VNIVERSITAT DE VALÈNCIA
Facultat de Fisioteràpia

DOCTORAL THESIS

UPPER LIMB FUNCTIONAL IMPROVEMENT AFTER ABDOMINAL DRAWING-IN MANEUVER ON CHRONIC STROKE SURVIVORS: A CROSSOVER STUDY

Presentada por:

Dña. Aenon Lee

Dirigida por:

Dr. José Casaña Granell

Dr. Joaquín Calatayud Villalba

Valencia, 2024

Universitat de València

Facultat de Fisioteràpia

“Upper limb functional improvement after Abdominal Drawing-In Maneuver on chronic stroke survivors: A crossover study ”

DOCTORAL THESIS

Presentada por:

Dña. Aenon Lee

Dirigida por:

Dr. D. José Casaña Granell

Dr. D. Joaquín Calatayud Villalba

Valencia, 2024

Dr. Jose Casaña Granell, Profesor Titular d' Universitat, adscrit al *Departament de Fisioteràpia de la Universitat de València.*

Dr. Joaquín Calatayud Villalba, Profesor Titular d' Universitat, adscrit al *Departament de Fisioteràpia, de la Universitat de València.*

Hace costar:

Que el trabajo presentado como Tesis Doctoral por Dña. Aenon Lee, titulado *"Upper limb functional improvement after Abdominal Drawing-In Maneuver on chronic stroke survivors: A crossover study"* ha sido realizado bajo la dirección para optar al grado de Doctor por la Universitat de València. Habiéndose concluido, y reuniendo a mi juicio las condiciones de originalidad y rigor científico necesarias, se autoriza su presentación a fin de que pueda ser defendido ante el tribunal correspondiente.

Y para que así conste, expide y firma la presente certificación en València, a 10 de Mayo de 2024.

José Casaña Granell

Joaquín Calatayud Villalba

VNIVERSITAT DE VALÈNCIA
Departament de Fisioteràpia

Nombre de reconocimiento (DN): cn=JOSE CASAÑA GRANELL - NIF:20154083B, serialNumber=20154083B, givenName=JOSE, sn=CASAÑA GRANELL, ou=CIUDADANOS, o=ACCV, c=ES
Fecha: 2024.06.13 13:09:24 +02'00'

JOAQUIN MANUEL| CALATAYUD|VILLALBA

Firmado digitalmente por JOAQUIN MANUEL| CALATAYUD| VILLALBA
Fecha: 2024.06.13 19:48:28 +02'00'

Gratitude

I wish to extend my sincere gratitude to all those who have supported and contributed to the successful completion of my doctoral thesis.

First of all, I am deeply thankful to Supervising Professor José Casaña Granell and Professor Joaquín Calatayud Villalba for their invaluable guidance and for inspiring direction in my research, which enabled me to achieve the overarching goals of my study.

Thanks to Professor Carlos Cruz-Montecinos for his invaluable assistance in the analysis of my paper. I am also grateful to Professor Rubén López-Bueno, Professor Luis Suso-Martí, and Professor Lars Louis Andersen for their insightful guidance. I express my heartfelt appreciation to Professor Sang-Hoon Kang of the Ulsan National Institute of Science and Technology for his proactive support in facilitating the experimental process and participant recruitment in Korea. His counsel and support were instrumental in initiating our experiments. Additionally, I extend my gratitude to my colleagues in the Rehabilitation Engineering Lab, especially Hyun-A Kang, Sung-Il Hwang, Jeongwoo Jeon, Chan-Soo Kim, Minjae Kim, and Dohoon Kim, as well as to Ms. Han-A Young of the Ulsan Welfare Center for Persons with Disabilities and Ms. Hye-Kyung Heo, the coordinator at the Ulsan Disabled Sports Complex, and other stakeholders for their invaluable assistance, which facilitated the smooth progression of my thesis.

I would also like to express my profound appreciation to the physical therapists who dedicated their efforts to the intervention process. Furthermore, I extend my deepest gratitude to my graduate school peers, Trinidad Bruna Melo, Marité Araneda Salamanca, and Suiane Lima Cavalcante, for their unwavering support and encouragement throughout this journey. Lastly, I am immensely grateful to my family and Edwar Fernand Torres Benitez for their constant encouragement and unwavering support.

I pledge to continue striving for excellence and integrity in the field of physical therapy research, with the aim of contributing to its further advancement.

Index

INDEX OF CONTENTS

INDEX OF FIGURES

INDEX OF TABLES

INDEX OF ABBREVIATION

ACA: Anterior Cerebral Artery

ADIM: Abdominal Drawing-In Maneuver

ADL: Activities of Daily Living

BMI: Body Mass Index

CI: Confidence Interval

CT: Conventional Therapy

DF: Degrees of Freedom

EMG: Electromyography

FMA: Fugl-Meyer Assessment

FND: Functional Neurological Disorders

ICC: Intraclass Correlation Coefficient

ICD: International Classification of Diseases

IQR: Interquartile range

IRBs: Institutional Review Boards

MAS: Modified Ashworth Scale

MCA: Middle Cerebral Artery

MS: Mean Square

NA: Not Available

PASS: Postural Assessment Scale

PCA: Posterior Cerebral Artery

PM: Premotor Area

ROM: Range of motion

SD: Standard Deviation

SMA: Supplementary Motor Area

SS: Sum of Squares

TENS: Transcutaneous electrical nerve stimulation

TIS: Trunk Impairment Scale

TrA: Transversus Abdominis

UE: Upper Extremity

UMN: Upper Motor Neurons

INTRODUCTION

1. INTRODUCTION

1.1. A stroke, cerebrovascular disease

Annually, 15 million individuals worldwide experience a stroke (World Health Organization Eastern Mediterranean Region, 2024). Stroke may happen at any age. However, the likelihood significantly elevates after the age of 55 (Soto-Cámara et al., 2020). As per the International Classification of Diseases 11th Revision (ICD-11), a stroke is characterized by brain dysfunctions associated with blood vessel diseases, categorized as hemorrhagic and ischemic strokes (International Classification of Diseases 11th Revision, 2023)

The primary causes encompass cerebral venous thrombosis, rupture of congenital vascular malformations, dural arteriovenous fistulae, and central nervous system vasculopathy, often resulting in herniation, elevated intracranial pressure, and a significant mass effect (Montaño et al., 2021). Ischemic stroke typically arise from either thrombotic or embolic cerebrovascular injuries in their etiology (Hui C et al., 2023). Distinct stroke types carry varying risks of mortality, with the survival odds after an ischemic stroke being seven times higher compared to a hemorrhagic stroke (Kuriakose & Xiao, 2020). The perforating artery operates by creating an alternative route, thereby facilitating the seamless continuation of the overall system. The regulation of blood supply to the brain is orchestrated by four primary arteries: two internal carotids in the front and two vertebral arteries in the back, collectively known as the Circle of Wills. The main branches of the Circle included the Anterior Cerebral Artery (ACA), Middle Cerebral Artery (MCA), Posterior Cerebral Artery (PCA) (Hui C et al., 2023). This complex network is designed to allow other vessels to take over and maintain the flow or function in the event of a blockage or obstruction in one specific area. In contrast, a hemorrhagic stroke occurs when an internal injury triggers a blood vessel to rupture, resulting in an abnormal accumulation of blood within the brain. Hemorrhagic strokes are more likely to result in death within the first month compared to ischemic strokes. The fatality rate for hemorrhagic strokes at one month is roughly 40% higher than that of ischemic strokes.

After a stroke, it is reported that there is an increase of about 75% in cases involving upper-limb impairment, and more than 50% of stroke survivors suffer from decrease in quality of life (Levin et al., 2009). Even with intensive and extended rehabilitation efforts, over 65% of these cases continue to experience lingering difficulties in the chronic stage, indicating that the impairments persist over time (Demers & Levin, 2017; Kwakkel et al., 2019).

1.2. Mechanism of functional movement disorder of Cerebral cortex

The middle cerebral artery (MCA) is commonly affected in stroke, leading to predominant impairment in the upper extremities due to the substantial size of this brain region (Hui C et al., 2023; Navarro-Orozco & Sánchez-Manso, 2023). Neurological lesions causing damage to the frontal cortex can result in a variety of changes in behavioral functions, including alterations in planning, cognitive flexibility, set-shifting, initiation, and response inhibition (Hanna-Pladdy, 2007).Specifically, dorsolateral prefrontal cortex plays a crucial role in executive functioning consequences of behaviors (CASEY HENLEY, 2021; Nejati et al., 2021; Wr & Newton Bw, 2023). This area sends the information to Premotor Area (PM) and Supplementary Motor Area (SMA). These areas play a rule in accurate movement and postural control intricately programmed through meticulous planning and preparation. Following the transmission of signals from the PM and SMA, the motor cortex initiates the execution of movements. Specifically, detailed movement information is conveyed along the corticospinal tract from the Primary Motor Cortex (M1) (Takakusaki, 2013). This process generates feedforward signals, which are subsequently compared to feedback from both interoceptive and external sources post-action. A multimodal output model is then juxtaposed with real-time visual and proprioceptive feedback from the hand (Herbort et al., 2008). Multimodal integration combined proprioceptive and visual information for postural representation. The anterior intraparietal area plans grasping movements using visual and somatosensory input, while the medial intraparietal area, part of the parietal reach region, controls reaching movements (Holmes et al., 2009). If the signals do not align in a multimodal integration, the movement is not recognized as voluntary. The brain maintains a model of the body and the surrounding environment, incorporating predictive coding into this multimodal integration. Multimodal output model recognize both current visual and proprioceptive feedback of joint. Feedback signals that deviate from predictive coding create a prediction error, initiating modifications to the model to ensure that subsequent feedback aligns with predictive coding. In functional Neurological Disorders (FND), it is theorized that an inaccurate update of prediction error perpetuates dysfunction (Floegel et al., 2023; Hallett et al., 2022). **Figure 1** illustrates a diagram related to functional movement disorders, specifically the signal from the motor cortex, though the underlying principles are applicable to all functional movement disorders, such as those involving tasks or activities of daily living (Database Center for Life Science (DBCLS), 14; Floegel et al., 2023; Hallett et al., 2022; Takakusaki, 2013).

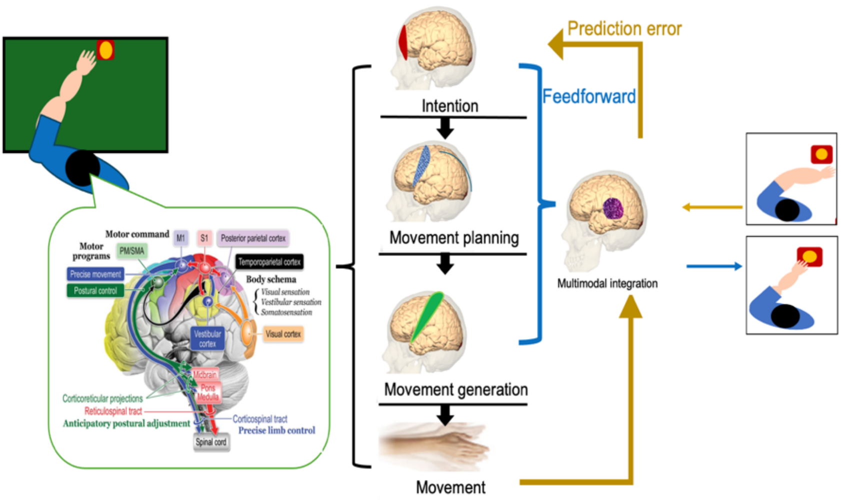

Figure 1. Mechanism of movement disorder

PM, PreMotor area; SMA, Supplementary Motor Area; M1, Primary Motor area

1.3. Abnormal flexor synergies in upper extremity

The corticospinal system serves as a primary neural substrate for executing a wide range of complex, skilled movements (Lang et al., 2013). When the corticospinal tract is damaged, it disrupts the coordinated communication between the muscles of the extremities and the trunk, leading to compromised postural stability and reduced movement accuracy (Javed K et al., 2022; Lalonde & Strazielle, 2007). The absence of proper proximal stabilization significantly affects limb movement, restricting the arm and leg to follow rigid, spastic patterns of motion (Karthikbabu et al., 2012). Specifically, the cerebral cortex plays a crucial role in controlling specific muscles (McMorland et al., 2015). The upper extremity encompasses approximately 32 muscles, underscoring the complexity of the muscular system involved in controlling these movements (Burns et al., 2017). Following a stroke, the brain’s control over movements becomes less efficient, resulting in an unusual combination of forces in the fingers, wrists, and elbow when attempting to lift the shoulder away from the body, known as the ‘flexion synergy’. The combined muscle synergies consist of shoulder flexion, abduction, and external rotation, along with elbow flexion and forearm supination (Levin, 1996). This issue is particularly noticeable in the weakened or paralyzed arm after a stroke (Suvada et al., 2020). These atypical muscle coordination patterns are not primarily attributed to factors such as muscle weakness, slow activation, excessive simultaneous contraction, or spasticity. Furthermore, flexor spasticity has a small role in reaching dysfunction. its impact on elbow extension is quickly overshadowed by flexor synergy, particularly under higher abduction loads (Ellis et al., 2017). Instead, they signify a challenge in generating the correct timing and sequence of muscle movements that align with the demands of the environment (Raghavan, 2015). The upper extremity displays abnormal pathological patterns, which may arise from synergies of muscle co-contraction by motor impairment (McMorland et al., 2015). Furthermore, increased muscle tone results from a loss of inhibition in the spinal cord due to damage to the corticospinal tract(Lang et al., 2013). Damage to upper motor neurons (UMN) can lead to heightened reflexes, increased muscle tone, a positive Babinski reflex, and spastic paresis. The corticospinal tract is primarily responsible for muscle control (Javed K et al., 2023). Synergies are the synchronized muscle movements that help produce steady force when our limbs are involved in typical movements or natural motor activities (Singh et al., 2018). The intensity of force is associated with motor units, which include factors like motor unit size and firing rate (Conwit et al., 1999). Poor movement variables may be affected by the decreased recruitment of agonist motor units, which are the ability to recruit high-threshold and fast-twitch motor units. This leads to the weakness of the muscle for agonist activation rather than high antagonist co-contraction (Levin, 1996; Lum et al., 2004).

1.4. Neurological Kinematics

One of the most common approaches to analyzing movement in the context of neurological pathology is the assessment of reaching and grasping movements (De Los Reyes-Guzmán et al., 2014). This method involves the precise measurement of specific motor abilities and movement characteristics. It encompasses a wide spectrum of neurological skills, including postural control and muscle coordination across complex multi-joint movements. The focus of quantitative measurement is on isolating and evaluating specific aspects of motor performance and movement features. This analytical strategy is crucial for comprehending and assessing neurological impairments and their impact on an individual's everyday activities. The computational analysis of movement within this framework places emphasis on variables like velocity, acceleration, and joint angles during physical activities. These parameters yield valuable insights into the complexities of motor control and coordination affected by neurological disorders. By delving into these quantitative and computational dimensions of movement, researchers and clinicians gain a deeper insight into the motor deficits associated with neurological conditions, ultimately leading to more effective interventions and treatments. **Figure 2** illustrates the prevalence of movement characteristics in a preliminary investigation study, as established by Saes, et al. (2022). The most common investigation are movement time and peak hand velocity in more than 40% rate. Additionally, more than 20% of the studies also examined other metrics such as average hand velocity, jerk, speed metric, endpoint accuracy, and reach efficiency. For showing movement smoothness, trunk metrics of speed, peaks, and jerk which refer to rapid changes in acceleration during movement. The smoothness metrics used in a particular context can be assessed by quantifying two different aspects: the number of sub-movements and the number of feedback corrections (Saes et al., 2022).

Table 1 shows systematic investigation based on their level of quantifying upper extremity. While De Los Reyes-Guzmán, et al. (2014) provided a classification of metrics into 9 groups for general quantification purposes, our study specifically focuses on metrics related to assessing the quantifying quantity of movement.

1.4.1. Movement quantity

Kinematic analysis involves a comprehensive assessment of movement control, incorporating aspects such as movement quality and motor performance through numerical expressions (Choi et al., 2023). Furthermore, quantitative measures play a role in articulating results, evaluating their effectiveness, and aiding decision-making in clinical settings (De Los Reyes-Guzmán et al., 2014). It assesses how quickly a functional task can be accomplished successfully (De Los Reyes-Guzmán et al., 2014). Postural performance measures pertain to specific elements, quantified in terms of target accuracy, related to impaired motor control, while excluding consideration of compensatory movements or the functional task context (Saes et al., 2022) and involve a variety of variables associated with quantitative movements.

- Elbow extension: It quantifies the angular measurement of the elbow joint throughout its movement.
- Shoulder flexion: Similar to the measurement of the elbow joint angle, this is a quantitative assessment of the angle at the shoulder joint.
- Trunk displacement: It entails quantifying the degree of movement in a specific direction, offering a numerical representation of the extent to which the trunk has shifted during reaching task.
- Total time: It represents the duration encompassing the entirety of a movement.

- Hand velocity: It is a quantitative measure that signifies the speed of the hand.
- Hand acceleration: It is a quantitative measure that assesses the rate of change in hand speed over a specific period.
- Elbow angular velocity: It refers to the change of angular displacement at a specific point in time.
- Elbow angular acceleration: Similar to angular velocity, it is a measurable quantity that signifies the rate of change in the elbow's movement.
- Movement unit: It evaluates the smoothness of movement by employing quantitative metrics. This involves examining factors such as acceleration and deceleration profiles, with smoother movements characterized by more gradual changes in speed and acceleration.

1.4.2. Movement quality

The quality of movement serves as an indicator of motor control proficiency and the sequence of motion, juxtaposed against age-matched normative benchmarks in individuals deemed to be in good health (Saes et al., 2022). This notion of movement quality is frequently applied in visual assessments, allowing for the identification of asymmetries, compensatory movements, impairments, and the effectiveness of functional motion, as opposed to relying solely on quantitative metrics like power and strength (Ressman et al., 2021).

