ORIGINAL ARTICLE

# Kinematic Differences Between Dominant and Non-dominant Upper Limbs During Reaching Task in Healthy Young Adults

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## ABSTRACT

**Background:** Understanding the kinematic aspect is crucial in rehabilitation as it allows for the assessment and intervention of motor function, irrespective of underlying forces. Although numerous studies have examined upper limb kinematics in older populations, limited research has focused on healthy subjects. This study aimed to investigate kinematic differences between the dominant and non-dominant upper limbs during a reaching task among healthy young adults. **Methods:** A quantitative cross-sectional study was conducted at the Human Motion Lab. The study utilized wireless wearable sensor devices known as "Shimmer" to measure linear velocity, and the Edinburgh Handedness Inventory assessed hand dominance. Participants performed a reaching forward movement first with their dominant arm followed by their non-dominant arm. The collected data were converted into linear velocity and analyzed using MATLAB software. **Results:** The study recruited 28 healthy young adults (21.87±1.06 years: 11 males and 17 females). The results showed no significant differences in linear velocity between the dominant and non-dominant shoulders and elbow joints. However, a significant difference was observed in the wrist joint (MD = 0.84; 95% CI: 0.22 to 1.46; p = 0.01), with the dominant wrist exhibiting higher velocity during the reaching task than the non-dominant wrist. **Conclusions:** The results of this study suggest that similar strategies can be applied for functional task training in both shoulder and elbow joints, regardless of dominance site. However, it is essential to consider the specific needs of the wrist joint to optimize motor function in the upper limb, as its performance may be influenced by dominance status.

**Keywords:** Hand dominance; Kinematic; Rehabilitation; Upper limb; Young adult

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## INTRODUCTION

The functional movements of the upper limb (UL) play a crucial role in essential activities of daily living, such as eating, drinking, grooming, and facial washing (Dogan et al. 2019). Recognizing this significance, researchers have increasingly focused on studying purposeful motion during real-life activities, with particular attention to its kinematic aspects (Grimm et al. 2021; Tsilomitrou et al. 2021). Kinematics, a fundamental discipline within biomechanics, enables a comprehensive analysis of various facets of human movement and allows the study of motion independently of underlying forces (Collins et al. 2018; Grimm et al. 2021). By employing kinematic analysis, researchers and healthcare professionals can gain valuable insights into the mechanics of human movement and customize interventions to address specific impairments, ultimately enhancing functional outcomes and independence for patients (Collins et al. 2018).

In recent years, the application of motion capture technology has significantly increased to assess upper limb motion (Collins et al. 2018; Tsilomitrou et al. 2021). Many studies have focused on analyzing upper limb kinematics during drinking tasks (Dimwamwa & Johnson 2015; Murphy et al. 2011; Murphy et al., 2018). These investigations primarily compare healthy individuals and stroke survivors, with a specific emphasis on reaching, drinking, and returning the hand to the initial position (Dimwamwa & Johnson 2015; Murphy et al. 2011). Notably, individuals with hemiplegia, a condition characterized by paralysis on one side of the body, exhibit distinctive shoulder joint patterns, including larger shoulder abduction and flexion angles (Kim et al. 2014). This often leads to compensatory adjustments in the elbow and wrist joints (Kim et al. 2014). Furthermore, stroke patients typically display lower kinematic performance in various aspects, such as movement times, peak velocities, smoothness of movement, and inter-joint coordination, when compared to their healthy counterparts (Murphy et al. 2011; Murphy et al. 2006).

Despite considerable research on drinking tasks, there is a noticeable gap in the literature regarding upper limb kinematics during reaching tasks among healthy individuals. It is essential to study reaching and grasping movements separately, as they can vary significantly based on the task's goals and constraints (Murphy et al. 2018; Paulette & Sheridan 2007). For instance, pointing movements exhibit different kinematics when compared to movements involving both reaching and grasping an object (Murphy et al. 2011).

Reach-to-grasp movements are a fundamental aspect of normal upper-limb function and consist of two primary components: the "transport" component, wherein the hand follows a distinct path towards the target object, and the "grasp" component, wherein the hand opens and closes to firmly hold the object (Paulette & Sheridan 2007). Understanding these distinct components and their kinematic characteristics can provide valuable insights into the complexities of upper limb motion during reaching tasks among healthy subjects (Ponvel et al. 2019). Therefore, the present research aims to fill this gap by conducting a comparative study on upper limb kinematics during reaching tasks among younger adults, exploring the differences between the dominant and non-dominant hands.

