HTechJ Health and Technology Journal (HTechJ)

Volume 04 Number 03
June 2026
p-ISSN: 2986-5662
e-ISSN: 2985-959X

Biomechanical and Ergonomic Evaluation of Joint Position in Assistive Chopsticks During a Food-Pulling Task

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Abstract:
Assistive chopsticks equipped with joint mechanisms effectively support individuals with limited hand function by facilitating grasping and food serving. However, their biomechanical impact on food-pulling, a fundamental preparatory eating action requiring sustained force and control, remains unclear. This study investigated the effects of joint position in assistive chopsticks on food-pulling performance and physical load. Ten healthy young males performed a standardized food-pulling task using their non-dominant hand to simulate reduced manual dexterity. Participants evaluated three chopstick conditions: conventional (unjointed), handle-joint, and top-joint. During the task, a simulated food item was pulled toward the participant while maximum pulling force, flexor digitorum superficialis muscle activity (via surface electromyography), and subjective comfort (via a visual analog scale) were quantitatively measured. Statistical analysis revealed no significant differences among the three conditions for maximum food-pulling force, normalized muscle activity, or subjective comfort. These findings indicate that variations in joint position do not adversely affect food-pulling performance or increase neuromuscular load. Although the participant sample was restricted to healthy young males, this study provides critical preliminary evidence that assistive chopsticks can be structurally optimized for specific grasping or serving tasks without compromising fundamental food manipulation. Ultimately, these results offer valuable design flexibility for the future development of ergonomic, task-specific assistive eating devices.

Article info:
Submitted:
31-03-2026
Revised:
06-05-2026
Accepted:
13-05-2026
Published:
13-06-2026

Keywords:
assistive design, chopsticks, ergonomics, food-pulling, joint position

DOI: https://doi.org/10.53713/htechj.v4i3.687

INTRODUCTION

Support for activities of daily living is essential for maintaining personal independence and quality of life, particularly as global populations age and physical disabilities increase (Feng et al., 2025; Kurniyawan et al., 2023). developing assistive technologies that empower autonomous task performance has become a critical priority in rehabilitation engineering (Umbelino et al., 2026). These innovations mitigate the psychosocial burdens of physical dependency while promoting sustained community integration and overall well-being (Muttaqin, 2025).

Within this broader domain, mealtime independence is critically dependent on the ability to safely and effectively manipulate food, a complex fine motor skill that is frequently compromised in individuals with limited hand function caused by neurological disorders, traumatic injuries, or the natural aging process (Hitzig et al., 2024). The loss of dexterity, grip strength, and coordinated bimanual finger movement can transform the simple act of eating into a frustrating and hazardous endeavor, underscoring the vital need for specialized adaptive eating utensils designed to restore functional capability and ensure adequate nutritional intake (Atigossou et al., 2025).

To address these specific mealtime challenges, assistive chopsticks equipped with mechanical joint mechanisms have been widely introduced to support users by facilitating synchronized opening and closing movements and stabilizing finger coordination (Kitagawa & Nagaoka, 2024). Previous empirical studies have robustly demonstrated that these joint mechanisms can significantly improve grasping performance, reduce operational difficulty, and enhance food-serving efficiency when compared with conventional, unjointed chopsticks (Taylor, 2025). Current design paradigms heavily focus on optimizing these joint configurations to maximize performance during the initial grasping and subsequent transporting phases of a meal, often overlooking the biomechanical demands of preparatory plate manipulation (Yang et al., 2022).

Eating with chopsticks involves a broader repertoire of actions beyond merely grasping or transporting, most notably the active manipulation of food directly on a plate (Tsuzuku et al., 2022). Food-pulling is formally defined as a manipulation task in which food is grasped and pulled toward the user on a plate prior to final grasping, repositioning, or separation during eating. Unlike dynamic grasping, this action often requires sustained isometric force generation and precise, stable finger control to prevent the food from slipping (Fu & Choji, 2026). Despite the critical importance of this preparatory action, the specific influence of joint position in assistive chopsticks on food-pulling performance and the associated physical load has not been sufficiently investigated in existing literature, representing a distinct and critical research gap that limits our understanding of holistic utensil usability.