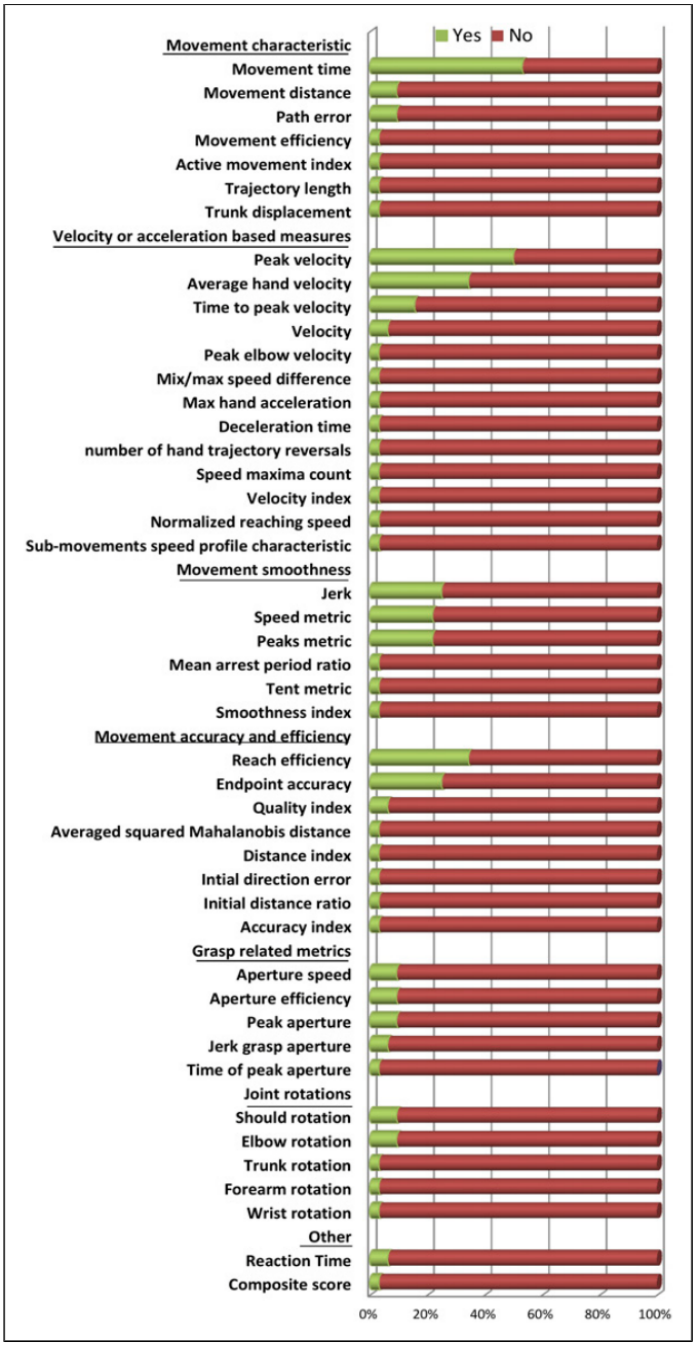

Figure 2. Frequent usage rate in kinematic metrics

Table 1. Systematic investigation into specific aspect of metrics analysis

Movement metrics / Reference	Neuro-muscular capability	Movement speed		Movement accuracy	Movement smoothness	Movement control strategy	Torque production	Movement efficacy	Movement coordination	Trunk displacement
	Reaching RoM	Movement time (total time)	Peak velocity	Target error	Number of velocity peaks	Time to velocity peak	Elbow maximum angular velocity	Active movement index		
Thrane et al. (2020) *Median [Q, Q]	(°) Arm abduction • healthy: 29.6 [23.4, 36.1] • acute stroke: 34.6 [29.3, 41.9] ($P < 0.05$) • chronic stroke: 35.8 [29.1, 42.0] ($P < 0.05$)	(s) • healthy: 6.4 [5.8, 7.4] • acute stroke: 9.4 [7.7, 11.8] ($P < 0.001$) • chronic stroke: 7.3 [5.8, 7.9] (N/S)	(cm/s) • healthy: 62.2 [54.6, 67.9] • acute stroke: 45.0 [39.6, 55.8] ($P < 0.001$) • chronic stroke: 55.8 [50.6, 61.9] (N/S)		• healthy: 6 [5.7, 7.0] • acute stroke:10.8 [9.1, 14] ($P < 0.001$) • chronic stroke: 7.5 [5.7, 10.3] ($P < 0.05$)	(%) • healthy: 43.9 [39, 48.1] • acute stroke: 37.1 [29.6, 44.2] ($P < 0.05$)	(°/s) • healthy: 103.3 [95.5, 126.2] • acute stroke: 75.2 [62.3, 92.1] ($P < 0.001$) • Chronic stroke: 89.5 [65.5, 105.6] ($P < 0.001$)			(mm) • healthy: 28.8 [19.5, 42.9] • acute stroke: 42.5 [32.7, 66.1] ($P < 0.001$) • Chronic stroke: 35.1 [28.5, 67.2] ($P < 0.01$)
Hussain et al. (2018) *Mean(SD)		(s) • healthy: 1.31 (0.25) • chronic stroke: 2.80 (1.97) ($P < 0.001$)	(mm/s) • healthy: 440.7 (91.81) • chronic stroke: 374.8 (134.6) ($P < 0.001$)		• healthy: 2.80 (0.53) • chronic stroke: 4.76 (2.65) ($P < 0.001$)	(%) • healthy: 33.29 (10.51) • chronic stroke: 31.34 (9.87)				
Merdler et al. (2013) *Mean(SD)	Shoulder flexion (°) • healthy: 86 (9) • stroke: 82 (11) (N/S) Elbow extension (°) • healthy:150(7) • stroke: 132(21) ($P < 0.05$) Shoulder adduction (°) • healthy19(6) • stroke: 7(10) ($P < 0.05$)		(mm/s) • healthy: 1091 (165) • chronic stroke: 1020 (250) (N/S)		• healthy: 1.17(0.34) • chronic stroke: 1.99 (1.18) ($P < 0.05$)	(s) • healthy: 0.4(0.1) • chronic stroke: 0.4 (0.1) (N/S)		• healthy: 0.95(0.03) • chronic stroke: 0.90 (0.11) (N/S)		(mm) • healthy: 28 (12) • chronic stroke: 111 (86) ($P < 0.05$)

Table 1. Systematic investigation into specific aspect of metrics analysis (Continue)

Movement metrics / Reference	Neuro-muscular capability	Movement speed		Movement accuracy	Movement smoothness	Movement control strategy	Torque production	Movement efficacy	Movement coordination	Trunk displacement
	Reaching RoM	Movement time (total time)	Peak velocity	Target error	Number of velocity peaks	Time to velocity peak	Elbow maximum angular velocity	Active movement index		
Murphy et al. (2011) *Mean(SD)	Arm flexion (°) • healthy: 45.6 (5.1) • chronic stroke: 44.5 (7.2) (N/S) Elbow extension (°) • healthy: 53.5 (7.8) • chronic stroke: 64.1(11.5) ($P < 0.05$)	•healthy:6.49 (0.83) • chronic stroke: 11.4 (3.1) ($P < 0.05$)	• healthy: 616 (93.8) • chronic stroke: 431(82.7) ($P < 0.05$)		• healthy:2.3(0.3) • chronic stroke: 8.4 (4.2) ($P < 0.05$)	(%) • healthy: 46.0 (6.9) • chronic stroke: 38.4 (8.6) ($P < 0.05$)	• healthy:121.8 (25.3) • chronic stroke: 64.9 (20.5) ($P < 0.05$)		• healthy:0.96 (0.02) • chronic stroke: 0.82 (0.35) (N/S)	(mm) • healthy:26.7 (16.8) • chronic stroke: 77.2 (48.6) ($P < 0.05$)
Cirstea et al. (2003) *Mean(SD)	Elbow extension (°) • healthy: 33.2 (12.5) • moderate-severe stroke: 3.3 (3.1) ($P < 0.001$)	• healthy: 0.67 (0.07) • moderate-severe stroke: 1.52 (0.27) ($P < 0.05$)	(cm/s) • healthy: 264.5 (16.5) • moderate-severe stroke: 114.9 (31.4) ($P < 0.01$)	(cm) • healthy: 6.5(1.0) • moderate-severe stroke: 14.7 (7.2) ($P < 0.05$)	• healthy: 1.2(0.3) • moderate-severe stroke: 4.1(1.8) ($P < 0.05$)			• healthy: 1.26 (0.04) • moderate-severe stroke: 1.37 (0.10) (N/S)		(cm) • healthy: 3.6 (1.3) • moderate-severe stroke: 17.7 (8.9) ($P < 0.05$)
Cirstea & Levin. (2000) *Mean(SD)	Shoulder flexion (°) • healthy: 86.5 (8.1) • Subacute and chronic stroke : 60.3 (20.3) ($P < 0.05$) Elbow extension (°) • healthy:34.4 (13.3) • Subacute and chronic stroke: 12.4(13.8) ($P < 0.05$) Shoulder adduction (°) • healthy 128.3(8.0) • Subacute and chronic stroke: 105.2(27.7) ($P < 0.05$)	• healthy: 0.62 (0.05) • Subacute and chronic stroke:1.27. (0.29) ($P < 0.05$)	(mm/s) • healthy: 2799.1 (190.4) • Subacute and chronic stroke: 1650.3(519.5) ($P < 0.05$)	(mm) • healthy: 64.2 (14.5) • Subacute and chronic stroke: 113.5 (50.9) ($P < 0.05$)						(mm) • healthy: 37.5 (14.1) • Subacute and chronic stroke: 110.2 (59.7) ($P < 0.05$)

1.5. Neuroplasticity

The brain's to extend axonal sprouting is regulated by specific proteins and factors. In the event of a brain injury, neurons adapt by allowing some axonal sprouting, promoting the growth of neurons near the damaged area (Eliassen et al., 2008). Motor learning can reshape and modify neuronal synapses in the cortico-cerebral cortex in response to sensory motor input. Engaging in activities and acquiring new information allows for adjustments in neuronal connections. This mechanism underlies how the brain stores and updates information in the central nervous system of animal groups (Johansson, 2000). This process is the brain's way of working to minimize the loss of neurons (Filippo et al., 2015). Neurological physiotherapy places emphasis on motor learning through the principles of neuroplasticity (Jones & Jefferson, 2011). It is widely believed that these methods play a substantial role in enhancing functional recovery for individuals with neurological conditions. With the growing acknowledgment and interest in documenting activity-induced neuroplasticity, it is imperative to ascertain whether interventions lead to the restoration of pre-existing movement patterns (recovery) or their replacement with innovative movement strategies (compensation) (Michaelsen et al., 2006a).

1.5.1. Motor compensation

Activation at the neuronal level is influenced by alternative brain regions, giving rise to patterns through the modification of existing motor elements or their substitution with actions performed by different parts of the body (Levin et al., 2009, 2016). In upper limb tasks, individuals often resort to excessive trunk movement to assist in extending the elbow for achieving the functional goal (Cirstea & Levin, 2000), suggesting a reliance on visual feedback to compensate for impaired feedforward control (Jones, 2017). According to preview study, individuals with stroke exhibit a tendency to employ compensatory strategies in reaching tasks for their upper limb, deviating from the normal approach observed in healthy individuals, as indicates in **Table 2**.

Table 2. Compensatory movement strategies for upper limb hemiparesis (Jones, 2017)

Reference	Normal strategy	Compensatory strategy
Bailey, et al. (2015) Haaland, et al. (2012) Han, et al. (2013) Nakayama, et al. (1994) Rinehart, et al. (2009) Sterr, et al. (2002) Taub, et al. (2014)	Use of both hands together	Dominant reliance on the non-paretic hand
Cirstea & Levin. (2000) Levin, et al. (2002)	Hand extended via elbow extension	Hand extended via trunk displacement
Levin, et al. (2016) Michaelsen, et al. (2004)	Hand oriented via wrist movements	Hand oriented via trunk rotation

While compensation proves effective in the short term, it can lead to abnormal pain and, importantly, contribute to a learned nonuse phenomenon on the paretic side, resulting in the underutilization of potential motor function (Jones, 2017). An individual with hemiparesis tends to rely more on their non-affected limb than the affected one. This indicates that rehabilitation efforts should prioritize skill training and daily practice for the non-affected limb (Poole et al., 2009).

1.5.2. Motor recovery

When a circulatory event impacts the brain, previously dormant regions become engaged to facilitate the recovery process, ultimately contributing to the restoration or repair of the brain's structures to their initial state (Levin et al., 2009). The functional recovery of individual with stroke is improved about only 25 to 35% in individual with motor deficit of 85% (Filippo et al., 2015). It can be described as the resumption of more typical movement or the reduction of limitations in movement (Jones, 2017). Brunnstrom's recovery stages further emphasize this progression, particularly from stage four to six, highlighting a decrease in spasticity and an enhancement of functional combinations through selective movements (Brunnstrom, 1966).This progression suggests that the trunk plays a crucial role in the reaching pattern and is not merely engaged as a response to restrictions in the range of arm movement (Levin et al., 2016).

1.6. Neurological physiotherapy

The objective of physiotherapy is to strengthen the recovery of functional movement and reintegrate individuals back into society. Specific task-oriented training promotes coordination and enhances motor learning. This approaches grounded in 'neurophysiological' principles underscore the essential interrelationship among the trunk, upper limb, and pelvis when executing tasks involving reaching beyond the base of support (Chung et al., 2014; Howe et al., 2005). A promising rehabilitation strategy to enhance trunk control and dynamic sitting balance involves the integration of trunk exercises (Cabanas-Valdés et al., 2021; Sorinola et al., 2014). Upper limb functions like reaching rely on the dynamic stability of the shoulder girdle, which is supported by a stable trunk (Miyake et al., 2013). Verheyden, et al. (2009) provided evidence of the favorable influence of lateral flexion achieved through selective upper and lower trunk exercise in participants with chronic stroke. Likewise, Saeys, et al. (2012) demonstrated that specific trunk exercises focusing on isolated engagement of the shoulder and pelvic girdle resulted in significant enhancements in dynamic sitting balance, ultimately leading to improved postural control during mobility over a 7-month period following stroke onset. Furthermore, Haruyama, et al. (2017) reported that core stability, achieved through pelvic exercises, led to improved dynamic sitting balance and trunk function in subacute participants with stroke. In preview study, when comparing with conventional therapy, trunk exercise improved trunk functional movement, specifically in modified reaching task, dynamic balance (Cabanas-Valdés et al., 2013;Verheyden et al., 2009). The consistent results from these studies align with our own findings, suggesting potential enhancement in upper limb function through a stabilized trunk via core exercise. This finding could be associated with motor control quality and the neurological recovery (Van Kordelaar et al., 2014). Many preliminary studies have reported that the trunk plays a crucial role in proximal stability and controls mobility during reaching exercises through trunk engagement (Van Criekinge et al., 2019). In fact, physical exercise has the potential to substantially influence the phenomenon of neuroplasticity, foster axonal growth, and facilitate the establishment of new synaptic connections within the vicinity of the infarcted area. Crucially, it plays a role in enhancing both motor function and cognitive abilities (Li et al., 2015; Xing & Bai, 2020).

1.6.1. ADIM (Abdominal Drawing-In Maneuver) concept

This is a functional exercise, requiring precise motor control to engage the relevant muscle with the appropriate level of intensity for targeted muscle control. With the recent progress in rehabilitation methodologies, core stabilization training places a strong emphasis on achieving precise control of the trunk. According to Miyake, et al. (2013), core training enhances neuromuscular coordination rather than focusing on muscle strength. This entails the activation of the Transversus abdominis (TrA) muscle, located deep within the abdominal region, as part of a targeted muscle engagement strategy (Haruyama et al., 2017). The TrA muscle serves as a primary anterior lumbopelvic postural stabilizer, functioning based on the feedforward principle (Allison et al., 2008; Faries et al., 2007; Kołcz et al., 2020). This mechanism aims to stabilize the spine without directly influencing the control of the primary task at hand, raising of the arms (Allison et al., 2008). It is evident that the ADIM exercise engages key deep core muscles, namely the Transversus Abdominis (TrA) and internal oblique muscles (Chon et al., 2012; Madokoro et al., 2020). These muscles collaboratively function to compress the abdominal cavity, thereby activating in direct mechanisms of the thoracolumbar fascia. This enhanced stability and posture can provide a more solid foundation for upper limb movements, including hand movements (Miyake et al., 2013). It is evident that trunk and extremity muscles form a complex and dynamic system through fascial connections (Turan & Özyemişçi-Taşkıran, 2022) and this indicates that the TrA has a limited capacity to stabilize on its own (Allison et al., 2008). A fundamental prerequisite for extremity movement is the stability of the pelvic and trunk regions (Endo & Sakamoto, 2014). Essentially, after a stroke, there is a noticeable delay in the activation of the TrA while moving the shoulder (Chon et al., 2012; Hodges & Moseley, 2003). This delay plays a role in worsening issues related to maintain a stable posture and controlling movements effectively. Moreover, a previous study has reported that there was an observed reduction in the thickness of the TrA muscle on the affected side in comparison to both the unaffected side and to measurements taken from healthy individuals (Kelli et al., 2020; Monjo et al., 2018). Despite recognizing the significance of trunk intervention, there remains a lack of quantitative evidence supporting targeted trunk control interventions. Due to the limited quantity of trunk exercises and the importance of isolated trunk control, it becomes essential to provide evidence of the efficacy of trunk exercises, particularly those targeting the trunk's specific muscles. The ADIM exercise was a technique developed to enhance the coordination and control of the muscles in the trunk (Madokoro et al., 2020). Research demonstrated that during rapid upper limb movement, the activated onset times of TrA were significantly earlier than that of pre-ADIM exercise (Madokoro et al., 2020). The TrA activation contributing to postural stability depends on movement. Specifically, when comparing the roles of both sides of the TrA in Electromyography (EMG), the muscle shows a stabilizing function in its contralateral region, while its ipsilateral region plays a role in feedforward mechanism (Allison et al., 2008; Marshall & Murphy, 2003). According to Marshall & Murphy (2003), After initiation of shoulder flexion, the anterior deltoid was the first muscle to activate, followed by the activation of the TrA muscle with a latency time, establishing it as the primary muscle (the TrA: 25 ± 26, EO: 72 ± 37, RA: 41 ± 30, $P < 0.0001$). Furthermore, the variation in TrA response during arm flexion could stem from differences in rotational forces influenced by the orientation of TrA fivers on the trunk (Urquhart & Hodges, 2005). Nevertheless, it is symmetrically triggered on both sides for stabilization during reaching (Thrane et al., 2018; Yu & Park, 2013).

1.7. Hypothesis and objective

1.7.1. Hypothesis

The application of that Abdominal Drawing-In Maneuver (ADIM) in individuals with chronic stroke can produce positive effects on postural control and upper extremities compared to conventional therapy.

1.7.2. Objective

The objective of this study was to evaluate the effectiveness of the Abdominal Drawing-In Maneuver (ADIM) exercise in patients with stroke in postural control and upper limb functional movement compared with conventional therapy.

1. Confirming improvement in joint range of motion (elbow extension and shoulder flexion) through ADIM exercise.
2. Verifying reduction in trunk compensation through ADIM exercise.
3. Verifying overall reduction in movement time through ADIM exercise.
4. Confirming increase in hand movement speed and acceleration through ADIM exercise.
5. Examining the increase in elbow movement speed and acceleration through ADIM exercise.
6. Assessing improvement in movement unit through ADIM exercise.

MATERIAL AND METHODS

2. MATERIAL AND METHODS

2.1. Ethical considerations

Experiments on human subjects are done in accord with Declaration of Helsinki of 1964 and the study was approved by the ethics committee of UNIST (UNISTIRB-22-43-A) and registered in ClinicalTrials.gov (NCT05767437). Written informed consent was obtained from all participants prior to their inclusion. This study adheres to Consolidated Standards of Reporting Trials (CONSORT) guidelines.

Experimental subjects

This study was a randomized crossover trial. The randomization was performed with a block size of 4 using Excel (Microsoft Excel 2022, Microsoft Inc., USA). The study took place from August 10, 2022, to August 10, 2023.

2.1.1. Crossover design

Group A received Abdominal drawing-in maneuver exercise for 4 weeks on period 1. Afterward, they had a month of washout period, followed by a period 2 (conventional physiotherapy). On the contrary, Group B received conventional physiotherapy on period 1 and abdominal drawing-in maneuver exercise on period 2 (separated by the washout period). **Figure 3** shows diagrammatic representation of experimental procedures.