## METHODS

### Study design

This study adopted a quantitative cross-sectional design. Ethical approval was obtained from the Secretariat for Research and Ethics of Universiti Kebangsaan Malaysia (UKM PP/111/8-JEP-2018-291).

### Study settings and participants

Participants were recruited from the Faculty of Health Sciences, Universiti Kebangsaan Malaysia (UKM), using simple random sampling. The study was conducted at the Human Motion Lab, UKM. Eligible participants were younger adults aged between 18 and 44 years (Alshabeeb et al. 2022; Dyussenbayev 2017).

Individuals with a history of primary shoulder pathology or surgery, neurological conditions, vertigo, neuromuscular disorders in the upper extremity, cognitive impairment, or upper limb fractures within the past 6 months were excluded from participation. The sample size of 28 participants was determined using G-Power software, with an effect size of 0.25, an alpha level of 5%, and a desired power of 85% (Kim et al. 2014).

### Instruments

#### *Wireless wearable sensors devices "Shimmer"*

Kinematic movement of the upper limb was assessed using wireless wearable sensors devices "Shimmer". A total of three reflective markers of sensors devices were placed on the acromion, lateral epicondyle, and radioulnar joint (Murphy et al. 2018). This wireless device measured kinematic data from the integrated altimeter and 9DoF inertial sensing via accelerometer, gyroscope, and magnetometer (Tsilomitrou et al. 2021). The acquired data was converted into linear velocity. In a study by Cudejko et al. (2022), the reliability and validity of the wearable sensors were assessed by comparing signal waveforms using the Linear Fit Method and Bland–Altman plots (Cudejko et al. 2022). The results demonstrated that the concurrent validity of the wearable sensors was high, ranging from fair to excellent in 91% of cases for accelerations and 84% for orientations (Cudejko et al. 2022). Furthermore, the test–retest reliability of accelerations was rated as fair to excellent in 97% of cases when the sensors were attached by a researcher, and in 84% of cases when applied by the participants (Cudejko et al. 2022).

#### *Edinburgh Handedness Inventory*

The Edinburgh Handedness Inventory (EHI) was used to assess hand dominance. It is a well-known short questionnaire designed to objectively determine whether an individual is left or right-handed (Veale 2013). It assesses handedness through self-report of preferred hand usage in common activities such as writing, drawing, throwing, and using utensils like a toothbrush, knife, and spoon (Veale 2013). The reliability and validity of the EHI have been extensively studied in various countries, with the overall Cronbach's alpha coefficient of correlation between the two halves of the questionnaire ranging from 0.92 to 0.97 (Veale 2013).

### Procedures

The Shimmer device was applied by a trained research assistant. For the shoulder joint, the marker was positioned at the ipsilateral acromion process. The Shimmer device was placed on the lateral epicondyle for the elbow joint, and on the distal radioulnar joint for the wrist joint (Murphy et al. 2018). After testing the dominant arm, all the devices were switched to the non-dominant arm. Each subject received instructions on performing the reaching task while seated (Figure 1).

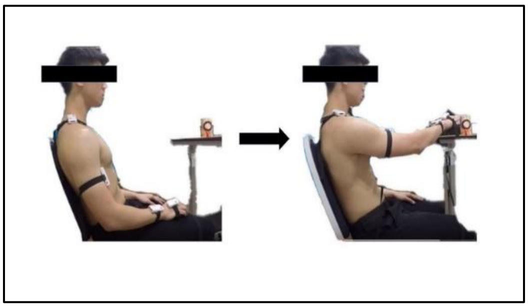

**Figure 1: Wireless wearable sensors and reaching task in a sitting position**

All subjects executed the reaching movement using their dominant arm. They remained seated, with their trunks stabilized against the back of a chair to minimize compensatory trunk movements. The start position involved the tested upper extremity resting on a pillow on the ipsilateral thigh, with the shoulder at approximately 0° flexion and extension, and 0° of internal rotation. The elbow was positioned at 75° to 90° flexion, with the wrist resting palm down and the finger joints slightly flexed on the pillow. Minor adjustments, such as increasing shoulder internal rotation to minimize positional discomfort, were made.

Each subject underwent recording for a minimum of three and up to six trials in one testing session, depending on the computer's ability to automatically track the markers. They were then instructed to reach forward as fast as possible and touch a 40-mm target (a standard size mug) placed 90% of the arm's length directly in front of the affected and dominant shoulder, at shoulder height. The three best recordings from each participant were selected based on marker visibility in each recording. The mean of these recordings provided the final measurement value for each participant. Furthermore, to ensure consistency and eliminate potential confounding effects related to subject height, the study utilized standardized chair and table heights. By carefully controlling for these factors, the researchers aimed to minimize any biases that subject height variations might introduce, thus enabling a more accurate investigation of the kinematic aspects of the upper limb during the reaching task.

