# Cross Correlational Analysis of Activities of Daily Living (ADLs): Applying Toothpaste onto a Toothbrush

David Ahn[1], Matthew Weintraub[1], Stephen Macneille[1], Aleksandra Kostic[1], Jean-Francois Daneault[2], Alice Chu[1]
Rutgers-[1]New Jersey Medical School, [2]School of Health Professions, Newark, NJ, USA
dba46@njms.rutgers.edu

**Disclosures**: David Ahn (N), Matthew Weintraub (N), Stephen Macneille (N), Aleksandra Kostic (N), Jean-Francois Daneault (N), Alice Chu (N)

INTRODUCTION: Cross-correlational analysis determines the similarity and time delay between movements with a correlation coefficient and a lag, respectively. The correlation coefficient, ranging from 0 to 1, indicates the degree of similarity, with higher values indicating greater similarity. Despite being widely used in gait analysis, cross-correlation remains underutilized for quantifying upper extremity (UE) movement. As the biomechanics of UE function is crucial for activities of daily living (ADLs), this study applies cross-correlation to investigate the relationship between proximal and distal UE joints while applying toothpaste onto a toothbrush, simulating a complex bimanual ADL. This research provides valuable references for understanding neuromuscular disabilities and evaluating the efficacy of various therapies.

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 was used to record 3-dimensional UE motion of the shoulder, elbow, and wrist joints in the anteroposterior (AP), mediolateral (ML), and superoinferior (SI) planes in 25 healthy participants. 21 markers were placed on the subjects' UE and torso. A toothbrush and toothpaste were placed in front of the subjects, who were asked to apply the toothpaste onto the toothbrush. This movement required the subjects to uncap the toothpaste, apply it to the toothbrush head, recap the toothpaste, then place both items back on the table. This task was repeated 3 times.

Noise was removed from the data, then the positional time series of the wrist, elbow, and shoulder joints were used to calculate the cross correlation and lag of each joint relative to the position of the hand through the task. For each subject, the cross-correlation and lag for the 3 trials were averaged before performing statistical analysis. A paired t-test evaluated potential differences between the cross-correlation of the dominant and non-dominant limbs. ANOVA with repeated measures compared the cross-correlations between 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 UE joints. Figure 2 shows the paired t-test results comparing the 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: Mediolateral movements of the wrist, elbow, and shoulder consistently had a higher cross-correlation to the hand movements compared to anteroposterior or superoinferior movements. Cross-correlation of the UE joints were directly related to the proximity to the hand, and lags were inversely related to the proximity of the hand: the movements of distal UE joints more closely resembled the motion of the hand with a lesser delay. There was no difference in cross-correlations between the dominant and non-dominant limb despite the different movement required of each hand during this bimanual ADL task.

In particular, a lower lag in the mediolateral plane was noted in the hand-elbow and hand-shoulder comparisons. This finding suggests that either this particular ADL task requires more stability during lateral movement, or that participants tend to rotate their toothbrush to accommodate lateral movement during application of toothpaste. Regardless, the act of putting toothpaste onto a toothbrush in normal controls is highly dependent on the mediolateral hand movement in coordination with the elbow and shoulder.

SIGNIFICANCE/CLINICAL RELEVANCE: The goal of this study is to describe normative values in healthy participants, in hopes that this data may be used in the future in comparison with that of patients with UE dysfunction. Similar additional research should be performed with other ADLs to develop a robust understanding of upper extremity movement.

IMAGES AND TABLES:

Figure 1. Cross Correlation and Lags

| | | Dominant | | Non-Dominant | |
|---|---|---|---|---|---|
| | Plane | Correlation | Lag (1/100s) | Correlation | Lag (1/100s) |
| **Hand-Wrist** | AP | 0.87 ± 0.09 | -0.16 ± 1.72 | 0.85 ± 0.15 | 1.38 ± 6.80 |
| | ML | 0.97 ± 0.03 | -0.01 ± 0.71 | 0.95 ± 0.08 | -0.28 ± 0.85 |
| | SI | 0.91 ± 0.07 | 0.00 ± 0.00 | 0.91 ± 0.07 | 0.00 ± 0.00 |
| **Hand-Elbow** | AP | 0.47 ± 0.25 | 32.56 ± 140.55 | 0.51 ± 0.29 | -28.95 ± 280.72 |
| | ML | 0.83 ± 0.25 | 8.85 ± 30.69 | 0.80 ± 0.28 | 54.62 ± 188.76 |
| | SI | 0.44 ± 0.28 | 57.99 ± 172.21 | 0.49 ± 0.29 | 70.11 ± 175.78 |
| **Hand-Shoulder** | AP | 0.25 ± 0.20 | 116.62 ± 176.47 | 0.32 ± 0.22 | 92.81 ± 180.87 |
| | ML | 0.54 ± 0.30 | 20.63 ± 84.94 | 0.58 ± 0.27 | 41.55 ± 166.28 |
| | SI | 0.41 ± 0.26 | 108.49 ± 174.47 | 0.50 ± 0.27 | 84.08 ± 122.48 |

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

| | Plane | Dominant | Non-Dominant | P-value |
|---|---|---|---|---|
| **Hand-Wrist** | AP | 0.87 | 0.85 | 0.4209 |
| | ML | 0.97 | 0.95 | 0.0864 |
| | SI | 0.91 | 0.91 | 0.9677 |
| **Hand-Elbow** | AP | 0.47 | 0.51 | 0.5955 |
| | ML | 0.83 | 0.8 | 0.5086 |
| | SI | 0.44 | 0.49 | 0.1792 |
| **Hand-Shoulder** | AP | 0.25 | 0.32 | 0.0732 |
| | ML | 0.54 | 0.58 | 0.3871 |
| | SI | 0.41 | 0.5 | 0.9099 |

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 |