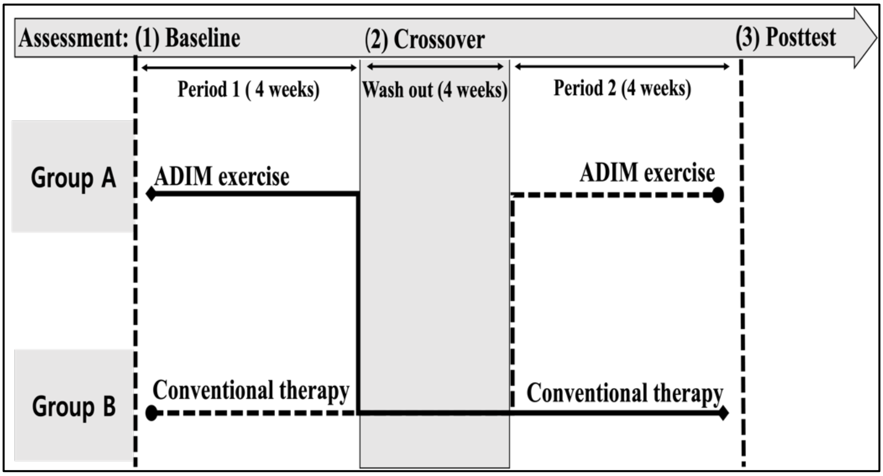

Figure 3. Diagrammatic representation

This research employed a two-period crossover design to assess how effective Abdominal Drawing-In Maneuver (ADIM) exercise is in comparison to conventional therapy for individuals with chronic stroke. Participants were recruited at the gym for the disabled at Ulsan city and the Ulsan National Institute of Science and Technology (UNIST). Participants with stroke were included in the study if they had (1) a physician's confirmation of chronic hemiplegia with ≥ 6 months onset; (2) 25 ≤ Mini-mental state examination; (3) the ability to maintain a sitting position on a chair alone; and (4) 60 > Fugl-Meyer Assessment in the upper extremities. We omitted scores above 60 on the Fugl-Meyer Assessment because they were within the range of change considered too small to be reliably detected (Thrane et al., 2019). Individuals with stroke were excluded if they had (1) muscle flaccidity (2) neglect syndrome, or (3) neurological or disease and orthopedic disease and lack of coordination. A research manager obtained written informed consent from all participants before their inclusion in the study.

2.2. Experimental protocol

2.2.1. Intervention

This was conducted by two physical therapists with over 10 years of experience.

2.2.1.1. ADIM exercise

This group was especially focused on enhancing the strength of the transversus abdominis muscle by using a simple device that observed pressure changes with a gauge. Participants received the abdominal drawing-in maneuver exercise twice a week for four weeks. Each exercise session lasted for 40 minutes, with an additional 10-minute dedicated to conventional therapy sessions, specifically trunk stretching and upper limb mobilization (Ko et al., 2016). Participants transitioned from the supine position to the hook-lying position (hip joint at 40° and knee joint at 80°). Biofeedback was placed below the lumbar lordosis and pull the abdomen towards the lumbar region using the Stabilizer^{TM} pressure Biofeedback (D.-J. Park & Lee, 2013) (see **Figure 4** and **Figure 5**). Participants were instructed to maintain controlled contractions while engaging in light breathing and maintaining their lumbar region inflated, with the physiotherapist providing palpation (Yoon et al., 2015). The regimen gradually increased the contraction of the transversus abdominis muscle to 40 mmHg $\pm$ 2 mmHg (D.-J. Park & Lee, 2013). The exercise intensity consisted of 10 repetitions per set, with each contraction held for 5 seconds. This routine was repeated for a total of 10 sets. Additionally, for the 10 minutes of conventional therapy, participants performed trunk stretching and mobilization exercises for the upper limb to alleviate shoulder joint pain and elongate trunk muscles. Participants engaged in this exercise regimen over a 4-week period.

Figure 4. Stabilizer™ pressure Biofeedback

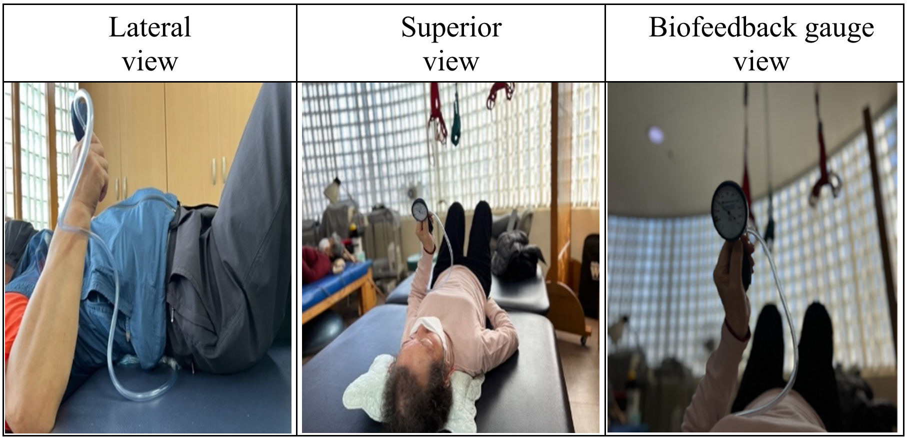

Figure 5. ADIM exercise with Stabilizer™

2.2.1.2. Conventional therapy

This intervention included a range of pain relief techniques, such as limb stretching, mobilization of the upper extremity, and targeted pelvic movements. To manage pain, a Transcutaneous Electrical Nerve Stimulation (TENS) (EMG FES 1000, Cyber medic, South Korea) was applied to the painful area on the affected side of the upper extremity for 20 minutes (**Figure 6**). Additionally, participants engaged in a series of movements during a supine position. It was worth noting that this conventional therapy approach was administered under the guidance of another physical therapist. In the supine position, participants received treatment for muscle tone release, upper limb stretching, and trunk mobilization. All participants completed 10 repetitions of each exercise per set, performing a total of 5 sets for each exercise. Participants attended two sessions per week for a period of 4 weeks, with each session lasting 40 minutes.

Figure 6. Conventional therapy with TENS

2.2.2. Outcomes measurement

2.2.2.1. Clinical outcomes

Another physiotherapist, who was not involved in the interventions, conducted the assessments. Participants were evaluated for upper limb impairment using the Fugl-Meyer Assessment and categorized based on the severity of impairment as mild (58-66), moderate (28-57), or severe (0-27) (Choi et al., 2023). The Fugl-Meyer Assessment demonstrated high reliability for total upper extremity motor scores, as evidenced by an intraclass correlation coefficient of 0.98. Additionally, its validity coefficient, evaluated in relation to motor function, was established at 0.76 (Kim et al., 2012). In addition to upper limb impairment evaluation, spasticity in the elbow flexor and extensor muscles was assessed using the Modified Ashworth Scale, which ranges from 0 (normal tone) to 4 (severe spasticity) (Fugl-Meyer, 1975). This scale has demonstrated reliability, assessed by an intraclass correlation coefficient of 0.83 (Gregson et al., 1999) and a validity coefficient of -0.72 (G. Lee et al., 2015). Our study recorded spasticity levels ranging from 0 to 2. Postural control of the upper limb was assessed using the Postural Assessment Scale for Stroke (Benaim et al., 1999), which yields a total score of 36 (the highest level of functionality). The intraclass correlation coefficient demonstrated by this scale is 0.84 (Chien et al., 2007) and the concurrent validity exhibited 0.92 (Wang et al., 2004). The Trunk Impairment Scale was also employed to evaluate static and dynamic sitting balance and coordination, on a 23-point scale (perfect performance). This scale has an intraclass correlation coefficient of 0.96 and a validity coefficient of 0.86 (Verheyden et al., 2004). Range of motion was assessed in the supine position with the knees up (Clarkson HM, 2013). A physical therapist passively evaluated the shoulder and elbow joints using a universal goniometer (12-inch transparent orthopedic angle ruler, Prasacco, China). Passive measurement by a goniometer has reported high intraclass correlation coefficient of 0.91 (Gajdosik & Bohannon, 1987) and concurrent validity of 0.94 (Current & Cert Yi Chung-hwi, 1995). The average reference range of motion values for the shoulder were flexion 180°, abduction 180°, adduction 50°, internal rotation 90°, and external rotation 90°. For the elbow joint, the range of motion values were flexion 145° and extension 0° (Hamilton et al., 2012). **Figure 7** depicts a clinical assessment conducted by a physical therapist.

(A) Pre-Interview	(B) Fugl-Meyer Assessment	(C) Range of motion assessment

Figure 7. Clinical assessment

2.2.2.2. Kinematic outcomes

The assessment of movement quantity in this study involved quantifying kinematic variables aimed at capturing various aspects of movement excursions, ensuring the reliability and validity of dependent variables. Our movement analysis encompassed both spatial and temporal kinematic variables, with a focus on primary and secondary measurements. The primary outcome measurement focused on trunk displacement and elbow extension for spatial analysis, and movement unit for temporal evaluation. Secondary spatial variables included shoulder flexion. Additionally, temporal variables encompassed total time, peak hand velocity, and acceleration, elbow angular velocity, and acceleration. **Table 3** and **Table 4** contain categorizations along with corresponding definitions for each variable.

Table 3. Definitions of spatial kinematic variables

Outcome measure	Variable	Definition
Spatial variables		
Primary	Elbow extension (degree) (Sternad & Schaal, 1999)	• Maximum angle • Acromion + lateral epicondyle + medial styloid process
Secondary	Shoulder flexion (degree) (Sternad & Schaal, 1999)	• Maximum angle • Lateral epicondyle + acromion + y-axis; y-axis, which is a line connecting C7 and T4, and the projection of the upper arm onto the sagittal plane
Primary	Trunk displacement (mm)	• Maximal displacement of the sternum of the thorax from the initial position during the reaching phase

Table 4. Definitions of temporal kinematic variables

Outcome measure	Variable	Definition
Temporal variables		
Secondary	Total time (s)	• The period from hand tangential velocity movement onset to offset. • Entire time of reaching and returning phase

Secondary	Peak hand velocity (mm/s)	• Maximal tangential velocity during the reaching phase
Secondary	Peak hand acceleration (mm/s^2)	• Peak hand velocity per unit time in the reaching phase
Secondary	Elbow peak angular velocity (rad/s)	• Peak velocity during elbow extension in the reaching phase
Secondary	Elbow peak angular acceleration (rad/s^2)	• Peak elbow angular velocity per unit time in the reaching phase
Primary	Movement unit (n) (Che-Nan & Rambely,2022)	• The difference between the local minimum and next maximum velocity value that exceeded the amplitude limits of 20 mm/s, and the time between two subsequent peaks had to be at least 150 ms from reaching and returning phase

2.2.2.2.1. Experimental setup

Three-dimensional marker positions were measured using eight infrared motion capture cameras (Optitrack Prime 13, NaturalPoint Inc., Corvallis, OR, USA) with a minimum distance of 2.5 meters from each camera. The Software, Motive 3.0.1 Final, provided with the Optitrack system, was used for data detection. Participants were asked to wear a dark tank top, and anthropometric measurements were recorded. A total of 11 reflective markers were placed on the anatomical landmarks of the proximal third metacarpophalangeal joint, medial and lateral styloid process, medial and lateral epicondyle, both mid-acromions, sternum, xiphoid process, seventh cervical vertebra (C7), and fourth thoracic vertebra (T4) on the affected arm in participants. The **Figure 8** shows segmental marker sets in anterior and posterior view, respectively.

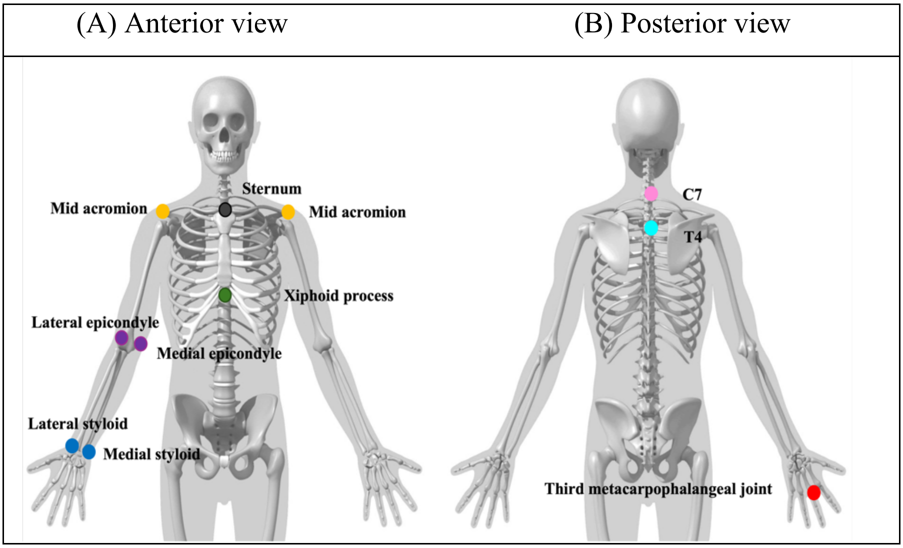

Figure 8. Segmental marker set

The positions of the three-dimensional space (x, y, z axes) were recorded at a frequency of 120 Hz. The global coordination system was defined with the x-axis directed laterally, the z-axis directed forward, and the y-axis directed upward. In **Figure 9**, the skeleton is depicted, and **Figure 10** and **Figure 11** illustrate movement analysis.

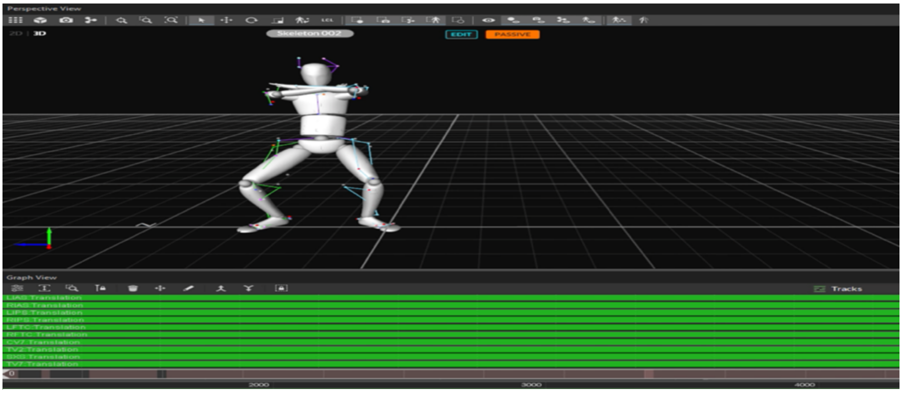

Figure 9. Demonstration with skeleton system

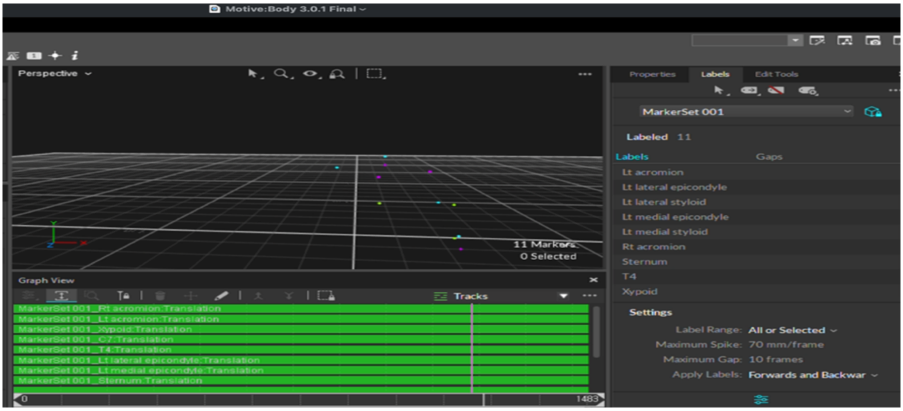

Figure 10. Frontal view

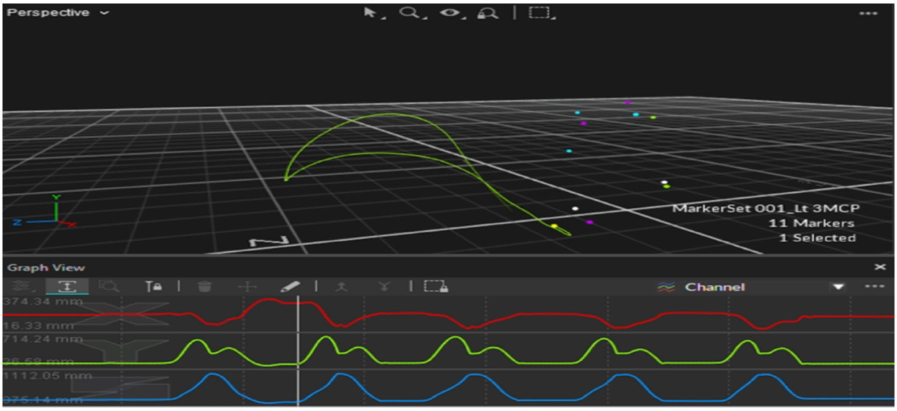

Figure 11. Lateral view

Hand movement in the reaching phase was defined for each trial and determined based on the tangential velocity of the 3rd distal metacarpal bone (Thrane et al., 2020). Hand movement onset was defined for each trial as the time at which the tangential velocity exceeded the baseline by 10% of the peak tangential velocity of the hand. Hand movement offset was defined as the time at which the tangential velocity decreased and remained below 10% of the peak tangential velocity. (Levin et al., 2002; Subramanian et al., 2010). **Figure 12** illustrates the definition of movement unit through the relationship between time and velocity. Data from three-dimensional motion capture analysis system was imported into MatLab R2021b (The MathWorks Inc., MA, USA) and filtered using a second-order low-pass Butterworth filter with a cut-off frequency of 6 Hz. Data was analyzed during the reaching phase.

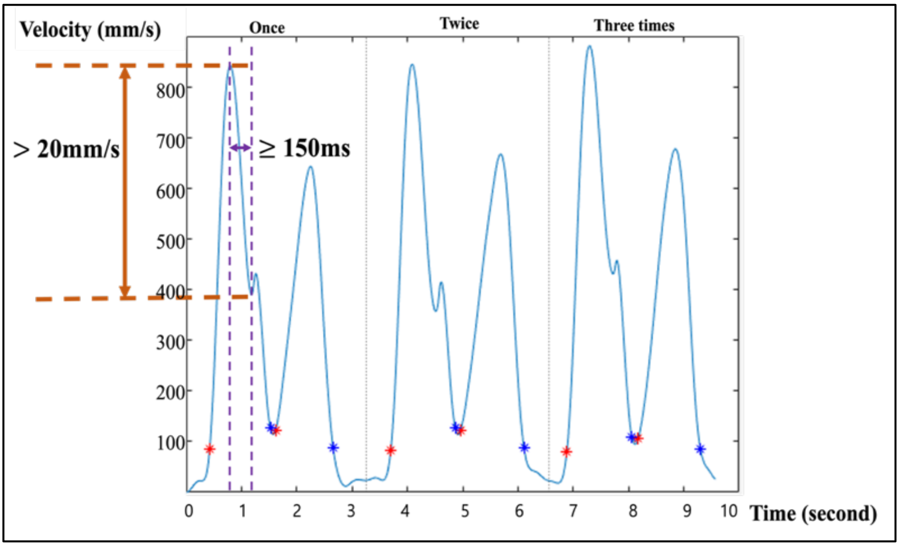

Figure 12. Time-Velocity relationship for movement unit

2.2.3. Experimental position

2.2.3.1. Beyond arm's length

Individuals with stroke tend to initiate forward movement of their trunk sooner when reaching beyond their normal arm reach. Additionally, they face challenges in effectively managing the trajectory of their hand's movement in such situations. It is conceivable that changes in how the trunk is controlled could be a main factor in the motor difficulties noticed when reaching beyond one's usual arm range following a stroke (Gera et al., 2016), trunk displacement represents a compensatory motor strategy, introducing an additional degree of freedom (Woodbury et al., 2009). Moreover, when reaching beyond arm's target, the lower limbs play a crucial role in slowing down the forward movement of the body and maintaining balance by shifting weight towards the feet (Messier et al., 2005). A bell (with a diameter of 7 cm and a height of 5 cm) was placed along the participant's mid-sagittal plane at a distance equivalent to 140% beyond the length of the arm to reach (Dean et al., 2007). Arm length was defined as the distance from the mid-acromion to the third metacarpal bone.