### Data Analysis

The data was transferred from Multi Shimmer software to Excel and then to MATLAB software for further analysis. For each recording, coordinate data showing linear velocity was calculated and plotted. The aspect measured was linear velocity, which represented the velocity of the object traveling in a straight line. Statistical analyses were performed using SPSS version 23. Descriptive analysis was used to report socio-demographic details of the participants. Paired T-tests were conducted to compare upper limb kinematics between dominant and non-dominant hands.

## RESULTS

### Participants characteristics

The study enrolled a total of 28 participants, comprising 11 males and 17 females, with an average age of 21.87 ± 1.06 years. Demographic information and handedness status of the study participants are presented in Table 1.

The participants exhibited an average body mass index (BMI) of 22.27 ± 0.46 kg/m2, with seven individuals classified as overweight, while the majority fell within the normal BMI range. Regarding handedness, 24 participants were right-handed, and four were left-handed.

**Table 1: Demographic characteristics of the participants (n = 28)**

| Variables | n (%) or Mean ± SD |
|---|---|
| Age (years) | 21.87 ± 1.06 |
| Gender (male/female) | 11/ 17 |
| Body mass index (kg/m$^2$) | 2.27 ± 0.46 |
| Hand dominance (right-handed/ left-handed) | 24/ 4 |
| Edinburgh Handedness Inventory score | 1.13 ± 0.352 |

### Kinematic analysis

The kinematic variable analyzed was linear velocity, focusing on the shoulder, elbow, and wrist movements during the reaching task. The output from MATLAB presents the mean linear position graph of shoulder displacement for both the dominant and non-dominant hands along three different axes, as illustrated in Figure 2. A paired T-test was employed to compare the dominant hand's velocity with the non-dominant hand's velocity for each of the three Shimmer sensors (Shimmer 1, Shimmer 2, and Shimmer 3).

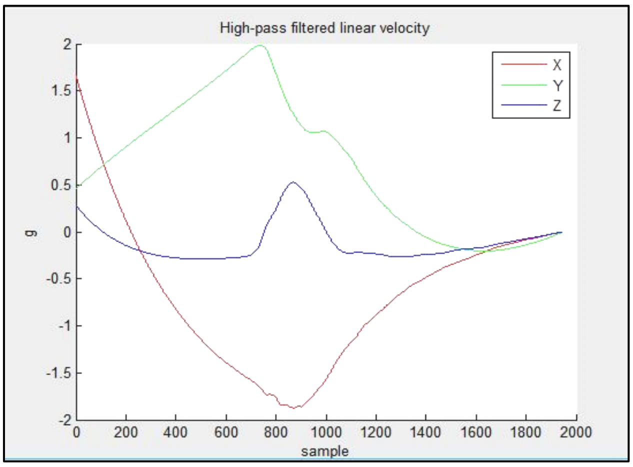


**Figure 2: Mean linear position graph of shoulder displacement for dominant and non-dominant hands along three axes**

Table 2 presents the *p*-values obtained from the paired T-tests for each joint (shoulder, elbow, and wrist) when comparing the dominant and non-dominant hands.

**Table 2: Differences between dominant and non-dominant upper limbs across joints and axes (n = 28)**

| Joints | Axes | *p*-value |
|---|---|---|
| Shoulder | X axis | 0.069 |
| | Y axis | 0.598 |
| | Z axis | 0.741 |
| Elbow | X axis | 0.536 |
| | Y axis | 0.225 |
| | Z axis | 0.488 |
| Wrist | X axis | 0.011* |
| | Y axis | 0.191 |
| | Z axis | 0.824 |

*Statistically significant ($p < 0.05$)

The results demonstrated that there was no significant difference in velocity between the dominant and non-dominant hands, except for the wrist joint.

Specifically, the wrist joint exhibited a significant difference, indicating that the velocity of the wrist movement during the reaching task was notably different between the dominant and non-dominant hands (mean ± SD = 0.84 ± 1.12; 95% CI: 0.22 to 1.46; $p = 0.01$). However, for the shoulder and elbow joints, the velocity did not significantly differ between the two hands.