From an assistive technology and ergonomic design perspective, this knowledge gap is nontrivial and requires urgent attention. Design features that enhance performance in one specific eating task may not necessarily exert the same beneficial effects across different biomechanical actions (Kurauchi et al., 2024). Design parameters optimized for grasping and serving tasks may still be acceptable for food-pulling if the pulling action is relatively robust to structural variations. Clarifying whether joint position influences food-pulling performance is therefore essential to understand the task-dependent effects of assistive chopstick design and to ensure that design improvements do not unintentionally hinder fundamental eating capabilities (Wen et al., 2023).

The primary purpose of this study was to quantitatively clarify the effects of joint position in assistive chopsticks on a standardized food-pulling task. By systematically evaluating maximum food-pulling force, flexor digitorum superficialis muscle activity, and subjective comfort, this research aims to provide the first specific investigation of the relationship between food-pulling actions and joint configuration (Komi et al., 2025). We hypothesized that differences in the joint positions of assistive chopsticks would significantly influence food-pulling performance and upper-limb muscle activity, thereby providing critical data to guide the evidence-based design of future assistive eating devices for diverse clinical populations.

METHOD

Participants and Experimental Setup

Ten healthy, right-handed males (mean age: 19.6 ± 0.5 years; height: 168.6 ± 5.8 cm; body mass: 72.6 ± 10.6 kg) with no upper-limb impairments participated in this exploratory pilot study. To simulate novice users or individuals with reduced dexterity, all tasks were performed using the non-dominant (left) hand, a standard approach to increase task difficulty while maintaining safety.

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Chopsticks Conditions

Three chopstick conditions were evaluated to isolate the effects of joint position (Figure 1): (1) Normal, conventional chopsticks without a joint; (2) Handle joint, featuring a joint at the grip area to support synchronized opening and closing; and (3) Top Joint, with a joint near the distal end that alters mechanical leverage.

To minimize confounding variables, all conditions utilized identical 21.0 cm commercial wooden chopsticks. By keeping the material, mass, length, and tip shape constant, the experimental design ensured that any observed differences in food-pulling performance, muscle activity, or subjective comfort were attributable solely to the joint's location.