2.2.3.2. Tri-Directional Movement Patterns

In **Figure 13**, the participants were asked to move the affected arm in for the reaching task of the (A) 45° towards the contralateral direction, (B) shoulder forward, (C) 45° towards the ipsilateral direction of the sagittal line. They were then instructed to use the palm surface of their affected arm to press the bell as quickly as possible. Participants were seated on adjustable chairs without back support, set to 100% of their lower leg's length. The table height was adjusted to be 5 cm below their elbow while sitting. They positioned their hands beside the hip joint, with elbow fully extended in a comfortable and natural alignment. After three practice trials in each direction, participants completed five reaches, and the mean value of the three trials per direction was calculated (Murphy et al., 2011).

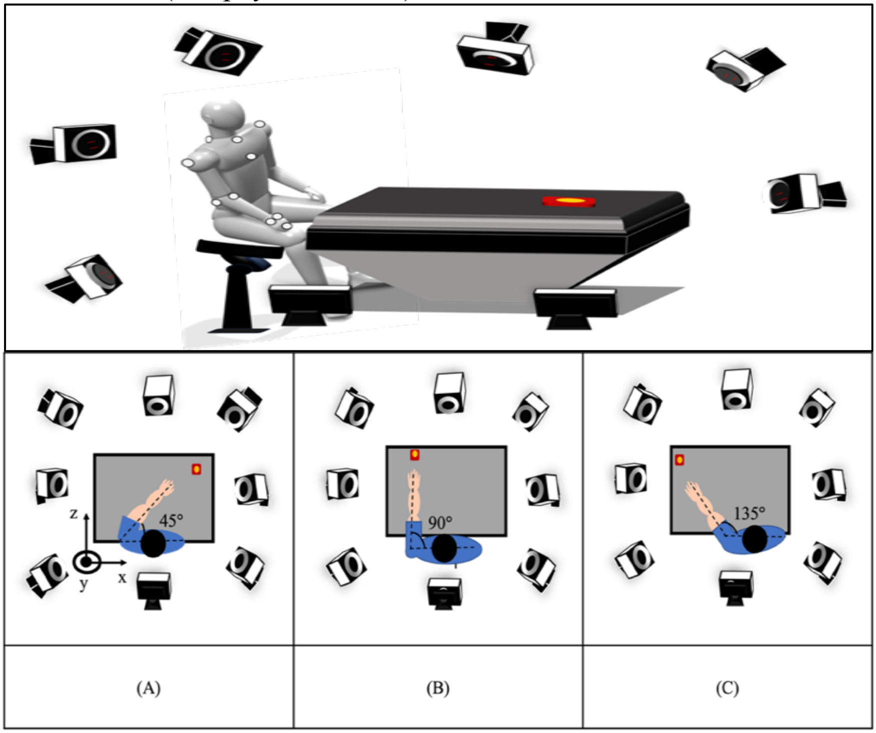

Figure 13. Experimental protocol. (above) Initial position with 8 cameras, (below) Tri-directional movement pattern.

2.2.4. Statistics analysis

Statistical analysis was performed with IBM SPSS 14 (version 28.0.1.1). Data were tested for normality using the Kolmogorov-Smirnov test. Kinematic data revealed normally distributed data ($P > 0.05$). The Chi-square test was used to assess the sex distribution of the participants. The independent *t*-test and Mann-Whitney *U* test, as a nonparametric test, were employed to compare the two groups concerning specific demographic and clinical characteristics. For the crossover analysis, it addresses carryover effects by combining data from both periods for each group. Next, it assesses period effects by examining the differences between the two groups for each treatment. The treatment effect (primary and secondary outcomes) was evaluated through a Mixed Analysis of Variance, involving two groups and three assessments. Utilizing interaction analysis, we explored the progression of changes between the groups over time. The *P*-value was adjusted for multiple comparisons using the Bonferroni correction, and statistical significance was determined at $P < 0.05$. Following this, post-hoc analyses were conducted employing the Bonferroni sample t-test to specifically compare the impact of each intervention within their respective groups. Specifically, pairwise comparisons were conducted for Group A and Group B across the three assessments to identify significant differences. The difference between the two groups in clinical outcomes was tested using a two-sided unpaired t-test, with a significance level of $P < 0.05$ used for all tests (Sczesny-Kaiser et al., 2019; Wellek & Blettner, 2012). To determine the sample size, the G*Power Version 3.1 was utilized (Franz Paul, Kiel, Germany) (Faul et al., 2007), incorporating an effect size of 0.44, $\alpha < 0.05$, power = 0.80, requiring total sample size of 12 participants (Dos Santos et al., 2019).

Results

3. RESULTS

35 participants were initially identified, with 20 meeting eligibility criteria before the baseline assessment. Prior to completing the baseline assessment, patients were randomly assigned to either Group A or Group B. The participant distribution within the two groups was as follows: Group A initially comprised 10 participants, whereas Group B also started with 10 participants. However, after the completion of the first intervention and during the washout period, a total of 4 participants from group B dropped out: 1 due to hospitalization and 3 due to refusal to participate in the experiment. Consequently, the final analysis included 10 participants from Group A and 6 participants from Group B. It's important to note that all participants were matched in terms of age. **Figure 14** shows the flow diagram and **Table 5** presents the demographics and clinical characteristics of the Fugl-Meyer Assessment participants.

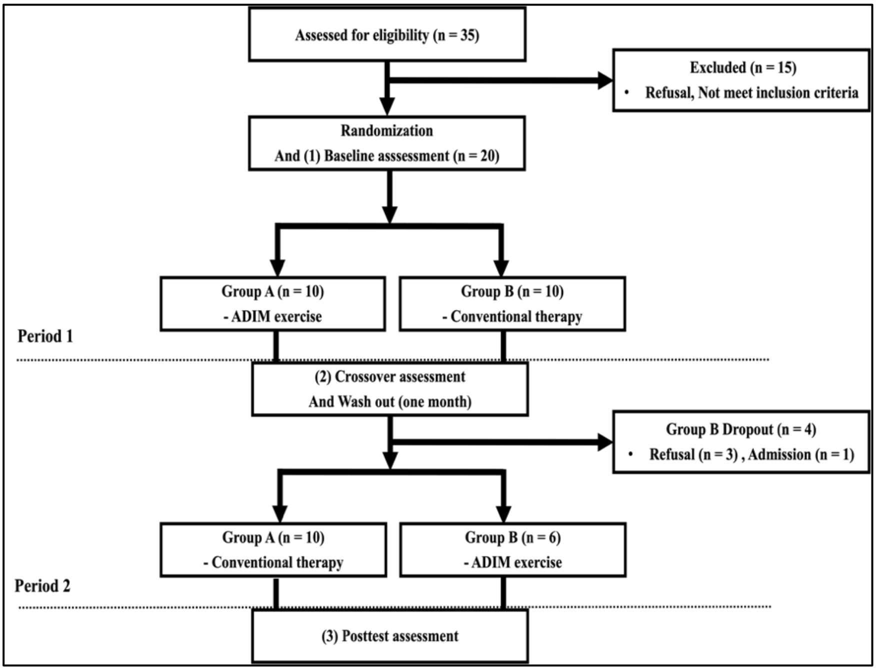

Figure 14. Flow diagram

Table 5. Demographics and clinical characteristics

	Sex	Age	Group	Onset	Pathology	Side	FMA
1	F	77	A	65	I	L	51
2	F	78	A	64	H	L	42
3	F	75	A	248	H	L	37
4	M	50	A	176	I	R	58
5	M	74	A	155	H	L	34
6	F	58	A	436	I	L	16
7	F	60	B	260	H	L	53
8	M	50	B	132	I	R	27
9	F	79	A	121	H	R	19
10	F	63	A	60	I	R	24
11	M	69	A	205	H	R	29
12	M	79	A	47	H	R	59
13	M	61	B	213	I	R	32
14	F	50	B	75	I	L	44
15	M	66	B	105	I	R	54
16	F	78	B	67	I	R	30

Note: Group A, Abdominal Drawing-In Maneuver (ADIM) exercise-Conventional therapy; Group B, Conventional therapy-ADIM exercise.

Abbreviations: Female, F; Male, M; Ischemic, I; Hemorrhagic, H; Left, L; Right, R; FMA, Fugl-Meyer Assessment.

3.1. Between groups demographic and clinical outcomes

Table 6 provides a description of the demographic characteristics between groups, including mean and standard deviation. There were no significant difference in demographics between the two groups, indicating that they were well-matched for age (P = 0.10), sex (P = 0.70), and other relevant factors. **Table 7** presents the clinical characteristics between groups, including median, interquartile range. There were no significant difference in clinical characteristics between two groups ($P < 0.05$).

Table 6. Between groups demographics

Variable	ADIM-CT group ($n = 10$)	CT-ADIM group ($n = 6$)	*P*-value
Age (y)	70.20 (10.05)	60.83 (10.55)	0.10
Sex (F;M)	6;4	3;3	0.70
Onset (mon)	157.70 (119.59)	142.00 (78.16)	0.78
Height (cm)	160.00 (4.90)	164.58 (7.93)	0.17
BMI (kg/m^2)	23.01 (2.51)	25.59 (2.71)	0.07
Side of paralysis (L;R)	5;5	2;4	NA
PASS	33.30 (2.36)	30.33 (4.76)	0.12
TIS	14.40 (3.98)	14.50 (5.32)	0.97
FMA	36.90 (15.47)	40.00 (11.95)	0.68

Note: values are presented as mean (SD, Standard Deviation), ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT-ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver.

Abbreviations: BMI, Body Mass Index; PASS, Postural Assessment Scale for Stroke; TIS, Trunk Impairment Scale; FMA, Fugl Meyer Assessment; NA, Not Available

Table 7. Between groups clinical outcomes

Variable			ADIM-CT group	CT-ADIM group	*P*-value
Passive ROM (°)	Shoulder	Flexion	150.00 (146.75; 160.00)	165.00 (155.00; 175.00)	0.06
		Abduction	120.00 (107.50; 143.75)	160.00 (125.00; 162.50)	0.21
		Adduction	45.00 (38.00; 51.25)	42.50 (38.75; 52.50)	0.96
		External rotation	70.00 (57.50; 80.00)	70.00 (57.50; 76.25)	0.87
		Internal rotation	90.00 (73.75; 90.00)	80.00 (47.50; 90.00)	0.44
	Elbow	Flexion	140.00 (131.50; 145.00)	142.50 (133.75; 145.00)	0.61
		Extension	0.00 (0.00; 2.50)	0.00 (0.00; 5.00)	1.00
MAS	Elbow	Biceps	2.00 (1.75; 2.00)	2.00 (0.75; 2.00)	0.47
		Triceps	1.50 (0.75; 2.00)	1.50 (0.75; 2.00)	0.95

Note: values are presented as median (IQR, Interquartile range), ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver.

Abbreviations: ROM, range of motion; MAS, Modified Ashworth Scale.

MAS grade of 1 is equivalent to 1, whereas a MAS grade of 1^{+} includes grade of 2, 2-3, 3-4

3.2. Crossover analysis

As a first step, we examined the presence of carryover and period effects between groups in each direction.

3.2.1. Carryover effect

Results of carryover effect revealed significant difference in trunk displacement (mm) in the forward direction (mean difference: -85.69, *P* = 0.009) in **Table 8** Ipsilateral direction for all variables was no significant carryover effect in **Table 10** In contralateral direction, there was a notable significant elbow angular acceleration (rad/s^2) (mean difference: 393.65, *P* = 0.03) in **Table 12**.

3.2.2. Period effect

In **Table 9**, a statistically significant impact was observed on elbow extension (mean difference: -10.38, *P* = 0.02) and hand velocity (mean difference: -297.64, *P* = 0.04). **Table 11** showed that there was no statistically significant period effect in the ipsilateral direction. However, in the contralateral direction, **Table 13** reveals a significant period effect in elbow angular acceleration (mean difference: 185.29, *P* = 0.006).

Table 8. Carryover effect in the forward direction

Variables	Mean difference Cl 95% [lower, upper]	P – value
Elbow extension (degree)	17.67 [-18.31, 53.66]	0.31
Shoulder flexion (degree)	5.19 [-9.45, 19.83]	0.46
Trunk displacement (mm)	-85.69 [-145.01, -26.37]	0.009**
Total time (s)	- 0.17 [-1.64, 1.30]	0.81
Hand velocity (mm/s)	139.41 [-505.66, 784.48]	0.65
Hand acceleration (mm/s^2)	1499.68 [-2680.14, 5679.50]	0.45
Elbow angular velocity (rad/s)	21.79 [-7.06, 50.63]	0.13
Elbow angular acceleration (rad/s^2)	302.46 [-17.27, 622.18]	0.06
Movement unit (n)	-2.04 [-4.44, 0.36]	0.09

CI, Confidence Interval
** $p < 0.01$

Table 9. Period effect in the forward direction

Variables	Mean difference Cl 95% [lower, upper]	*P* – value
Elbow extension (degree)	-10.38 [-18.46, -2.29]	0.02*
Shoulder flexion (degree)	-1.66 [-14.76,11.45]	0.79
Trunk displacement (mm)	37.61 [-17.15, 92.37]	0.16
Total time (s)	0.33 [-0.10, 0.75]	0.12
Hand velocity (mm/s)	-297.64 [-572.74, -22.53]	0.04*
Hand acceleration (mm/s^2)	120.10 [-998.41, 1238.61]	0.82
Elbow angular velocity (rad/s)	12.47 [-8.85, 33.79]	0.23
Elbow angular acceleration (rad/s^2)	226.38 [-25.16, 477.93]	0.07
Movement unit (n)	1.74 [-0.41, 3.89]	0.09

CI, Confidence Interval, * $p < 0.05$.

Table 10. Carryover effect in the ipsilateral direction

Variables	Mean difference Cl 95% [lower, upper]	P - value
Elbow extension (degree)	12.87 [-17.82, 43.56]	0.38
Shoulder flexion (degree)	2.70 [-18.87, 24.27]	0.79
Trunk displacement (mm)	-16.15 [-56.74, 24.44]	0.40
Total time (s)	-0.12 [-2.84, 2.60]	0.92
Hand velocity (mm/s)	-138.01 [-699.68, 423.66]	0.61
Hand acceleration (mm/s^2)	102.97 [-1967.80, 2173.75]	0.92
Elbow angular velocity (rad/s)	14.72 [-13.76, 43.20]	0.29
Elbow angular acceleration (rad/s^2)	138.54 [-84.22,361.30]	0.20
Movement unit (n)	-0.23 [-2.81, 2.36]	0.84

CI, Confidence Interval

Table 11. Period effect in the ipsilateral direction

Variables	Mean difference Cl 95% [lower, upper]	P - value
Elbow extension (degree)	13.05 [-2.45, 28.55]	0.09
Shoulder flexion (degree)	3.71 [-14.86, 22.27]	0.68
Trunk displacement (mm)	22.95 [-37.00, 82.91]	0.43
Total time (s)	-0.59 [-1.60, 0.41]	0.23
Hand velocity (mm/s)	-29.49 [-315.75, 256.77]	0.83
Hand acceleration (mm/s^2)	335.95 [-844.66, 1516.56]	0.55
Elbow angular velocity (rad/s)	13.16 [-6.39, 32.71]	0.17
Elbow angular acceleration (rad/s^2)	146.28 [-60.33, 352.89]	0.15
Movement unit (n)	0.53 [-1.37, 2.43]	0.52

CI, Confidence Interval

Table 12. Carryover effect in the contralateral direction

Variables	Mean difference Cl 95% [lower, upper]	P - value
Elbow extension (degree)	16.28 [-25.62, 58.17]	0.42
Shoulder flexion (degree)	-0.37 [-18.91, 18.17]	0.97
Trunk displacement (mm)	9.35 [-97.09, 115.78]	0.85
Total time (s)	0.17 [-1.63, 1.98]	0.84
Hand velocity (mm/s)	307.58 [-349.13, 964.29]	0.33
Hand acceleration (mm/s^2)	1431.20 [-1694.29, 4556.69]	0.34
Elbow angular velocity (rad/s)	14.56 [-7.33, 36.46]	0.18
Elbow angular acceleration (rad/s^2)	393.65 [49.69, 737.62]	0.03*
Movement unit (n)	-0.87 [-3.77, 2.02]	0.53

CI, Confidence Interval, * $p < 0.05$.

Table 13. Period effect in the contralateral direction

Variables	Mean difference Cl 95% [lower, upper]	P - value
Elbow extension (degree)	-10.51 [-24.02, 3.01]	0.12
Shoulder flexion (degree)	-0.95 [-21.66, 19.76]	0.92
Trunk displacement (mm)	-8.92 [-86.25, 68.40]	0.81
Total time (s)	-0.23 [-1.54, 1.09]	0.72
Hand velocity (mm/s)	-246.00 [-740.86, 248.86]	0.30
Hand acceleration (mm/s^2)	-1064.02 [-2930.30, 802.26]	0.24
Elbow angular velocity (rad/s)	12.31 [-10.49, 35.11]	0.27
Elbow angular acceleration (rad/s^2)	185.29 [62.15, 308.42]	0.006^{**}
Movement unit (n)	0.76 [-1.67, 3.18]	0.52

CI, Confidence Interval, ** $p < 0.01$.

3.2.3. Treatment effect in the forward direction

3.2.3.1. Elbow extension in the forward direction (degree)

In **Table 14**, we present the mean and standard deviation values for elbow extension. **Figure 15** provided a visual representation of the comparison between groups across the three assessments. The results of the inferential statistics could be found in **Table 15**. A significant interaction emerged between the factor 'group' and 'assessment' ($F_{2,28}$ = 9.00, P < 0.001). Subsequently, post-hoc analyses were conducted using Bonferroni simple *t*-tests to examine the treatment effect for ADIM-CT group and CT-ADIM group separately in **Table 16**.

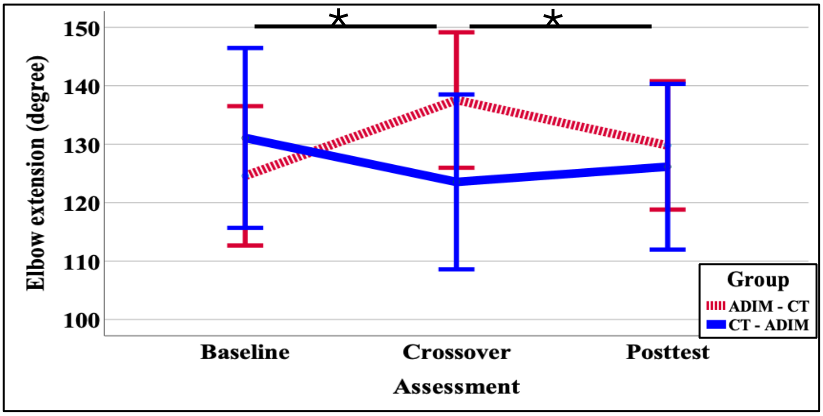

Figure 15. Linear graph representing elbow extension

* indicated post hoc simple *t*-test after significant effect for interaction. $P < 0.05$.

Table 14. Descriptive statistics of Elbow extension

Group \ Assessment	Baseline	Crossover	Posttest
	Mean (SD)	Mean (SD)	Mean (SD)
ADIM-CT	124.59 (18.74)	137.57 (15.21)	129.80 (15.23)
CT-ADIM	131.07 (15.30)	123.54 (20.04)	126.15 (17.80)

ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver.

