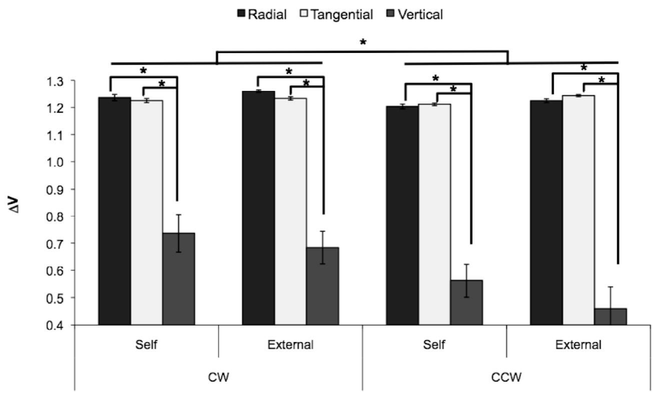

Figure 2: Synergy strength, measured by ΔV, for radial, tangential, and vertical force components. *$p<.05$.

CONCLUSIONS

The results of this study suggest that the CNS controls pen-hand contact forces synergistically during handwriting so that the kinematic outputs can be consistent for a repetitive circle drawing tasks. The kinetic synergy is stronger for the force components, radial and tangential, which are critical for shaping the desired kinematic handwriting outputs although normal force component also showed relatively strong synergistic actions of pen-hand contact forces.

REFERENCES

1. Hooke AW & Shim, *J Biomch* **41**: 2060-2064, 2008.
2. Shim JK, et al. Motor Control **12**: 311-329, 2008.
3. Scholz & Schoner, *Exp Brain Res* **126**: 289-306, 1999.
4. Shim JK, et al., *J Neurophysiol.* **93**: 3649-3658, 2005