Figure 1. Chopsticks conditions

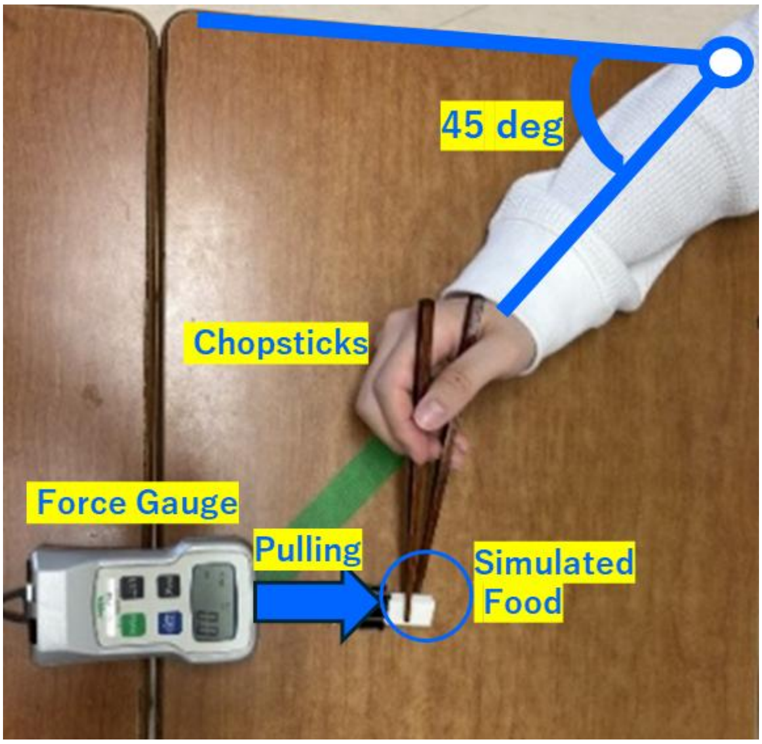

Figure 2. Experimental setup

Experimental Procedure

A food-pulling task was designed to simulate a fundamental preparatory eating action (Figure 2). To ensure consistency and repeatability, a rectangular eraser (17 × 43 × 11 mm; 11 g) served as the simulated food item, providing stable contact with minimal deformation. The eraser was secured to a digital force gauge (FGJN-2, Nidec Shimpo Co., Japan) via a binder clip. The investigator held the gauge firmly throughout the task to prevent unintended movement and isolate the participant's pulling force.

Participants were seated at a table 76.0 cm high. To standardize posture, the task arm's elbow was aligned with the table edge, and the forearm was positioned at approximately 45 °. The force gauge was individually adjusted to allow a natural grasp without awkward wrist or finger positioning, minimizing excessive shoulder movement.

Participants used their non-dominant hand to perform the task across all three chopstick conditions. To minimize fatigue and learning effects, each condition was tested only once per participant in a randomized order. Following a familiarization period for each condition, participants were instructed to securely grasp the eraser and pull it toward themselves with maximal effort while maintaining the prescribed posture.

Measurement

Maximum food-pulling force was recorded using the peak-hold function of a digital force gauge to capture the peak force of each trial. muscle activity of the flexor digitorum superficialis was measured using a wireless surface EMG sensor (SS-EMGD-SM, Sports Sensing Co., Japan) sampled at 1000 Hz. Signals were band-pass filtered, full-wave rectified, and time-averaged. To minimize inter-individual variability, EMG data were normalized to the maximum voluntary contraction (MVC) and expressed as a percentage of MVC (%MVC).

Subjective comfort was evaluated after each trial using a 100-mm visual analog scale (VAS). Participants rated the perceived ease of force exertion during the task, with 0 mm indicating "extremely difficult" and 100 mm indicating "extremely easy."

Data Analysis

Maximum food-pulling force, %MVC, and subjective comfort were compared across the three chopstick conditions using non-parametric tests due to the small sample size. The Kruskal–Wallis test assessed overall differences, followed by Bonferroni-corrected post hoc comparisons for significant effects. Statistical significance was set at $p < 0.05$.

Ethical Approval and Consent

The study adhered to the Declaration of Helsinki and was approved by the Ethics Committee of the National Institute of Technology (KOSEN), Hachinohe College (Approval No. R7-3). Written informed consent was obtained from all participants following a detailed explanation of the procedures, objectives, and their right to withdraw at any time.

RESULT

Figure 3 shows the maximum food-pulling force measured under the three chopstick conditions: "Normal," "Handle Joint," and "Top Joint." No significant difference in maximum food-pulling force was observed among the three conditions (Kruskal–Wallis test, $p = 0.424$; Normal: 5.65 ± 3.42 N; Handle Joint: 6.47 ± 3.11 N; Top Joint: 7.26 ± 2.92 N). Although not statistically significant, a tendency toward slightly higher values was observed in the Handle Joint and Top Joint conditions.

Figure 4 presents the normalized muscle activity of the flexor digitorum superficialis during the food-pulling task. No significant difference in muscle activity was observed among the three conditions (Kruskal–Wallis test, $p = 0.842$; Normal: 36.7 ± 30.9 %MVC; Handle Joint: 35.2 ± 26.6 %MVC; Top Joint: 41.1 ± 34.8 %MVC). Although not statistically significant, a tendency toward slightly higher values was observed in the Top Joint condition.

Figure 5 illustrates subjective comfort during food-pulling, evaluated using the visual analog scale (VAS). No significant difference in VAS score was observed among the three conditions

(Kruskal–Wallis test, $p = 0.121$; Normal: 30.3 ± 33.7 mm; Handle Joint: 61.8 ± 30.4 mm; Top Joint: 57.0 ± 32.3 mm). Although not statistically significant, a tendency toward slightly higher values was observed in the Handle Joint and Top Joint conditions.