Table 15. Inferential statistics for kinematic variables

Effect		SS	DF	MS	F	P-value	μ^2
Within subject	Assessment	70.64	2	35.32	0.81	0.46	0.05
	Assessment × Group	788.55	2	394.27	9.00	$< 0.001^{***}$	0.39
	Error	28					
Between group	Group	156.60	1	156.60	0.20	0.66	0.01
	Error	14					

SS, Sum of Squares; DF, Degrees of Freedom; MS, Mean Square; μ^2, Partial Eta Squared, *** $p < 0.001$

Table 16. post-hoc with Bonferroni simple *t*-test

ADIM-CT	Mean difference	P-value	95% CI	
			Lower	Upper
Baseline - crossover	-12.98	0.01^{*}	-22.25	-3.71
Crossover - Posttest	7.77	0.01^{*}	1.50	14.04
Posttest - Baseline	5.21	0.33	-3.10	13.51

CI, Confidence Interval, * $p < 0.05$.

3.2.3.2. Shoulder flexion in the forward direction (degree)

Table 17 displayed the mean and standard deviation values for shoulder flexion. **Table 18** contained the results of the inferential statistics. The main effect analysis for the ‘assessment’ factor indicated no significant difference ($F_{2,28} = 2.09$, $P = 0.14$), and likewise for the ‘group’ factor between groups ($F_{1,14} = 0.05$, $P = 0.83$). Additionally, no significant interaction effect was observed between ‘assessment’ and ‘between group’ ($F_{2,28} = 0.29$, $P = 0.75$). **Figure 16** illustrated that the ADIM-CT group exhibited a similar pattern to the CT-ADIM group, regardless of whether participants underwent ADIM exercise or conventional therapy.

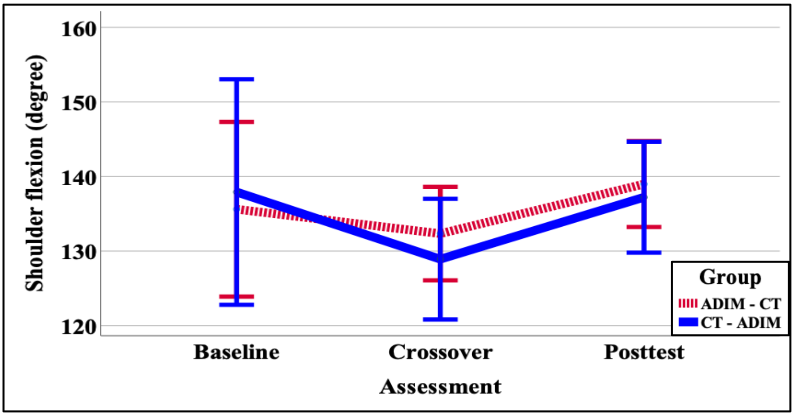

Figure 16.Linear graph representing shoulder flexion

Table 17. Descriptive statistics of Shoulder flexion

Group \ Assessment	Baseline	Crossover	Posttest
	Mean (SD)	Mean (SD)	Mean (SD)
ADIM-CT	135.62 (20.20)	132.34 (2.67)	138.99 (10.55)
CT-ADIM	137.92 (10.03)	128.92 (15.03)	137.23 (1.26)

ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver.

Table 18. Inferential statistics for kinematic variables

Effect		SS	DF	MS	F	P-value	μ^2
Within subject	Assessment	476.60	2	238.30	2.09	0.14	0.13
	Assessment × Group	65.19	2	32.59	0.29	0.75	0.20
	Error	28					
Between group	Group	10.39	1	10.39	0.05	0.83	0.003
	Error	14					

SS, Sum of Squares; DF, Degrees of Freedom; MS, Mean Square; μ^2, Partial Eta Squared.

3.2.3.3. Trunk displacement in the forward direction (mm)

In **Table 19**, we present the mean and standard deviation values for trunk displacement. The results of the inferential statistics could be found in **Table 20**. The analysis of trunk displacement yielded a statistically significant interaction between the variables 'group' and 'assessment' ($F_{2,28} = 3.75$, $P = 0.04$). Employing Bonferroni correction in conjunction with simple t-test, we observed a notable disparity between groups during the crossover assessment, with a mean difference of -61.65 ($P = 0.04$, 95% Cl [-119.94, -3.36]) in **Table 21**. The ADIM exercise caused significant reduction in trunk movement during the crossover assessment. **Figure 17** provided a visual representation of the comparison between groups

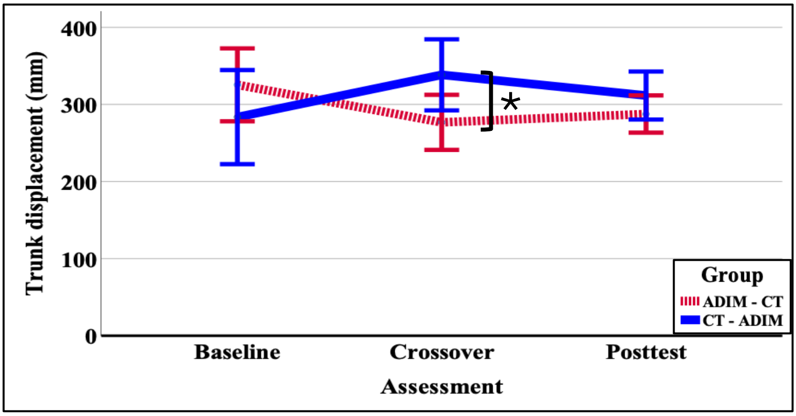

Figure 17. Linear graph presenting trunk displacement

*indicated post hoc simple *t*-test after significant effect for interaction. $P < 0.05$.

Table 19. Descriptive statistics of Trunk displacement

Group \ Assessment	Baseline	Crossover	Posttest
	Mean (SD)	Mean (SD)	Mean (SD)
ADIM-CT	325.49 (83.54)	276.80 (64.23)	287.58 (44.19)
CT-ADIM	283.62 (32.40)	338.45 (18.14)	311.62 (5.37)

ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver.

Table 20. Inferential statistics for kinematic variables

Effect		SS	DF	MS	F	P-value	μ^2
Within subject	Assessment	491.45	2	245.72	0.09	0.92	0.006
	Assessment × Group	20593.46	2	10296.73	3.75	0.04*	0.21
	Error	28					
Between group	Group	2400.23	1	2400.23	0.70	0.42	0.05
	Error	14					

SS, Sum of Squares; DF, degrees of freedom; MS, Mean Square; μ^2, Partial Eta Squared. * $p < 0.05$.

Table 21. post-hoc with Bonferroni simple *t*-test

Between groups	Mean difference	P-value	95% CI	
			Lower	Upper
Baseline	41.87	0.26	-35.35	119.09
Crossover	-61.65	0.04*	-119.94	-3.36
Posttest	-24.04	0.21	-63.45	15.37

CI, Confidence Interval, * $p < 0.05$.

3.2.3.4. Total time in the forward direction (second)

In **Table 22**, we presented the mean and standard deviation values for trunk displacement. The inferential statistics results are detailed in **Table 23**. The analysis of total time indicated that there was no significant interaction ($F_{1.45,20.27}$ = 0.60, P = 0.51). Furthermore, there were no significant main effects observed for either the group ($F_{1,14}$ = 0.03, P = 0.87) or assessment ($F_{1.45,\ 20.27}$ = 3.17, P = 0.08). **Figure 18** provided a clear visual representation of the total time in a linear graph.

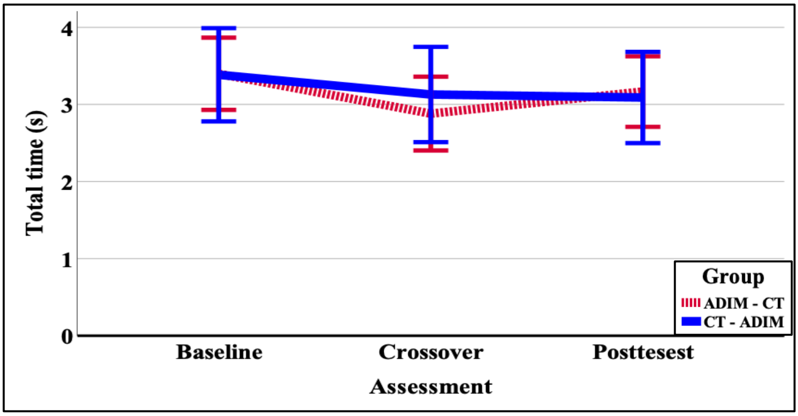

Figure 18. Linear graph representing total time

Table 22. Descriptive statistics of Total time

Group \ Assessment	Baseline	Crossover	Posttest
	Mean (SD)	Mean (SD)	Mean (SD)
ADIM-CT	3.40 (0.72)	2.88 (0.56)	3.17 (0.61)
CT-ADIM	3.39 (0.64)	3.13 (0.91)	3.09 (0.78)

ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver.

Table 23. Inferential statistics for kinematic variables

Effect		SS	DF	MS	F	P-value	μ^2
Within subject	Assessment	1.17	1.45	0.81	3.17	0.08	0.18
	Assessment × Group	0.22	1.45	0.15	0.60	0.51	0.04
	Error	20.27					
Between group	Group	0.03	1	0.03	0.03	0.87	0.002
	Error	14					

SS, Sum of Squares; DF, Degrees of Freedom; MS, Mean Square; μ^2, Partial Eta Squared.

3.2.3.5. Hand velocity in the forward direction (mm/s)

In **Table 24**, we presented the mean and standard deviation values for hand velocity. The results of the inferential statistics could be found in **Table 25**. Results of hand velocity revealed significant interaction effect of ($F_{2,28}$ = 3.54, P = 0.04). Following the meticulous application of separate Bonferroni t-test to scrutinize the treatment effect within each group and assessment, notable findings emerged. Specifically, in the CT-ADIM group, a significant improvement was observed following the implementation of ADIM exercise. Demonstrating a substantial mean difference of -362.38 (P = 0.009, 95% Cl [-637.97,-86.78]) in **Table 26**. **Figure 19** illustrates linear graph representing hand velocity.

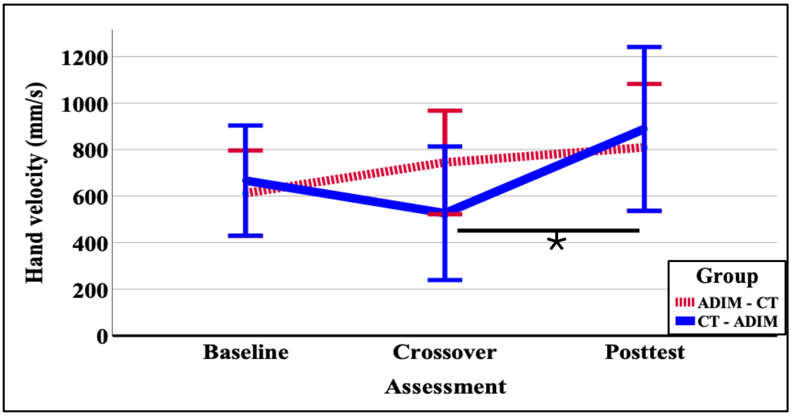

Figure 19. Linear graph representing hand velocity

* indicated post.hoc simple t-test after significant effect for interaction. $P < 0.05$.

Table 24. Descriptive statistics of Hand velocity

Group \ Assessment	Baseline	Crossover	Posttest
	Mean (SD)	Mean (SD)	Mean (SD)
ADIM-CT	612.93 (335.11)	745.13 (400.87)	809.86 (444.13)
CT-ADIM	666.98 (51.26)	526.60 (110.13)	888.98 (313.33)

ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver.

Table 25. Inferential statistics for kinematic variables

Effect		SS	DF	MS	F	P-value	μ^2
Within subject	Assessment	447496.69	2	223748.34	7.74	0.002**	0.36
	Assessment × Group	204389.19	2	102194.60	3.54	0.04*	0.20
	Error	28					
Between group	Group	9109.17	1	9109.17	0.03	0.86	0.002
	Error	14					

SS, Sum of Squares; DF, Degrees of Freedom; MS, Mean Square; μ^2, Partial Eta Squared. * $p < 0.05$, ** $p < 0.01$

Table 26. post-hoc with Bonferroni simple *t*-test

CT-ADIM	Mean difference	P-value	95% CI	
			Lower	Upper
Baseline - crossover	140.37	0.28	-70.39	351.14
Crossover - Posttest	-362.38	0.009**	-637.97	-86.78
Posttest - Baseline	222.00	0.20	-83.26	527.27

CI, Confidence Interval, ** $p < 0.01$

3.2.3.6. Hand acceleration in the forward direction (mm/s^2)

Table 27 provided descriptive statistics, offering the means and standard deviations. **Table 28** presented the inferential statistics, delving into deeper insights. Notably, the analysis revealed a non-significant interaction effect ($F_{2,28}$ = 0.02, P = 0.98), suggesting minimal impact from this variable. Furthermore, there was no statistically significant distinction observed between the groups ($F_{1,14}$ = 0.68, P = 0.42), indicating a similar degree of improvement between the ADIM exercise and conventional therapy. **Figure 20** showed linear graph representing hand acceleration.

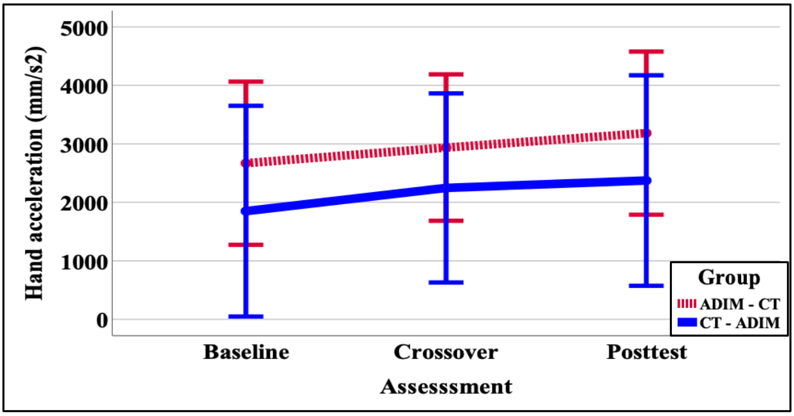

Figure 20. Linear graph representing hand acceleration

Table 27. Descriptive statistics of Hand acceleration

Group \ Assessment	Baseline	Crossover	Posttest
	Mean (SD)	Mean (SD)	Mean (SD)
ADIM-CT	2669.83 (2465.94)	2937.03 (2080.68)	3183.73 (2471.70)
CT-ADIM	1850.22 (949.69)	2247.23 (1319.97)	2373.84 (913.91)

ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver.

Table 28. Inferential statistics for kinematic variables

Effect		SS	DF	MS	F	P-value	μ^2
Within subject	Assessment	2071262.87	2	1035631.44	1.02	0.37	0.07
	Assessment × Group	39213.81	2	19606.90	0.02	0.98	0.001
	Error	28					
Between group	Group	6723882.39	1	6723882.39	0.68	0.42	0.05
	Error	14					

SS, Sum of Squares; DF, Degrees of Freedom; MS, Mean Square; μ^2, Partial Eta Squared.

3.2.3.7. Elbow angular velocity in the forward direction (rad/s)

Table 29 provided a comprehensive overview of the descriptive statistics. Furthermore, **Table 30** presented the inferential statistics measurements. The analysis of elbow angular velocity yielded no statistically significant interaction ($F_{2,28}$ = 1.52, P = 0.24). Additionally, there was no statistically significant distinction observed between the groups ($F_{1,14}$ = 1.99, P = 0.18) or assessment factor ($F_{2,28}$ = 1.54, P = 0.23). **Figure 21** offered a visual representation of the differences in elbow angular velocity.

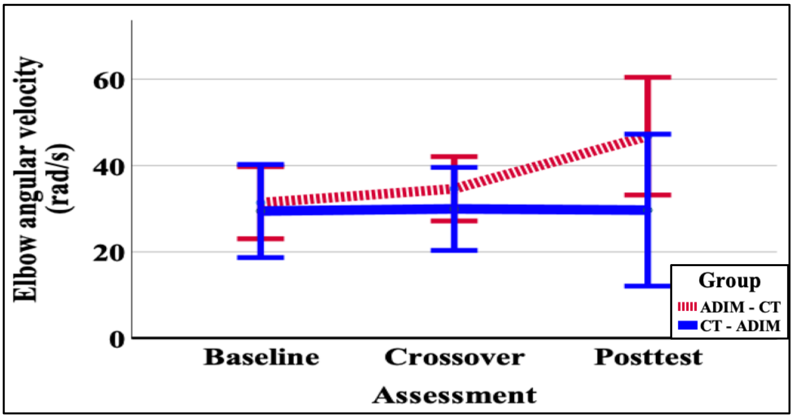

Figure 21. Linear graph representing elbow angular velocity

Table 29. Descriptive statistics of Elbow angular velocity

Group \ Assessment	Baseline	Crossover	Posttest
	Mean (SD)	Mean (SD)	Mean (SD)
ADIM-CT	31.40 (12.57)	34.62 (10.74)	46.81 (22.93)
CT-ADIM	29.48 (11.84)	29.97 (11.39)	29.69 (13.59)

ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver.

Table 30. Inferential statistics for kinematic variables

Effect		SS	DF	MS	F	P-value	μ^2
Within subject	Assessment	499.61	2	249.80	1.54	0.23	0.10
	Assessment × Group	492.66	2	246.33	1.52	0.24	0.10
	Error		28				
Between group	Group	702.74	1	702.74	1.99	0.18	0.13
	Error		14				

SS, Sum of Squares; DF, Degrees of Freedom; MS, Mean Square; μ^2, Partial Eta Squared.

3.2.3.8. Elbow angular acceleration in the forward direction (rad/s^2)

Table 31 furnished descriptive statistics, including means and standard deviations. **Figure 22** illustrated a linear graph depicting elbow angular acceleration. In **Table 32**, we delved into inferential statistics, providing more detailed insights. Noteworthy was the finding off a non-significant interaction effect ($F_{2,28}$ = 1.81, P = 0.18). Additionally, there was no statistically significant distinction observed between the groups ($F_{1,14}$ = 4.48, P = 0.05) and assessment factor ($F_{2,28}$ = 2.10, P = 0.14)

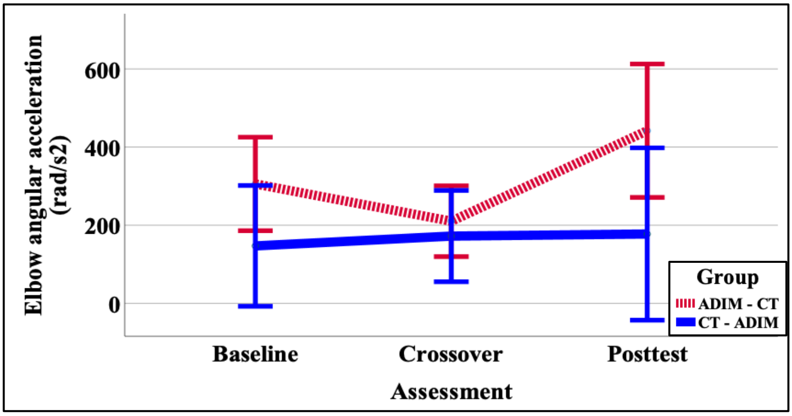

Figure 22. Linear graph representing elbow angular acceleration

Table 31. Descriptive statistics of Elbow angular acceleration

Group \ Assessment	Baseline	Crossover	Posttest
	Mean (SD)	Mean (SD)	Mean (SD)
ADIM-CT	305.76 (213.15)	210.31 (151.39)	442.02 (302.97)
CT-ADIM	147.15 (74.24)	172.27 (92.98)	177.60 (110.74)

ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver.

