Cross-Correlational Analysis of Upper Extremity Function During Water Bottle Opening

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INTRODUCTION: Healthy individuals perform activities of daily living (ADL) throughout each day with little to no difficulty. Inability to properly perform ADLs may lead to unsafe conditions and suboptimal quality of life. These tasks, which may be trivial to healthy individuals, may pose great challenges to patients with musculoskeletal, neurological, or other conditions. This study examines the relationship between the movement of proximal and distal upper extremity (UE) joints during an ADL task: a bottle opening task. Cross-correlation, a variable which has been used to understand the gait and lower extremity biomechanics, will be applied to UE joints to better understand the kinematic motion during a bimanual bottle opening task in healthy participants.

METHODS: All procedures complied with state and federal guidelines, was approved by the local institutional review board, and informed consents were collected. A *Vicon Vero* motion capture system recorded the UE motion of 25 healthy subjects during a bottle opening task. First, 21 markers were placed on the subjects' UE and torso to capture 3-dimensional movements of the wrist, elbow, and shoulder joints in the anteroposterior (AP), mediolateral (ML), and superoinferior (SI) planes. Subjects were then asked to pick up a closed water bottle from a table, unscrew the cap, place the cap and bottle back on the table, then pick up both items to re-cap the water bottle before placing it back on the table. Subjects were not instructed on a specific way to open the bottle, but were instructed to bimanually complete the task. The task was repeated 3 times.

Data was processed to remove noise, then the positional time-series of the wrist, elbow, and shoulder joint were used to calculate the cross-correlation and lag of each joint relative to the hand movement. Cross-correlation and lags of the 3 trials per subject were averaged then statistically analyzed. A paired t-test examined differences between the cross-correlation of the dominant and non-dominant limbs. ANOVA with repeated measures compared the cross-correlation of all three joints in a single 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 paired t-test results comparing the mean cross-correlations of dominant and non-dominant limb. Figure 3 shows the results of ANOVA with repeated measures for all three joints within a single limb.

DISCUSSION: Capturing and describing the motion of opening a bottle has unique challenges compared to other ADLs. Opening a bottle is a bimanual task, in which both limbs are serving different functions – one hand holds the bottle, while the other hand twists the cap. Observationally, in our experiment, all of the subjects opened the bottle cap with their dominant hand and held the bottle in their non-dominant hand. This observation, coupled with the data, elucidates the unique biomechanics of this task.

Excluding the anteroposterior motion of the dominant limb, the cross correlation decreases as the distance from the hand increases. This suggests that the closer a joint is to the hand, the more similar their mediolateral and superoinferior motions are. However, in the anteroposterior plane, the dominant shoulder had a greater correlation to the hand than the elbow, suggesting greater dependence of the shoulder in this plane to position the hand on the bottle. This is counterintuitive since one would expect the more distal joints to be more involved in removing the bottle cap.

Our data also showed a higher cross-correlation of the dominant elbow in the superoinferior plane and of the dominant wrist in the mediolateral plane than their respective non-dominant counterparts. This may be in part due to the fact that subjects unscrew the bottle cap with their dominant limb. Since the non-dominant limb is only used for the stabilization of the bottle, less inter-joint coordination may be required. Both dominant and non-dominant elbows had negative lag values, indicating that the elbow is performing the task before the hand. This suggests that in the context of this task, the motion of opening a bottle is initiated by the elbow.

SIGNIFICANCE/CLINICAL RELEVANCE: The goal of the study is to understand normative values in healthy patients to be used in future comparisons with the motion of patients with UE dysfunction. Opening a bottle involves rotational motion to remove the cap, which warrants further analysis of angular motion between proximal and distal joints during this motion to enhance the cross-correlational model.

IMAGES AND TABLES:

Figure 1. Cross Correlation and Lags

		Dominant		Non-Dominant	
		Correlation ± SD	Lag (1/100s) ± SD	Correlation ± SD	Lag (1/100s) ± SD
Hand-Wrist	AP	0.92 ± 0.11	-0.98 ± 6.41	0.90 ± 0.08	0.16 ± 1.18
	ML	0.96 ± 0.05	0.24 ± 1.36	0.94 ± 0.08	-0.04 ± 1.09
	SI	0.97 ± 0.04	0.00 ± 0.00	0.97 ± 0.03	5.22 ± 128.92
Hand-Elbow	AP	0.50 ± 0.30	-0.13 ± 119.58	0.55 ± 0.32	-26.23 ± 97.15
	ML	0.73 ± 0.26	-7.78 ± 65.09	0.81 ± 0.17	-7.32 ± 19.61
	SI	0.74 ± 0.29	-16.35 ± 63.54	0.52 ± 0.26	-15.95 ± 99.10
Hand-Shoulder	AP	0.65 ± 0.26	16.89 ± 87.55	0.49 ± 0.26	16.08 ± 89.82
	ML	0.39 ± 0.22	-19.87 ± 118.95	0.31 ± 0.22	-17.95 ± 114.42
	SI	0.62 ± 0.31	32.95 ± 92.33	0.36 ± 0.24	5.22 ± 128.92

Figure 2. Paired T-Test (Dominant vs Non-Dominant Cross-Correlation)

	Plane	Dominant	Non-Dominant	P-value
Hand-Wrist	AP	0.92	0.9	0.32
	ML	0.96	0.94	0.03
	SI	0.97	0.97	0.45
Hand-Elbow	AP	0.5	0.55	0.20
	ML	0.73	0.81	0.57
	SI	0.74	0.52	0.02
Hand-Shoulder	AP	0.65	0.49	0.05
	ML	0.39	0.31	0.39
	SI	0.62	0.36	0.09

Figure 3. ANOVA with repeated measures (Cross-correlation between all three joints in a single limb)

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