Overall, the results indicate that joint position in assistive chopsticks did not significantly influence food-pulling force, muscle activity, or subjective comfort of food-pulling in the present experimental task. These results were consistent across all outcome measures, suggesting that the differences in joint position did not alter the ability to generate pulling force or the associated muscular demand during the task.

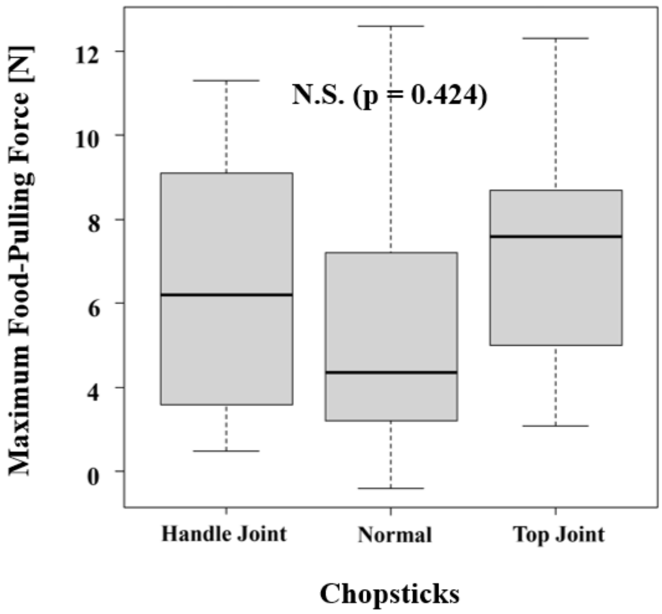

Figure 3. Food-pulling forces in three conditions (N.S.: not significant, p = 0.424)

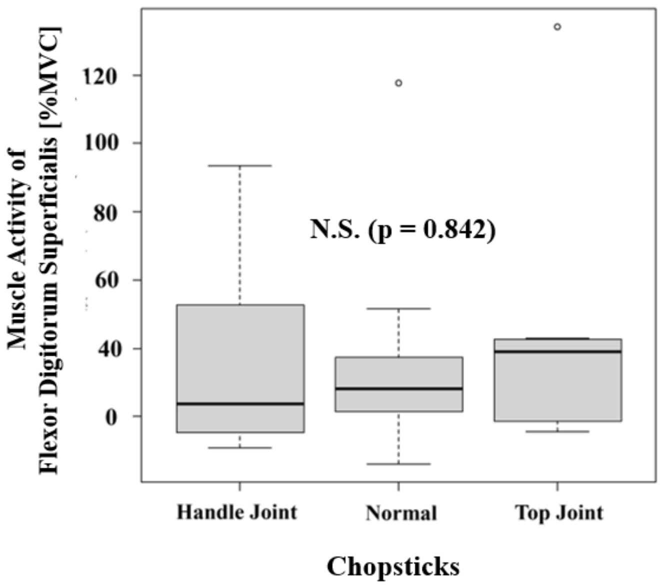

Figure 4. Muscle activities in three conditions (N.S.: not significant, p = 0.842)

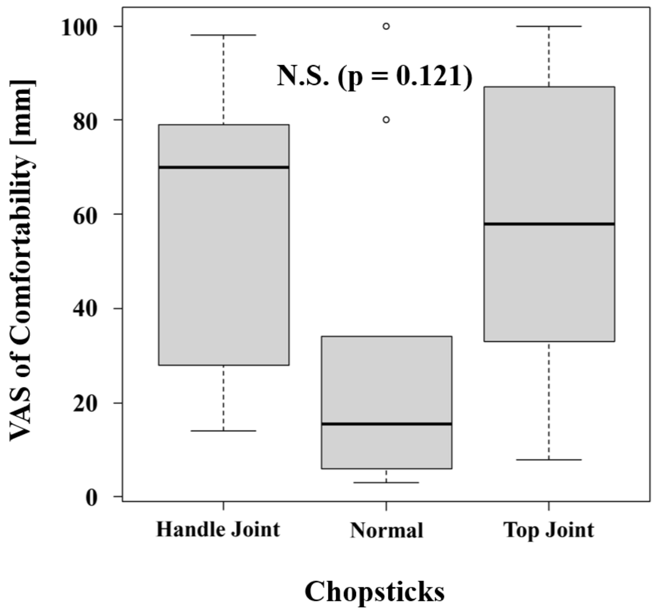

Figure 5. VAS scores in three conditions (N.S.: not significant, p = 0.121)