Table 32. Inferential statistics for kinematic variables

Effect		SS	DF	MS	F	P-value	μ^2
Within subject	Assessment	111150.36	2	55575.18	2.10	0.14	0.13
	Assessment × Group	96226.39	2	48113.20	1.81	0.18	0.12
	Error	28					
Between group	Group	265727.05	1	265729.05	4.48	0.05	0.24
	Error	14					

SS, Sum of Squares; DF, Degrees of Freedom; MS, Mean Square; μ^2, Partial Eta Squared.

3.2.3.9. Movement unit in the forward direction (*n*)

Table 33 revealed descriptive outcome measurement. Movement units through ADIM exercise revealed a noteworthy distinction in the forward direction, as outlined in **Table 34**. Regarding the main effect, there was no significant difference observed in either the assessments ($F_{2,28} = 1.17$, $P = 0.33$) or between groups ($F_{2,28} = 1.22$, $P = 0.29$). However, after undergoing crossover assessment, these comparisons demonstrated statistical significance. This significance became apparent after interaction between group and assessment ($F_{2,28} = 4.45$, $P = 0.02$). Following this, utilizing a post-hoc analysis with Bonferroni *t*-test, there was significant mean difference -1.89 between groups ($P = 0.02$, 95% CI [-3.43, -0.35]) in **Table 35**. The visual linear graph of movement unit is illustrated in **Figure 23**.

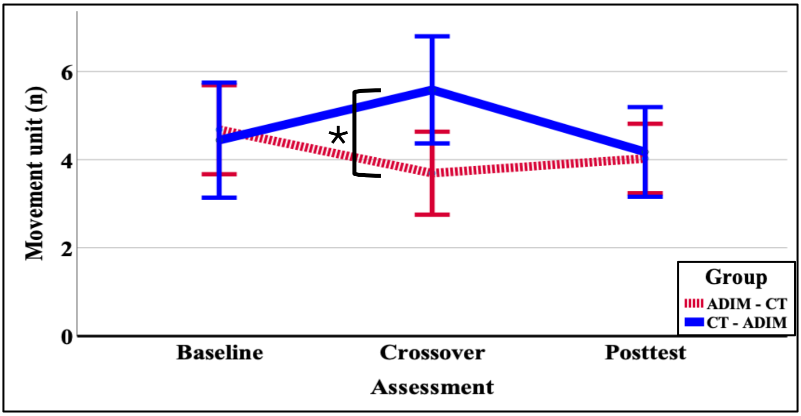

Figure 23. Linear graph representing movement unit

* indicated post hoc simple *t*-test after significant effect for interaction. $P < 0.05$.

Table 33. Descriptive statistics of Movement unit

Group \ Assessment	Baseline	Crossover	Posttest
	Mean (SD)	Mean (SD)	Mean (SD)
ADIM-CT	4.68 (1.66)	3.70 (1.02)	4.03 (1.18)
CT-ADIM	4.44 (1.13)	5.58 (1.87)	4.18 (1.13)

ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by abdominal Drawing-In Maneuver

Table 34. Inferential statistics for kinematic variables

Effect		SS	DF	MS	F	P-value	μ^2
Within subject	Assessment	2.53	2	1.27	1.17	0.33	0.08
	Assessment × Group	9.62	2	4.81	4.45	0.02*	0.24
	Error	28					
Between group	Group	4.06	1	4.06	1.22	0.29	0.08
	Error	14					

SS, Sum of Squares; DF, Degrees of Freedom; MS, Mean Square; μ^2, Partial Eta Squared. * $p < 0.05$.

Table 35. post-hoc with Bonferroni simple *t*-test

Between groups	Mean difference	P-value	95% CI	
			Lower	Upper
Baseline	0.24	0.76	-1.41	1.89
Crossover	-1.89	0.02*	-3.43	-0.35
Posttest	-0.15	0.81	-1.44	1.14

CI, Confidence Interval, * $p < 0.05$.

3.2.4. Treatment effect in the ipsilateral direction

3.2.4.1. Elbow extension in the ipsilateral direction (degree)

Table 36 provided a detailed overview of the outcomes observed during elbow extension. As depicted in **Figure 24**, the ADIM-CT group demonstrates an average increase of 3.38 degrees in posttest measurements, whereas the CT-ADIM group exhibited a reduction of 9.67 degrees in response to elbow extension. **Table 37** illustrated that the main effect of ‘assessment’ factor ($F_{2,28} = 0.35$, $P = 0.71$) and the ‘between group’ factor ($F_{2,28} = 0.39$, $P = 0.54$) did not yield significant results. Additionally, there was no significant interaction effect ($F_{2,28} = 2.23$, $P = 0.13$).

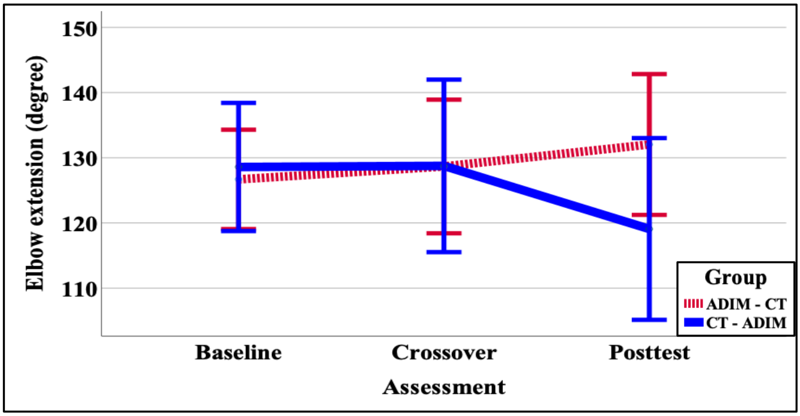

Figure 24. Linear graph representing elbow extension

Table 36. Descriptive statistics of Elbow extension

Group \ Assessment	Baseline	Crossover	Posttest
	Mean (SD)	Mean (SD)	Mean (SD)
ADIM-CT	126.70 (4.00)	128.67 (13.42)	132.05 (17.74)
CT-ADIM	128.59 (18.01)	128.76 (17.74)	119.09 (11.99)

ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver.

Table 37. Inferential statistics for kinematic variables

Effect		SS	DF	MS	F	P-value	μ^2
Within subject	Assessment	76.00	2	38.49	0.35	0.71	0.02
	Assessment × Group	492.93	2	246.46	2.23	0.13	0.14
	Error	28					
Between group	Group	150.53	1	150.53	0.39	0.54	0.03
	Error	14					

SS, Sum of Squares; DF, Degrees of Freedom; MS, Mean Square; μ^2, Partial Eta Squared.

3.2.4.2. Shoulder flexion in the ipsilateral direction (degree)

In **Table 38**, the mean and standard deviation of descriptive measurement outcomes were provided. The pattern between groups was similar across all three assessments, as illustrated in **Figure 25**. Consequently, there was no significant main effect for the assessment factor ($F_{2,28} = 3.32$, $P = 0.05$), nor for the group factor ($F_{1,14} = 0.16$, $P = 0.70$). Additionally, **Table 39** showed that the interaction revealed no significant difference ($F_{2,28} = 0.14$, $P = 0.87$).

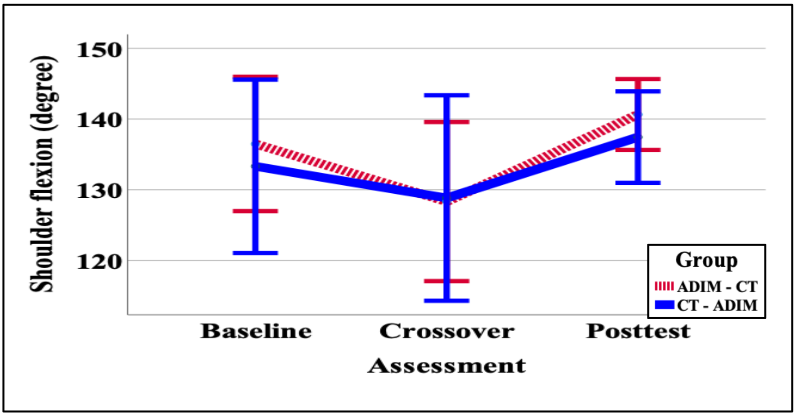

Figure 25. Linear graph representing shoulder flexion

Table 38. Descriptive statistics of Shoulder flexion

Group \ Assessment	Baseline	Crossover	Posttest
	Mean (SD)	Mean (SD)	Mean (SD)
ADIM-CT	136.48 (15.57)	128.33 (18.06)	140.65 (8.21)
CT-ADIM	133.52 (10.66)	128.33 (13.56)	137.45 (5.63)

ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver.

Table 39. Inferential statistics for kinematic variables

Effect		SS	DF	MS	F	P-value	μ^2
Within subject	Assessment	833.27	2	416.64	3.32	0.05	0.19
	Assessment × Group	33.99	2	17.00	0.14	0.87	0.01
	Error	28					
Between group	Group	43.06	1	43.06	0.16	0.70	0.01
	Error	14					

SS, Sum of Squares; DF, Degrees of Freedom; MS, Mean Square; μ^2, Partial Eta Squared.

3.2.4.3. Trunk displacement in the ipsilateral direction (mm)

Table 40 offered a descriptive analysis off trunk displacement. For a visual representation, referred to **Figure 26** displaying the linear graph. As indicated in **Table 41**, there were no statistically significant differences found in the main effect for assessment ($F_{1.38,\ 19.35} = 1.64$, $P = 0.22$) or for group ($F_{1,14} = 1.00$, $P = 0.33$). Furthermore, no significant interaction was observed between assessment and group ($F_{1.38,\ 19.35} = 0.48$, $P = 0.56$).

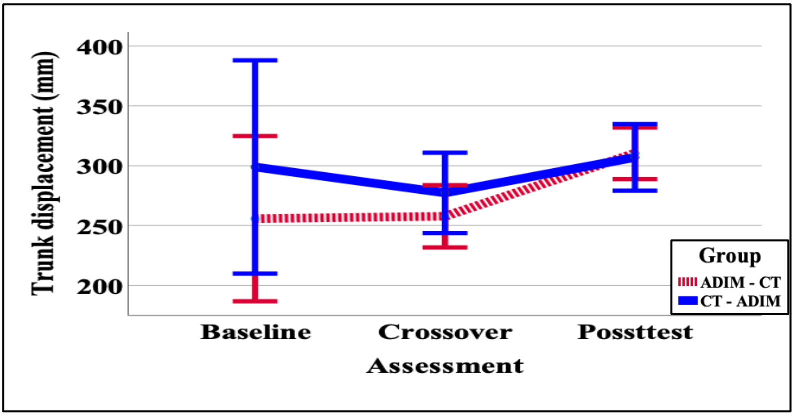

Figure 26. Linear graph representing trunk displacement

Table 40. Descriptive statistics of Trunk displacement

Group \ Assessment	Baseline	Crossover	Posttest
	Mean (SD)	Mean (SD)	Mean (SD)
ADIM-CT	255.78 (84.50)	257.77 (42.76)	310.38 (38.08)
CT-ADIM	298.94 (127.11)	277.32 (28.82)	306.98 (14.85)

ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver.

Table 41. Inferential statistics for kinematic variables

Effect		SS	DF	MS	F	P-value	μ^2
Within subject	Assessment	13850.27	1.38	10020.15	1.64	0.22	0.11
	Assessment × Group	4064.73	1.38	2940.68	0.48	0.56	0.03
	Error	19.35					
Between group	Group	4396.53	1	4396.53	1.00	0.33	0.07
	Error	14					

SS, Sum of Squares; DF, Degrees of Freedom; MS, Mean Square; μ^2, Partial Eta Squared.

3.2.4.4. Total time in the ipsilateral direction (second)

Table 42 presented the descriptive statistics for total time. **Figure 27** visually demonstrated that ADIM-CT group and CT-ADIM group exhibited a similar pattern. **Table 43** provided the results of inferential statistics. The main effect of the 'assessment' factor did not reach statistical significance ($F_{1.41,\ 19.68} = 3.38$, $P = 0.07$), and similarly, there was no significant effect observed for the 'between groups' factor ($F_{1,14} = 0.00$, $P = 0.98$). Additionally, no significant differences emerged between the crossed factors of 'assessment' and 'between groups' in the interaction ($F_{1.41,\ 19.68} = 0.52$, $P = 0.54$).

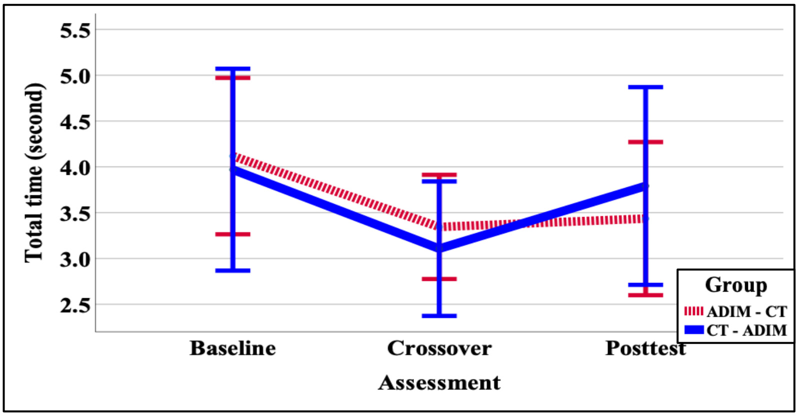

Figure 27. Linear graph representing total time

Table 42. Descriptive statistics of Total time

Group \ Assessment	Baseline	Crossover	Posttest
	Mean (SD)	Mean (SD)	Mean (SD)
ADIM-CT	4.12 (1.34)	3.34 (0.68)	3.44 (0.98)
CT-ADIM	3.97 (1.10)	3.11 (1.07)	3.79 (1.59)

ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver.

Table 43. Inferential statistics for kinematic variables

Effect		SS	DF	MS	F	P-value	μ^2
Within subject	Assessment	5.02	1.41	3.57	3.38	0.07	0.20
	Assessment × Group	0.77	1.41	0.55	0.52	0.54	0.04
	Error	19.68					
Between group	Group	0.001	1	0.01	0.00	0.98	0.00
	Error	14					

SS, Sum of Squares; DF, Degrees of Freedom; MS, Mean Square; μ^2, Partial Eta Squared.

3.2.4.5. Hand velocity in the ipsilateral direction (mm/s)

Table 44 provided the descriptive statistics for hand velocity. **Figure 28** displays a linear graph illustrating hand velocity. **Table 45** indicated a statistically significant difference in main factor of assessment ($F_{2,28}$ = 4.76, P = 0.02). However, there was no significant distinction observed between the ADIM- CT group and the CT-ADIM group in terms of between-group difference ($F_{1,14}$ = 0.002, P = 0.97). Furthermore, there was no significant difference in interaction ($F_{2,28}$ = 1.64, P = 0.21).

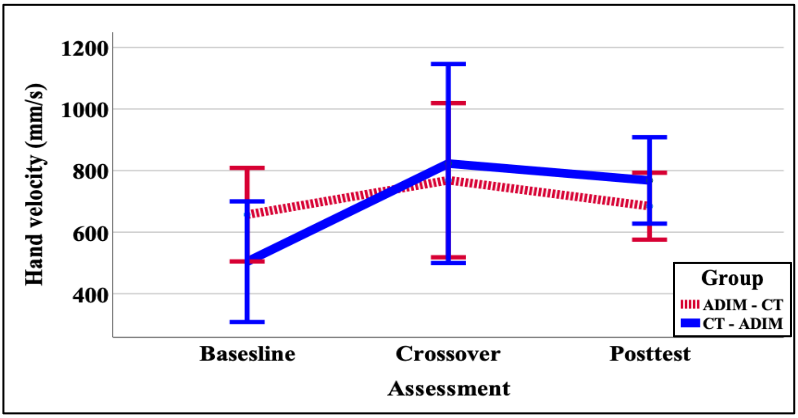

Figure 28. Linear graph presenting hand velocity

Table 44. Descriptive statistics of Hand velocity

Group \ Assessment	Baseline	Crossover	Posttest
	Mean (SD)	Mean (SD)	Mean (SD)
ADIM-CT	656.95 (238.97)	768.77 (423.04)	684.42 (188.50)
CT-ADIM	504.10 (194.17)	823.03 (243.99)	768. 17 (89.10)

ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver.

Table 45. Inferential statistics for kinematic variables

Effect		SS	DF	MS	F	P-value	μ^2
Within subject	Assessment	362394.34	2	181197.17	4.76	0.02*	0.25
	Assessment × Group	124686.95	2	62343.47	1.64	0.21	0.11
	Error	28					
Between group	Group	275.56	1	275.56	0.002	0.97	0.00
	Error	14					

SS, Sum of Squares; DF, Degrees of Freedom; MS, Mean Square; μ^2, Partial Eta Squared. * $p < 0.05$.

3.2.4.6. Hand acceleration in the ipsilateral direction (mm/s^2)

Table 46 provided the descriptive statistics for hand acceleration, while **Figure 29** presented a linear graph illustrating hand acceleration. In **Table 47**, inferential statistics were detailed. A significant difference was observed across the three assessments ($F_{2,28}$ = 5.14, P = 0.01). However, no significant effects were found between groups ($F_{1,14}$ = 0.45, P = 0.52) or in the interaction ($F_{2,28}$ = 3.33 P = 0.05). Despite the absence of interaction effects, the partial square value of 0.19 indicated a large effect size.

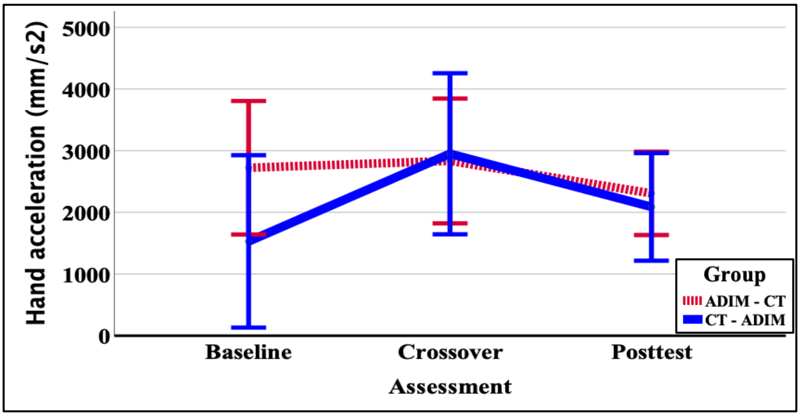

Figure 29. Linear graph representing hand acceleration

Table 46. Descriptive statistics of Hand acceleration

Group \ Assessment	Baseline	Crossover	Posttest
	Mean (SD)	Mean (SD)	Mean (SD)
ADIM-CT	2723.69 (1924.02)	2834.28 (1848.89)	2308.72 (1166.88)
CT-ADIM	1529.47 (684.81)	2950.77 (276.16)	2089.26 (572.30)

ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver.

Table 47. Inferential statistics for kinematic variables

Effect		SS	DF	MS	F	P-value	μ^2
Within subject	Assessment	5364583.60	2	2682291.80	5.14	0.01*	0.27
	Assessment × Group	3476220.93	2	1738110.46	3.33	0.05	0.19
	Error	28					
Between group	Group	2103398.50	1	2103398.50	0.45	0.52	0.03
	Error	14					

SS, Sum of Squares; DF, Degrees of Freedom; MS, Mean Square; μ^2, Partial Eta Squared, * $p < 0.05$.