## DISCUSSION

This study examined the kinematic differences during a reaching task between the dominant and non-dominant upper limbs among twenty-eight healthy young adults. The findings revealed that while there were no significant differences in linear velocity between the dominant and non-dominant shoulders and elbow joints, a significant difference was observed in the wrist joint. Specifically, the dominant wrist exhibited higher velocity during the reaching task compared to the non-dominant wrist. This suggests that limb dominance may not play a substantial role in determining the speed of reaching movements at the shoulder and elbow joints among healthy young adults.

While previous research has suggested that dominant hands might perform certain tasks faster or more accurately (Murphy et al. 2011; Sachlikidis & Salter 2007; Wang & Sainburg 2007), the present study in healthy younger adults indicates that this may not be the case for linear velocity during the reaching task. Several other studies have also explored upper limb kinematics in various populations and tasks, providing valuable comparisons and context for the current findings (Lott & Johnson 2016; Poston et al. 2009; Xiao et al. 2019). For instance, Xiao et al. (2019) investigated the effects of handedness on motion accuracies and 3D kinematic data in reaching performance of dominant and non-dominant hands, revealing no significant difference between them during fast speed movements (Xiao et al. 2019). Similarly, Lott et al. (2016) studied upper limb kinematics in adults with cerebral palsy during bilateral functional tasks and found comparable velocities between the dominant and non-dominant hands, consistent with the results for healthy controls (Lott & Johnson 2016). Additionally, Poston et al. (2009) examined age-related differences in movement structure for the dominant and non-dominant arms during goal-directed movements, uncovering similar movement times and velocities for both arms in both younger and older adults (Poston et al. 2009).

Moreover, the absence of significant differences in the shoulder and elbow joints among our cohort of young adults could be attributed to their relatively healthy and youthful status, suggesting that the impact of limb dominance may become more apparent with aging or in the presence of specific pathologies (Collins et al. 2018; Murphy et al. 2018). This observation aligns with a systematic review conducted by Ponvel et al. (2019), which identified age, physical activity level, and health status as crucial factors influencing upper extremity kinematics, a context that is relevant to our study as well (Ponvel et al. 2019). Additionally, our observation of no significant differences in velocity between the dominant and non-dominant shoulders and elbows during the reaching task is consistent with previous research that has often focused on upper limb kinematics during drinking tasks (Dimwamwa & Johnson 2015; Kim et al. 2014; Murphy et al. 2006). Such studies indicate that the shoulder and elbow joints are less influenced by hand dominance, and compensatory adjustments in these joints are less common in healthy individuals (Dimwamwa & Johnson 2015; Kim et al. 2014; Murphy et al. 2006). These findings underscore the importance of considering specific task contexts and functional movements when exploring the impact of hand dominance on joint kinematics and motor performance (Collins et al. 2018).

Interestingly, the significant difference in wrist velocity suggests that hand dominance may have a more substantial impact on wrist joint mechanics during reaching movements (Anderton et al. 2022; Grimm et al. 2021). This phenomenon can be explained based on the wrist's pivotal role in reaching movements, as fine adjustments and manipulations are often required during reaching tasks (Anderton et al. 2022). The dominant hand is typically more skilled and adept in executing precise movements (Sachlikidis & Salter 2007), which might be reflected in the higher velocity observed in the dominant wrist during the reaching task (Anderton et al. 2022). On the other hand, the non-dominant hand might exhibit slower and less precise wrist movements due to its lesser experience in executing fine motor tasks (Anderton et al. 2022). Consequently, hand dominance may influence the execution of wrist movements, contributing to the observed differences in velocity.

The findings suggest that individualised rehabilitation approaches based on hand dominance should be explored, rather than solely focusing on improving the non-dominant hand to match the dominant hand. Customizing interventions to address the unique requirements of the non-dominant wrist, such as precision and coordination, could lead to improved motor function and performance in reaching tasks. However, it is important to note some limitations of this study. The sample size was relatively small, consisting of only 28 healthy young adults, which might limit the generalizability of the findings. Furthermore, while the study investigated linear velocity, future investigations could include other kinematic variables, such as acceleration, joint angles, or movement time, to gain a more comprehensive understanding of upper limb motion during reaching tasks.

## CONCLUSION

The findings of this study indicate that hand dominance
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does not significantly affect reaching task velocity for the shoulder and elbow joints in healthy young adults, with the exception of the wrist joint. This emphasizes the relevance of incorporating hand dominance into rehabilitation strategies, specifically targeting the wrist movement component. Nonetheless, to refine approaches for individuals with movement impairments, further research with larger sample sizes and exploration of additional kinematic variables is warranted.


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## CONFLICT OF INTEREST

All authors declare no relevant financial or non-financial competing interests to disclose.


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