DISCUSSION

The primary objective of this study was to clarify the effects of joint position in assistive chopsticks on a food-pulling task by evaluating maximum pulling force, muscle activity, and subjective comfort. The principal finding is that there are no significant differences among conventional chopsticks, assistive chopsticks with a handle joint, and assistive chopsticks with a top joint across any evaluated indices. These results demonstrate that variations in mechanical joint position do not adversely affect food-pulling performance or alter the physical load experienced by the user. Integrating a joint mechanism, regardless of its specific placement, maintains the fundamental capability to execute food-pulling maneuvers effectively (Besari et al., 2022).

These findings extend the current understanding of assistive eating utensils by confirming that joint-equipped designs do not compromise fundamental food manipulation tasks, even while enhancing other specific actions. Previous studies have demonstrated that joint mechanisms in assistive chopsticks can significantly improve grasping performance, reduce operational difficulty, and enhance food-serving efficiency when compared with conventional chopsticks (Kitagawa & Nagaoka, 2024; Taylor, 2025). The present results complement this literature by establishing that such mechanical modifications can be applied without degrading food-pulling performance. Essentially, assistive chopsticks with varying joint positions retain their previously reported advantages in grasping and serving tasks while maintaining food-pulling capabilities that are statistically comparable to those of conventional, unjointed chopsticks.

The absence of significant joint-position effects can be primarily attributed to the distinct biomechanical characteristics and specific motor demands of the food-pulling task. Unlike grasping or food-serving actions, which require repeated, precise opening and closing movements, food-pulling primarily involves generating a sustained pulling force toward the user while maintaining continuous contact with the food item. This action relies heavily on gross force generation and sustained finger flexion rather than the fine, dynamic modulation of chopstick aperture (Choji et al., 2026). Because the task does not demand intricate adjustments of the joint mechanism during the pulling phase, the mechanical coupling introduced by the joint has a limited influence on the overall motor strategy required for successful food manipulation.

This biomechanical interpretation is further supported by the electromyographic data, which indicated that the activation level of the flexor digitorum superficialis remained unaltered across the different chopstick configurations. The flexor digitorum superficialis plays a central role in finger flexion and force generation during powerful, sustained gripping actions, making it the primary muscle of interest for this force-dominant task. The observation that its muscle activity, expressed as a percentage of maximum voluntary contraction, did not vary with joint position suggests that the central nervous system employs a consistent force-generation strategy regardless of the tool's mechanical layout (Tessari et al., 2025). The physical load imposed on the primary flexor muscles remains constant, reinforcing the conclusion that food-pulling is robust against moderate variations in mechanical design.

These observations align with broader biomechanical principles regarding human interaction with tools, particularly in the context of pinch and precision grip tasks. The existing literature indicates that changes in joint posture or mechanical constraints typically influence kinematic patterns and fine motor coordination much more strongly than they affect maximum force generation (Zhou & Liu, 2026). Force-dominant actions tend to be highly robust to moderate variations in tool configuration, as the neuromuscular system prioritizes achieving the required endpoint force over optimizing the tool's internal joint mechanics. The present results confirm that the sensitivity of eating performance to assistive-design features is highly task-dependent, and not all eating actions are equally influenced by mechanical modifications.

From a practical perspective, the finding that joint position does not negatively affect food-pulling performance is highly significant for end-users' daily lives. Food-pulling is a ubiquitous preparatory action during meals, particularly for individuals who must reposition food on a plate before successfully grasping it. If assistive chopsticks hindered this basic action, their practical usefulness in real-world eating situations would be severely limited, regardless of their benefits in other areas (Sae-Ueng et al., 2026). The present results demonstrate that users can benefit from the enhanced grasping and serving capabilities of assistive chopsticks without compromising their ability to manipulate and retrieve food from a shared dish.