3.2.4.7. Elbow angular velocity in the ipsilateral direction (rad/s)

Table 48 presented the descriptive statistics for elbow angular velocity. **Figure 30** visually depicted the linear differences between groups. In **Table 49**, a significant difference emerged across the three assessments ($F_{2,28} = 6.88$, $P = 0.004$). However, no significant effects were observed between groups ($F_{1,14} = 1.18$, $P = 0.30$), nor was there a significant interaction ($F_{2,28} = 1.26$ $P = 0.30$).

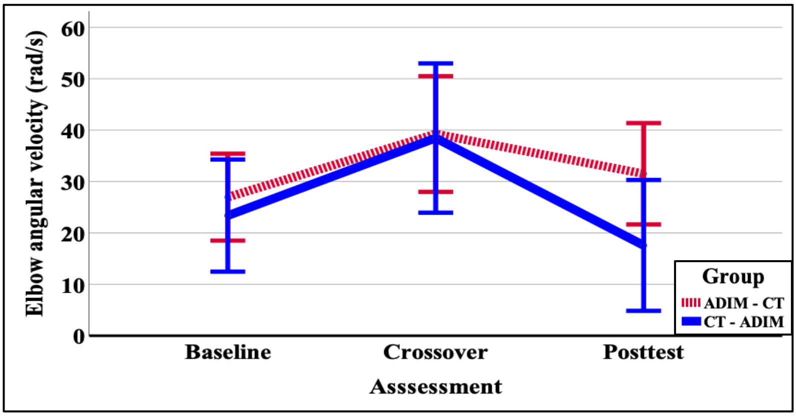

Figure 30. Linear graph representing elbow angular velocity

Table 48. Descriptive statistics of Elbow angular velocity

Group \ Assessment	Baseline	Crossover	Posttest
	Mean (SD)	Mean (SD)	Mean (SD)
ADIM-CT	26.96 (12.83)	39.25 (16.20)	31.52 (17.41)
CT-ADIM	23.37 (11.77)	38.47 (17.26)	17.58 (6.77)

ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver.

Table 49. Inferential statistics for kinematic variables

Effect		SS	DF	MS	F	P-value	μ^2
Within subject	Assessment	1963.62	2	981.81	6.88	0.004*	0.33
	Assessment × Group	360.12	2	180.06	1.26	0.30	0.08
	Error	28					
Between group	Group	419.38	1	419.38	1.18	0.30	0.08
	Error	14					

SS, Sum of Squares; DF, Degrees of Freedom; MS, Mean Square; μ^2, Partial Eta Squared, * $p < 0.05$.

3.2.4.8. Elbow angular acceleration in the ipsilateral direction (rad/s^2)

Table 50 presented the descriptive statistics for elbow angular acceleration. **Figure 31** provided a visual representation of the distinct linear patterns between the ADIM-CT and CT-ADIM groups. Moving to **Table 51**, we found the inferential statistics. No significant differences were observed across the three assessments ($F_{1.44, 20.09} = 0.06$, $P = 0.89$). Likewise, there were no significant effects between groups ($F_{1,14} = 2.77$, $P = 0.12$), and no significant interaction was noted ($F_{1.44,20.09} = 2.24$, $P = 0.14$).

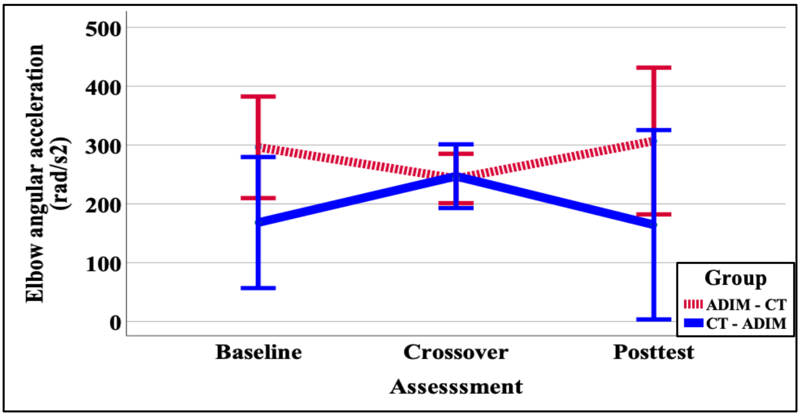

Figure 31. Linear graph representing elbow angular acceleration

Table 50. Descriptive statistics of Elbow angular acceleration

Group \ Assessment	Baseline	Crossover	Posttest
	Mean (SD)	Mean (SD)	Mean (SD)
ADIM-CT	296.21 (154.00)	243.16 (23.42)	306.87 (217.04)
CT-ADIM	168.23 (51.36)	247.03 (98.71)	164.47 (191.34)

ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver.

Table 51. Inferential statistics for kinematic variables

Effect		SS	DF	MS	F	P-value	μ^2
Within subject	Assessment	1333.11	1.44	929.08	0.06	0.89	0.004
	Assessment × Group	48735.90	1.44	33965.22	2.24	0.14	0.14
	Error		20.09				
Between group	Group	88791.69	1	88791.69	2.77	0.12	0.17
	Error		14				

SS, Sum of Squares; DF, Degrees of Freedom; MS, Mean Square; μ^2, Partial Eta Squared.

3.2.4.9. Movement unit in the ipsilateral direction (*n*)

Table 52 provided descriptive measurements for movement unit in the ipsilateral direction. **Figure 32** illustrated the variations among the three assessments between the groups through a linear graph. **Table 53** revealed a statistically significant difference in the main effect of the assessment factor ($F_{2,28} = 41.28$, $P < 0.001$). However, no significant interaction effect was observed between 'assessment' and 'group' ($F_{2,28} = 1.27$, $P = 0.30$) and there was no significant main effect for the between-group factor ($F_{1,14} = 0.13$, $P = 0.72$).

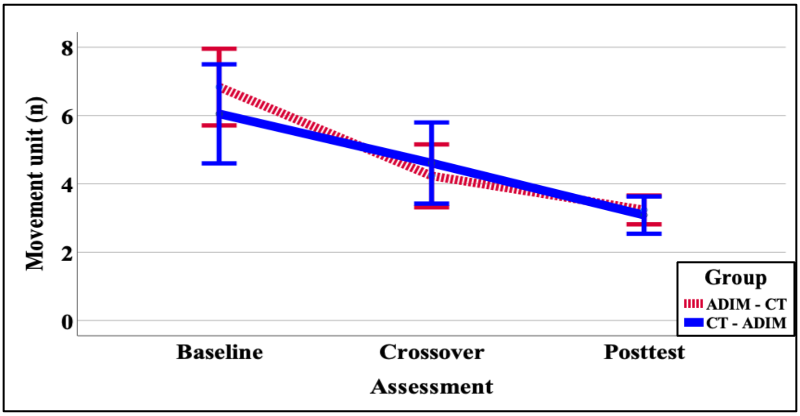

Figure 32. Linear graph representing movement unit

Table 52. Descriptive statistics of Movement unit

Group \ Assessment	Baseline	Crossover	Posttest
	Mean (SD)	Mean (SD)	Mean (SD)
ADIM-CT	6.84 (1.47)	4.23 (0.68)	3.24 (0.63)
CT-ADIM	6.05 (1.95)	4.61 (2.08)	3.09 (0.60)

ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver.

Table 53. Inferential statistics for kinematic variables

Effect		SS	DF	MS	F	P-value	μ^2
Within subject	Assessment	82.22	2	41.11	41.28	< 0.001***	0.75
	Assessment × Group	2.54	2	1.27	1.27	0.30	0.08
	Error	28					
Between group	Group	0.40	1	0.40	0.13	0.72	0.01
	Error	14					

SS, Sum of Squares; DF, Degrees of Freedom; MS, Mean Square; μ^2, Partial Eta Squared. *** $P < 0.001$

3.2.5. Treatment effect in the contralateral direction

3.2.5.1. Elbow extension in the contralateral direction (degree)

Table 54 revealed mean and standard deviation for elbow extension. **Figure 33** showed visual linear graph for elbow extension. The analysis revealed a significant interaction effect ($F_{2,28} = 3.65$, $P = 0.04$) in **Table 55**. Subsequent post-hoc Bonferroni *t*-test were conducted to assess group by assessment differences. Within each assessment, no statistically significant differences were observed at baseline, the mean difference was -9.16 (P = 0.09); at crossover, the mean difference was 13.39 (P = 0.27); at posttest, the mean difference was 2.89 (P = 0.75). Furthermore, within-subject comparisons in each group did not yield significant differences. In the ADIM-CT group, the mean difference between baseline and crossover assessments was -16.62 (P = 0.06), between crossover and posttest assessment was 3.60 (P =1.00), and between posttest and baseline assessments was 13.03 (P = 0.06). In the CT-ADIM group, the mean difference between baseline and crossover assessments was 5.93 (P = 1.00), between crossover and posttest assessments was -6.91 (P = 0.56), and between posttest and baseline assessments was 0.99 (P = 1.00).

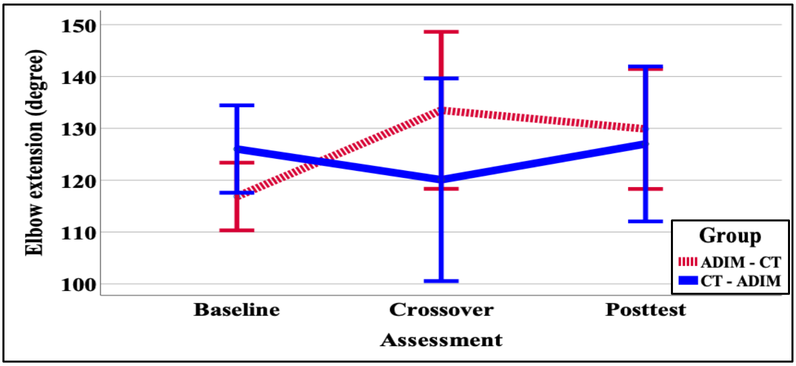

Figure 33. Linear graph representing elbow extension

Table 54. Descriptive statistics of Elbow extension

Group \ Assessment	Baseline	Crossover	Posttest
	Mean (SD)	Mean (SD)	Mean (SD)
ADIM-CT	116.86 (6.76)	133.48 (20.60)	129.89 (16.94)
CT-ADIM	126.02 (13.30)	120.09 (25.15)	127.00 (19.30)

ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver.

Table 55. Inferential statistics for kinematic variables

Effect		SS	DF	MS	F	P-value	μ^2
Within subject	Assessment	402.29	2	201.14	1.54	0.23	0.10
	Assessment × Group	954.68	2	477.34	3.65	0.04*	0.21
	Error	28					
Between group	Group	63.39	1	63.39	0.10	0.75	0.01
	Error	14					

SS, Sum of Squares; DF, Degrees of Freedom; MS, Mean Square; μ^2, Partial Eta Squared. * $P < 0.05$

3.2.5.2. Shoulder flexion in contralateral direction (degree)

Table 56 presented the descriptive statistics for shoulder flexion. **Figure 34** provides a visual representation of this linear progression in shoulder flexion. In **Table 57**, revealed that there were no statistically significant differences observed across the three assessments ($F_{2,28}$ = 1.88, P = 0.17), between groups ($F_{1,14}$ = 0.19, P = 0.67), nor in the interaction effect ($F_{2,28}$ = 0.37, P = 0.69).

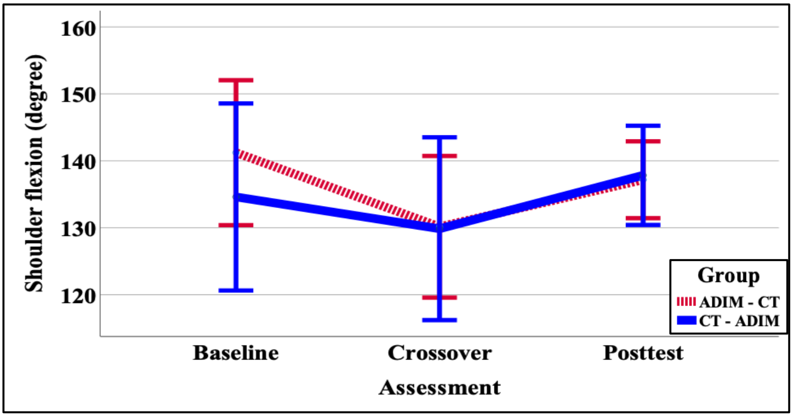

Figure 34. Linear graph representing shoulder flexion

Table 56. Descriptive statistics of Shoulder flexion

Group \ Assessment	Baseline	Crossover	Posttest
	Mean (SD)	Mean (SD)	Mean (SD)
ADIM-CT	141.22 (16.90)	130.15 (17.19)	137.18 (9.08)
CT-ADIM	134.61 (14.10)	129.86 (12.22)	137.84 (7.22)

ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver.

Table 57. Inferential statistics for kinematic variables

Effect		SS	DF	MS	F	P-value	μ^2
Within subject	Assessment	594.97	2	297.48	1.88	0.17	0.12
	Assessment × Group	117.28	2	58.64	0.37	0.69	0.03
	Error	28					
Between group	Group	48.73	1	48.73	0.19	0.67	0.01
	Error	14					

SS, Sum of Squares; DF, Degrees of Freedom; MS, Mean Square; μ^2, Partial Eta Squared.

3.2.5.3. Trunk displacement in contralateral direction (mm)

Table 58 provided the descriptive statistics for trunk displacement. **Figure 35** visually depicted these trends in a liner graph representing trunk displacement. Moving to **Table 59**, it showed that there was a significant difference observed across the three assessments ($F_{2,28}$ =5.92, P = 0.01). However, there were no significant effects detected between groups ($F_{1,14}$ = 1.15, P = 0.30) nor in the interaction effect ($F_{2,28}$ = 1.74, P = 0.20).

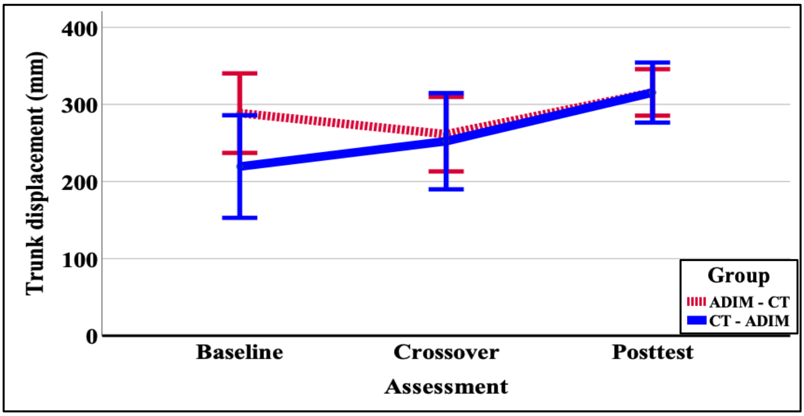

Figure 35. Linear graph representing trunk displacement

Table 58. Descriptive statistics of Trunk displacement

Group \ Assessment	Baseline	Crossover	Posttest
	Mean (SD)	Mean (SD)	Mean (SD)
ADIM-CT	288.78 (92.32)	261.46 (46.96)	315.66 (54.69)
CT-ADIM	219.47 (29.16)	252.32 (101.22)	315.45 (12.41)

ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver.

Table 59. Inferential statistics for kinematic variables

Effect		SS	DF	MS	F	P-value	μ^2
Within subject	Assessment	36112.22	2	18056.11	5.96	0.01*	0.30
	Assessment × Group	10594.30	2	5297.15	1.74	0.20	0.11
	Error	28					
Between group	Group	7733.87	1	7733.87	1.15	0.30	0.08
	Error	14					

SS, Sum of Squares; DF, Degrees of Freedom; MS, Mean Square; μ^2, Partial Eta Squared. * $P < 0.05$

3.2.5.4. Total time in contralateral direction (second)

Table 60 provided the descriptive statistics for total time. **Figure 36** illustrates a visual representation of these trends in a linear graph. Importantly, **Table 61** showed that no significant effects were observed for the main effect ($F_{2,28}$ = 0.94, P = 0.40) intervention ($F_{2,28}$ = 0.09, P = 0.92), or between groups ($F_{1,14}$ = 0.01, P = 0.91).

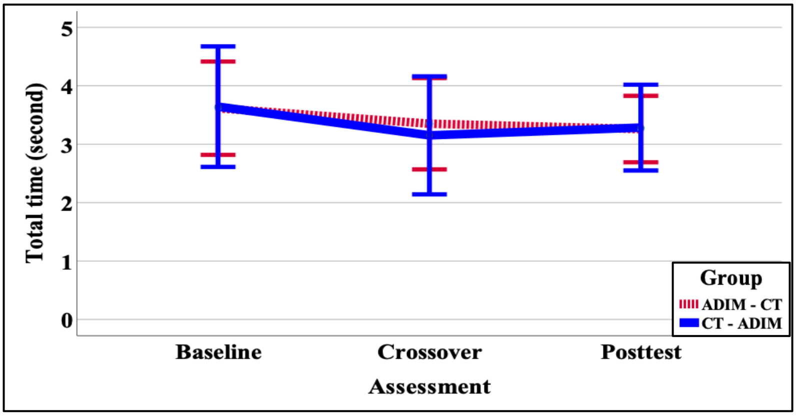

Figure 36. Linear graph representing total time

Table 60. Descriptive statistics of Total time

Group \ Assessment	Baseline	Crossover	Posttest
	Mean (SD)	Mean (SD)	Mean (SD)
ADIM-CT	3.62 (1.08)	3.35 (1.13)	3.26 (0.63)
`	3.64 (1.34)	3.15 (1.19)	3.28 (1.12)

ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver.

Table 61. Inferential statistics for kinematic variables

Effect		SS	DF	MS	F	P-value	μ^2
Within subject	Assessment	1.36	2	0.68	0.94	0.40	0.06
	Assessment × Group	0.13	2	0.06	0.09	0.92	0.01
	Error	28					
Between group	Group	0.03	1	0.03	0.01	0.91	0.001
	Error	14					

SS, Sum of Squares; DF, Degrees of Freedom; MS, Mean Square; μ^2, Partial Eta Squared.

3.2.5.5. Hand velocity in contralateral direction (mm/s)

Table 62 presented the descriptive statistics for total time. **Figure 37** provided a visual representation of these trends in a linear graph. It was worth nothing that **Table 63** revealed no statistically significant effects for the main effect ($F_{2,28} = 3.00$, $P = 0.07$) intervention ($F_{2,28} = 1.71$, $P = 0.20$), or between groups ($F_{1,14} = 0.13$, $P = 0.73$).

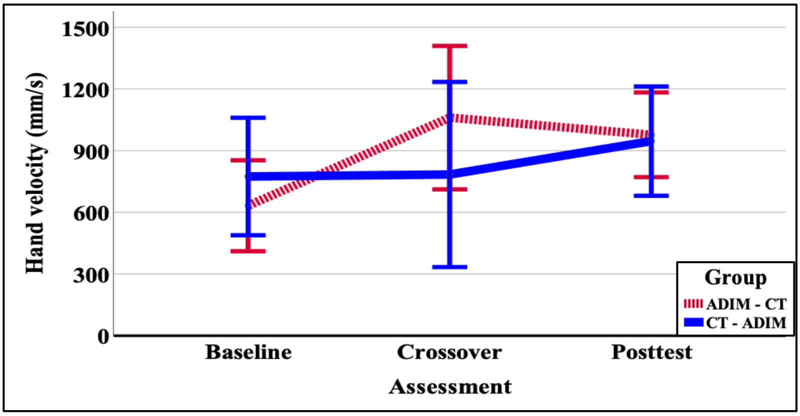

Figure 37. Linear graph representing hand velocity

Table 62. Descriptive statistics of Hand velocity

Group \ Assessment	Baseline	Crossover	Posttest
	Mean (SD)	Mean (SD)	Mean (SD)
ADIM-CT	632.46 (373.15)	1061.08 (607.20)	977.58 (327.61)
CT-ADIM	774.56 (217.87)	784.29 (277.36)	946.79 (254.82)

ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver.

