Applying Motion Analysis to Block Stacking Task: A Cross Correlation Analysis

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INTRODUCTION: Cross-correlation analysis has been utilized to explore gait and lower extremity biomechanics, but its application to upper extremity function remains limited. This technique enables the examination of the relationship between joint movement in both temporal and spatial dimensions by computing cross-correlation coefficients and lag values. The correlation coefficient, ranging from 0 to 1, reflects the similarity between two movements, while the lag signifies the time delay between them. In this study, we employ cross-correlation analysis to establish a connection between proximal and distal upper extremity (UE) joint motions during a standardized block-stacking task.

METHODS: A Vicon Vero motion capture system recorded the movements of 25 healthy subjects as they performed a standardized blocks-stacking task. Using 21 markers placed across the subjects' upper extremity (UE) and torso, we captured the 3-dimensional movements of the shoulder, elbow, and wrist joints in the anteroposterior (AP), mediolateral (ML), and superoinferior (SI) planes. Subjects were instructed to stack six 1in x 1in blocks, with their dominant or non-dominant hand, repeating this task 3 times with each.
The motion capture data was processed to eliminate noise. The positional time series of the wrist, elbow, and shoulder joints were then utilized to calculate cross-correlation and lag with respect to the hand position during the task for each trial. The average cross-correlation and lag across all trials for each subject's dominant and non-dominant limb were recorded and subjected to statistical significance tests.
A paired t-test was used to identify any differences between the correlation of dominant and non-dominant limbs. ANOVA with repeated measures was used to compare the correlations between all three joints of one 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 UE joints. Figure 2 shows the results of ANOVA with repeated measures for all three joints within a single limb. Figure 3 shows the paired t-test results comparing the cross-correlations of dominant and non-dominant 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 common assessment 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 and Lags

		Dominant		Non-Dominant	
	Plane	Correlation	Lag	Correlation	Lag
Hand-Wrist	AP	0.96 ± 0.03	0.04 ± 0.79	0.96 ± 0.02	-0.25 ± 0.70
	ML	0.98 ± 0.01	-0.20 ± 0.50	0.97 ± 0.05	0.20 ± 1.56
	SI	0.96 ± 0.14	0.61 ± 3.07	0.97 ± 0.05	-3.08 ± 15.40
Hand-Elbow	AP	0.63 ± 0.28	26.57 ± 151.97	0.61 ± 0.27	31.9 ± 148.46
	ML	0.86 ± 0.17	-1.21 ± 4.82	0.85 ± 0.18	17.41 ± 50.36
	SI	0.67 ± 0.20	9.19 ± 56.56	0.67 ± 0.13	2.05 ± 53.30
Hand-Shoulder	AP	0.40 ± 0.24	46.02 ± 99.59	0.45 ± 0.22	28.62 ± 87.59
	ML	0.54 ± 0.26	33.79 ± 73.10	0.58 ± 0.26	20.35 ± 53.22
	SI	0.49 ± 0.26	1.52 ± 78.61	0.43 ± 0.24	10.45 ± 89.29

Figure 2: ANOVA with repeated measures

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

Figure 3: Paired T-Test

	Plane	Dominant	Non-Dominant	P-value
Hand-Wrist	AP	0.96 ± 0.03	0.96 ± 0.02	0.92
	ML	0.98 ± 0.01	0.97 ± 0.05	0.09
	SI	0.96 ± 0.14	0.97 ± 0.05	0.33
Hand-Elbow	AP	0.63 ± 0.28	0.61 ± 0.27	0.52
	ML	0.86 ± 0.17	0.85 ± 0.18	0.66
	SI	0.67 ± 0.20	0.67 ± 0.13	0.8
Hand-Shoulder	AP	0.40 ± 0.24	0.45 ± 0.22	0.06
	ML	0.54 ± 0.26	0.58 ± 0.26	0.42
	SI	0.49 ± 0.26	0.43 ± 0.24	0.21