These findings provide valuable design flexibility for engineers and ergonomists developing the next generation of assistive eating devices. Because the joint location does not adversely affect food-pulling performance, designers are no longer constrained to optimize joint placement specifically for this task. They can select joint positions based on other critical design requirements, such as long-term durability, manufacturing feasibility, weight distribution, or optimization for specific grasping tasks. This mechanical flexibility enables a more holistic approach to assistive device development, allowing the overall usability and structural integrity of the product to be prioritized without inadvertently degrading the user's food-pulling capabilities (Turgeon et al., 2022).

Despite these promising findings, several methodological limitations must be acknowledged, primarily concerning the demographic characteristics of the participant pool. The study exclusively utilized healthy young male participants, meaning the results may not directly generalize to elderly individuals or users with specific hand impairments, who constitute the primary target demographic for assistive chopsticks. Although the use of the non-dominant hand was intentionally employed to simulate reduced dexterity, this approach cannot fully replicate the complex motor deficits, muscle weakness, or altered sensory feedback associated with pathological conditions (Özden et al., 2025). Caution must be exercised when extrapolating these performance metrics to the clinical populations that will ultimately utilize these assistive devices in their daily lives.

A second significant limitation concerns the ecological validity of the experimental task and the physical properties of the simulated food item used during the trials. The food-pulling task was performed only once per chopstick condition to minimize fatigue, and a simplified, uniform rectangular eraser was used rather than actual food. While this experimental simplification was strictly necessary to ensure consistency and precise force measurement across all participants, it fails to capture the wide variety of food textures, shapes, and frictional properties encountered in real-world dining scenarios. Real food items often deform or slip, potentially introducing subtle interaction effects at the chopstick joint that were not observable with a rigid test object.

While this study comprehensively evaluated kinetic and physiological outcomes, it did not assess kinematic indices such as finger motion trajectories, joint angles, or overall hand movement patterns. Force, muscle activity, and subjective comfort provide critical insights into the user's physical load and performance capacity. However, they offer an incomplete picture of the underlying motor control strategies (Wang & Amirouche, 2025). It is possible that participants adopted subtle compensatory movements or altered wrist kinematics to accommodate the different joint positions, even though maximum force output and muscle activation levels remained statistically unchanged. Without kinematic data, the study cannot fully elucidate whether the mechanical design of the chopsticks influences the quality or naturalness of the movement execution.

To address these limitations and build upon the current findings, future studies must adopt a more comprehensive methodological approach that includes diverse participant populations and advanced measurement techniques. Subsequent research should include participants with actual functional impairments and evaluate food-pulling performance across a broader range of realistic food properties, with repeated trials to account for fatigue and learning effects. Incorporating quantitative analysis of hand and finger kinematics using advanced image-based motion analysis systems would provide a much more comprehensive understanding of movement coordination during food-pulling tasks (Besari et al., 2022; Choji et al., 2025). By integrating these kinematic measurements, researchers will be able to examine subtle differences in movement strategies associated with joint position, ultimately contributing to the evidence-based design of assistive chopsticks that seamlessly support diverse eating actions.

CONCLUSION

This study investigated the influence of joint position in assistive chopsticks on food-pulling performance by evaluating maximum pulling force, forearm muscle activity, and subjective comfort. The results demonstrated no significant differences across conventional chopsticks and assistive variants with varying joint placements, indicating that mechanical modifications do not compromise this fundamental eating action. joint-equipped assistive chopsticks can effectively support food-pulling maneuvers without increasing neuromuscular load or perceived difficulty, thereby preserving their established benefits for grasping and serving tasks. By highlighting the task-dependent nature of utensil mechanics, this research provides critical design flexibility for ergonomic interventions. Future investigations incorporating clinical populations and ecologically valid dining scenarios are essential to translate these preliminary findings into robust, evidence-based assistive device development.

ACKNOWLEDGEMENT

The authors would like to thank all experimental participants for their cooperation and involvement in this study.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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