Motion Capture Cross-Correlational Analysis of Upper Extremity During Rings Task

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INTRODUCTION: Cross-correlational analysis quantifies the similarity and time delay between movements with a correlation coefficient and a lag, respectively. The correlation coefficient indicates the degree of similarity between movements, on a scale from 0 to 1 with higher values representing higher similarity. This study applies cross-correlation analysis to investigate the relationship between the movements of proximal and distal upper extremity (UE) joints during a rings task.

METHODS: A Vicon Vero motion capture system recorded the UE motion of 25 healthy subjects during a rings task. 21 markers were placed on subjects' UE and torso. 3-dimensional movements in the anteroposterior (AP), mediolateral (ML), and superoinferior (SI) planes were captured. Subjects were asked to transfer a large ring from one hand to the other, then place the ring on a cone placed contralaterally to the receiving hand. The task was repeated 3 times.
Data was processed to remove noise, then positional time-series of the shoulder, elbow, and wrist joints were used to calculate the cross-correlation and lag of each joint relative to the movement of the hand. For each subject, the cross-correlation and lag were averaged among 3 trials and statistically analyzed. A paired t-test evaluated the differences between the cross-correlation of the dominant and non-dominant hand. ANOVA with repeated measures compared the cross-correlation of all three joints within a limb.

RESULTS SECTION: Figure 1 shows the mean cross-correlation coefficients and lag (mean ± SD) of each joint relative to the hand in the dominant and non-dominant limbs. Figure 2 shows results of the paired t-tests comparing the cross-correlation coefficients of the dominant and non-dominant limb. Figure 3 shows the results of ANOVA with repeated measures for all three joints within a single UE limb.

DISCUSSION: The goal of this study is to describe the relationship between hand movement and the movements of more proximal and distal UE joints during a functional task. Cross-correlation was used to measure the relationship between the hand and wrist, hand and elbow, as well as hand and shoulder. Cross-correlation coefficient and phase lag have been used to quantify the similarity between two time-series data as a way of describing kinematic coordination. Our data demonstrates a direct relationship between correlation and proximity to the hand – the motion of more distal joints most closely resembles that of the hand. There is also less variability within the more distal UE joints. Finally, the relationship is consistent regardless of hand dominance. Paired t-tests revealed no notable differences between joint cross-correlations and hand dominance; motion of the dominant and non-dominant limbs is similar.
Our analysis revealed a distinct lag in elbow movement along the AP dimension that deviates from the general trend observed in other elbow lags. This atypical lag exhibits the highest variability among all measurements, suggesting significant variability among healthy individuals in this plane. Despite this movement variability, all subjects successfully completed the task without any impact on hand function and positioning. The underlying mechanics of this finding remain uncertain, highlighting the need for further research to identify the origin of this inconsistency, and whether this relationship is consistent among different types of tasks.
Our data may be used in the future in comparison with data on upper extremity deformities such as cerebral palsy (CP). For example, we theorize that in patients with distal upper extremity dysfunction, there will be a heavier reliance on proximal joints (i.e. shoulder), which would translate to a higher cross-correlation between the hand and shoulder when compared to a healthy control. We also theorize that there will be less variance between all 3 joints (wrist, elbow, shoulder) of the affected limb, as patients overcome challenges of ADLs by moving the entire upper limb more like a single unit.

SIGNIFICANCE/CLINICAL RELEVANCE: (1-2 sentences): This study applies motion and cross correlation analysis to determine normative values for the relationship between upper extremity joints in a ring stacking task. In the future this data and technique can be applied to studying patient with upper extremity disfunction to better understand motion patterns and assess treatments.

IMAGES AND TABLES:

Figure 1: Cross-correlation coefficients and lag in dominant and non-dominant UE limb

		Dominant		Non-Dominant	
	Plane	Correlation	Lag	Correlation	Lag
Hand-Wrist	AP	0.997 ± 0.003	0 ± 0	0.998 ± 0.004	0.04 ± 0.18
	ML	0.992 ± 0.005	0 ± 0	0.993 ± 0.007	0.04 ± 0.20
	SI	0.937 ± 0.064	2.10 ± 2.54	0.929 ± 0.070	3.07 ± 3.49
Hand-Elbow	AP	0.948 ± 0.063	-3.25 ± 9.01	0.956 ± 0.049	-4.46 ± 11.33
	ML	0.928 ± 0.070	-1.89 ± 3.07	0.900 ± 0.240	1.45 ± 18.84
	SI	0.235 ± 0.613	-38.68 ± 63.69	0.200 ± 0.511	-24.77 ± 40.86
Hand-Shoulder	AP	0.911 ± 0.097	-4.47 ± 11.63	0.928 ± 0.053	-6.5 ± 5.95
	ML	0.662 ± 0.505	3.35 ± 39.68	0.744 ± 0.455	-3.03 ± 31.22
	SI	0.269 ± 0.451	-47.43 ± 75.97	0.369 ± 0.404	-50.35 ± 47.25

Figure 2: Paired T-Test of Dominant vs. Non-Dominant Cross-correlation coefficients

	Plane	Dominant	Non-Dominant	P-value
Hand-Wrist	AP	0.997 ± 0.003	0.998 ± 0.004	0.769
	ML	0.992 ± 0.005	0.993 ± 0.007	0.203
	SI	0.937 ± 0.064	0.929 ± 0.070	0.321
Hand-Elbow	AP	0.948 ± 0.063	0.956 ± 0.049	0.039
	ML	0.928 ± 0.070	0.900 ± 0.240	0.485
	SI	0.235 ± 0.613	0.200 ± 0.511	0.685
Hand-Shoulder	AP	0.911 ± 0.097	0.928 ± 0.053	0.088
	ML	0.662 ± 0.505	0.744 ± 0.455	0.029
	SI	0.269 ± 0.451	0.369 ± 0.404	0.360

Figure 3: ANOVA with repeated measures for all three joints within a single UE limb

	Plane	P-value
Dominant	AP	<0.001
	ML	<0.001
	SI	<0.001
Non-dominant	AP	<0.001
	ML	0.005
	SI	<0.001