Table 63. Inferential statistics for kinematic variables

Effect		SS	DF	MS	F	P-value	μ^2
Within subject	Assessment	582547.56	2	291273.78	3.00	0.07	0.18
	Assessment × Group	332342.70	2	166171.35	1.71	0.20	0.11
	Error	28					
Between group	Group	34230.02	1	34230.02	0.13	0.73	0.01
	Error	14					

SS, Sum of Squares; DF, Degrees of Freedom; MS, Mean Square; μ^2, Partial Eta Squared.

3.2.5.6. Hand acceleration in contralateral direction (mm/s^2)

Table 64 provided the descriptive statistics for total time. **Figure 38** visually depicted these trends in a linear graph. Importantly, **Table 65** showed that no significant effects were observed for the main effect ($F_{2,28} = 1.48$, $P = 0.25$), intervention ($F_{2,28} = 0.94$, $P = 0.40$) and between groups ($F_{1,14} = 1.18$, $P = 0.30$).

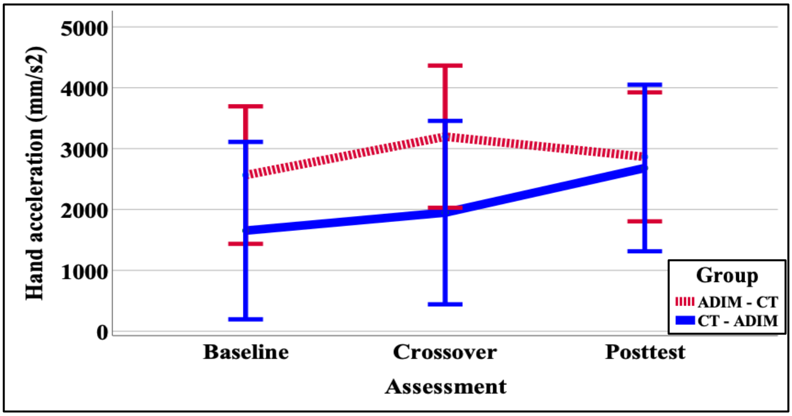

Figure 38. Linear graph representing hand acceleration

Table 64. Descriptive statistics of Hand acceleration

Group \ Assessment	Baseline	Crossover	Posttest
	Mean (SD)	Mean (SD)	Mean (SD)
ADIM-CT	2565.95 (2013.04)	3196.87 (1967.62)	2865.41 (1350.88)
CT-ADIM	1653.42 (683.62)	1949.26 (1150.83)	2681.82 (1883.06)

ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver.

Table 65. Inferential statistics for kinematic variables

Effect		SS	DF	MS	F	*P*-value	μ^2
Within subject	Assessment	3478754.87	2	1739377.43	1.48	0.25	0.10
	Assessment × Group	2219731.37	2	1109865.68	0.94	0.40	0.06
	Error	28					
Between group	Group	6866340.59	1	6866340.59	1.18	0.30	0.08
	Error	14					

SS, Sum of Squares; DF, Degrees of Freedom; MS, Mean Square; μ^2, Partial Eta Squared.

3.2.5.7. Elbow angular velocity in contralateral direction (rad/s)

Table 66 presented the descriptive statistics for elbow angular velocity. **Figure 39** provided a visual representation of these data in a linear graph. Importantly, **Table 67** indicated that no significant effects were detected for the main effect ($F_{2,28} = 2.10$, $P = 0.14$), intervention ($F_{2,28} = 0.84$, $P = 0.44$), or between groups ($F_{1,14} = 2.89$, $P = 0.11$).

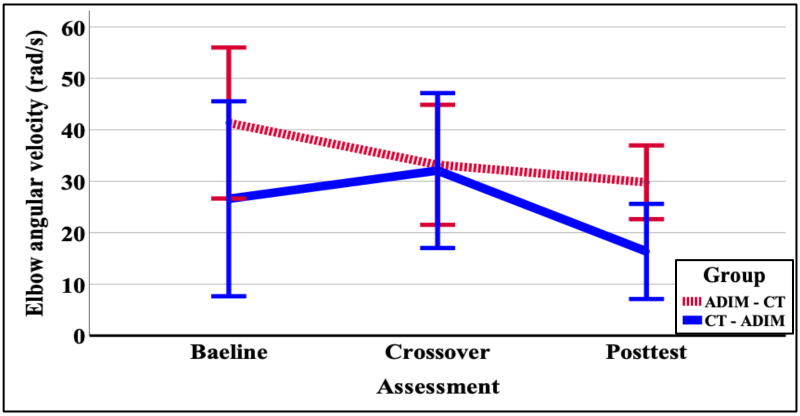

Figure 39. Linear graph representing elbow angular velocity

Table 66. Descriptive statistics of Elbow angular velocity

Group \ Assessment	Baseline	Crossover	Posttest
	Mean (SD)	Mean (SD)	Mean (SD)
ADIM-CT	41.33 (26.21)	33.20 (16.72)	29.80 (12.76)
CT-ADIM	26.59 (8.61)	32.08 (18.01)	16.36 (4.45)

ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver.

Table 67. Inferential statistics for kinematic variables

Effect		SS	DF	MS	F	P-value	μ^2
Within subject	Assessment	1057.98	2	528.99	2.10	0.14	0.13
	Assessment × Group	423.03	2	211.52	0.84	0.44	0.06
	Error	28					
Between group	Group	1072.64	1	1072.64	2.89	0.11	0.17
	Error	14					

SS, Sum of Squares; DF, Degrees of Freedom; MS, Mean Square; μ^2, Partial Eta Squared.

3.2.5.8. Elbow angular acceleration in contralateral direction (rad/s^2)

Table 68 provided the descriptive statistics for elbow angular acceleration. **Figure 40** visually represented these trends in a linear graph depicting elbow angular acceleration. **Table 69** illustrated a significant interaction between groups and assessments ($F_{2,28}$ = 9.04, P < 0.001). Additionally, a noteworthy difference between groups was observed ($F_{1,14}$ = 4.68, P = 0.048). Further investigating the interaction, a significant posttest between-group effect was found, with a mean difference of 289.47 (P = 0.002, CI 95% [126.10, 452.84]). Moreover, in the ADIM-CT group, a significant difference between posttest and baseline was noted, with a mean difference of 119.73 (P < 0.001, CI 95% [51.55, 187.90]). In the CT-ADIM group, there was also a significant difference between posttest and baseline assessments, with a mean difference of -113.20 (P = 0.01, CI 95% [-201.21,-25.19]), as detailed in **Table 70**.

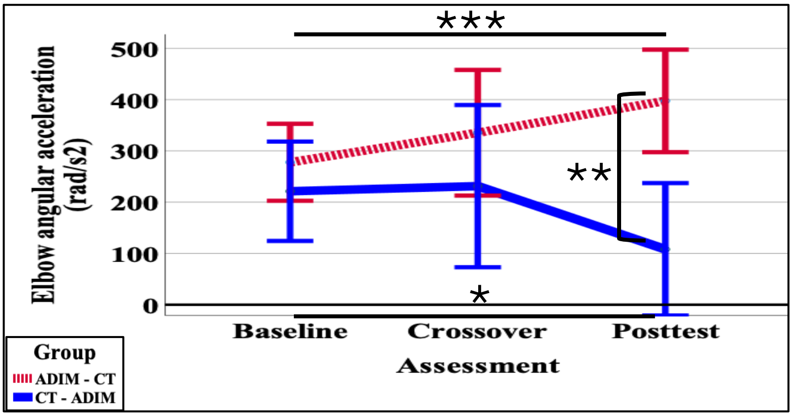

Figure 40. Linear graph representing elbow angular acceleration

* indicated post hoc simple t-test after significant effect for interaction.

* P < 0.05, ** P < 0.01, *** P < 0.05.

Table 68. Descriptive statistics of Elbow angular acceleration

Group \ Assessment	Baseline	Crossover	Posttest
	Mean (SD)	Mean (SD)	Mean (SD)
ADIM-CT	277.87 (129.97)	335.49 (208.41)	397.60 (183.62)
CT-ADIM	221.33 (62.30)	231.30 (115.00)	108.13 (15.13)

ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver.

Table 69. Inferential statistics for kinematic variables

Effect		SS	DF	MS	F	*P*-value	μ^2
Within subject	Assessment	10422.88	2	5211.44	0.83	0.45	0.06
	Assessment × Group	113569.90	1.49	76268.71	9.04	< 0.001***	0.39
	Error			28			
Between group	Group	253346.21	1	253346.21	4.68	0.048*	0.25
	Error			14			

SS, Sum of Squares; DF, Degrees of Freedom; MS, Mean Square; μ^2, Partial Eta Squared. * $P < 0.05$, *** $P < 0.001$

Table 70. Post-hoc with Bonferroni simple *t*-test

Between/Within Subject	Assessment	Mean difference	*P*-value	95% CI	
				Lower	Upper
Between-group	Baseline	56.54	0.34	-66.02	179.11
	Crossover	104.18	0.28	-95.93	304.30
	Posttest	289.47	0.002**	126.10	452.84
ADIM - CT	Baseline - crossover	-57.61	0.62	-176.18	60.95
	Crossover - Posttest	-62.11	0.30	-157.66	33.43
	Posttest - Baseline	119.73	< 0.001***	51.55	187.90

CT - ADIM	Baseline - crossover	-9.97	1.00	-163.04	143.09
	Crossover - Posttest	123.17	0.05	-0.18	246.52
	Posttest - Baseline	-113.20	0.01*	-201.21	-25.19

ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver. CI, Confidence Interval, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

3.2.5.9. Movement unit in contralateral direction (n)

Table 71 displayed the descriptive statistics for movement units. **Figure 41** provided a visual representation of these trends in a linear graph representing movement unit. In **Table 72**, it revealed inferential statistics. There were no significant main effect for assessment factor ($F_{1.40,\ 19.66}$ = 3.56, P = 0.06), between groups ($F_{1,14}$= 0.68, P = 0.43), nor interaction ($F_{1.40,\ 19.66}$ = 0.47, P = 0.56).

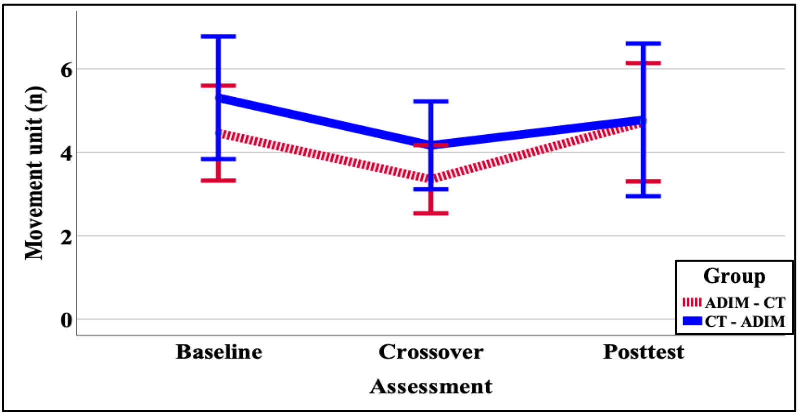

Figure 41. Linear graph representing movement unit

Table 71. Descriptive statistics of Movement unit

Group \ Assessment	Baseline	Crossover	Posttest
	Mean (SD)	Mean (SD)	Mean (SD)
ADIM-CT	4.46 (1.60)	3.35 (1.03)	4.72 (2.08)
CT-ADIM	5.31 (1.81)	4.17 (1.46)	4.78 (2.12)

ADIM-CT, Abdominal Drawing-In Maneuver following by Conventional Therapy; CT- ADIM, Conventional therapy following by Abdominal Drawing-In Maneuver.

Table 72. Inferential statistics for kinematic variables

Effect		SS	DF	MS	F	P-value	μ^2
Within subject	Assessment	11.28	1.40	8.03	3.56	0.06	0.20
	Assessment × Group	1.50	1.40	1.06	0.47	0.56	0.03
	Error	19.66					
Between group	Group	3.69	1	3.69	0.68	0.43	0.05
	Error						

SS, Sum of Squares; DF, Degrees of Freedom; MS, Mean Square; μ^2, Partial Eta Squared.

DISCUSSION

4. DISCUSSION

4.1. Consideration of carryover and period effects

Utilizing a crossover design, we observed the presence of both carryover and period effects in both forward and contralateral directions. Certain variables, such as trunk displacement in the forward direction and elbow angular acceleration in the contralateral direction, were unaffected by the washout, indicating a potential resilience to these effects. Our results demonstrated kinematic variables retaining their characteristics even after a one-month washout period, highlighting the persistence of both carryover and period effects. A washout period is required to eliminate any carryover effects (Lim & In, 2021; Sturdevant & Lumley, 2021). If carryover effects are detected, the typical approach is to treat the study as if it were a parallel group trial and confine the analysis to the first period alone (Hippisley-Cox et al., 1998; Lim & In, 2021). Additionally, we noted a significant period effect that influenced the specific order in the predetermined sequence. The period effect refers to the phenomenon where the treatment effect varies over time, leading to an interaction between treatment and time periods. This is more likely to occur when the treatment periods are extended (Li et al., 2015). The same treatment administered at two different time periods may yield different outcomes. Because the first and second treatments are inherently temporally separated, an observed effect may be contingent on the measurement period rather than the treatment itself (Lim & In, 2021). The ADIM-CT group demonstrated a notable enhancement in elbow extension, presenting a marked contrast to the relatively modest progress observed with conventional therapy. This substantial improvement may be attributed to period effect. Likewise, in the CT-ADIM group, there was an increase in hand velocity in the forward direction during the posttest compared to a similar pattern observed between baseline and crossover. This suggests the presence of a potential period effect about learning and adaptation. Our findings support the existence of a period effect. When examining the contralateral direction, the CT-ADIM group showed comparable effectiveness between ADIM exercise and conventional therapy. Notably, the ADIM-CT group demonstrated a significant increase in elbow angular acceleration at the posttest, potentially indicating a learning effect through enhanced movement execution.

4.2. General consideration

The objective of this study was to evaluate the effectiveness of ADIM exercise in patients with stroke in postural control and upper limb functional movement compared with conventional therapy. The findings of this study hold several important implications for stroke rehabilitation. The demonstrated effectiveness of the ADIM highlights its potential as a valuable addition to conventional therapy for chronic stroke participants. Our study employed quantitative measurements to evaluate the efficacy of the ADIM exercise. Specifically, numerical variables were utilized to enhance the objectivity of our findings. Despite stroke survivors engaging in the ADIM exercise for a brief period, we observed an enhancement in their functional movements during reaching tasks. Additionally, it is imperative to conduct a more extensive assessment over a prolonged duration through the ADIM exercise to provide a comprehensive quantitative evaluation.

4.2.1. Consideration of Forward direction

The observed enhancements in movement unit, particularly in the forward direction, underscore the practical benefits of incorporating ADIM exercise into rehabilitation protocols. Moreover, the increased elbow extension in within subject and reduced trunk dislocation between subjects suggest that ADIM contributes to improved performance in reaching tasks, potentially leading to greater functional independence for stroke survivors.

According to isokinetic study of Lum, et al. (2004), stroke survivors showed reduced ability to generate force for extending their muscles when the movement was faster. It might result from agonist activation weakness, antagonist co-contraction, and increased stretch-reflex excitability (Pan et al., 2018; Thrane et al., 2020). It is crucial to incorporate compensatory trunk movements into post-stroke movement patterns and assessment models (Murphy et al., 2011). When the elbow or shoulder movements are insufficient to reach the target, compensatory trunk movements increase (Thrane et al., 2018). In our study, the ADIM exercise within the group led to an increase in elbow extension. Specifically, Michaelsen & Levin (2004a) observed a notable enhancement of over 10 degrees ($P < 0.05$) in individuals with stroke who underwent trunk restraint training, as detailed in the initial report and Woodbury, et al. (2009)reported that trunk compensation restraint demonstrated elbow extension ($P = 0.022$). When comparing individuals who have had a stroke to those who are healthy, there are differences in the way their shoulder muscles are engaged during reaching movements. In healthy individuals, while upper limb activation primarily relies on the contralateral corticospinal pathway (Ferbert et al., 1992; Palmer & Ashby, 1992), middle part of the shoulder muscle (deltoid) is more active than the front part (anterior deltoid) ($P < 0.001$) (Subramaniam et al., 2019). However, individuals recovering from a stroke exhibit increased activity in both the front and middle parts of the deltoid during reaching. Notably, the compensatory mechanism observed in stroke survivors involves a heightened activation of the anterior deltoid during forward-reaching movements. This adjustment helps shift the arm's support against gravity toward the middle deltoid, facilitating the movement (Roh et al., 2013). Additionally, the enhanced elbow extension through ADIM exercise in within group, represents a promising approach to enhance upper limb function. However, no significant superiority was observed in shoulder flexion between the ADIM exercise group and the conventional therapy group. In individuals with stroke, from mild to severe synergies, there is an observed heightened activation of abnormal shoulder flexion (pectoralis major) compared with control group (Pan et al., 2018). Previous well designed randomized controlled trials consistently demonstrate that targeted training leads to improved elbow extension and reduced trunk motion, highlighting the importance of effective trunk control (Michaelsen et al., 2006a; Michaelsen & Levin, 2004b). It's a complex interplay of muscle activations and joint movements that allows for functional motion. This mechanism plays a crucial role in achieving trunk stability and control during the forward motion. This improvement was associated with enhanced trunk control facilitated by trunk restraint. Trunk stabilization exercise has impact on physical movements, encompassing both the trunk and limbs as a synergistic muscle (Yoon et al., 2015).

The improvements in movement unit align with the findings on movement time (Thrane et al., 2020). In our study, the group that engaged in ADIM exercise demonstrated greater improvement and a reduction in total movement time compared to those receiving conventional therapy. While no significant difference in total movement time was observed between groups, the pattern resembled that previous study (Thrane et al., 2020). Prior research has also emphasized a strong connection between movement unit and movement time (Murphy et al., 2011; Van Dokkum et al., 2014). Specifically, the movement time was associated with a recruitment of agonist motor units rather than an increase in antagonist co-contraction (Levin, 1996). In short, engaging in the ADIM exercise may positively influence upper limb synergy by enhancing core stability and promoting more efficient neuromuscular coordination. Additionally, neural impairments in achieving well-paced and smooth reaching motions are associated with the secondary motor areas of the brain (Buma et al., 2016). In our study, participants in the ADIM-CT group exhibited a moderate stroke, as indicated by a the Fugl-Meyer Assessment score below 60 (4.68 ± 1.66 in movement unit) at the baseline. This corresponds with the results of a prior study conducted by Pomeroy, et al. (2018) which focused on individuals with moderate stroke. Furthermore, participants with the Fugl-Meyer Assessment scores ranging from 32 to 57 demonstrated an average of 5.24 ± 2.90 movement unit. In comparison to a related study, Cirstea, et al. (2003) reported that 4.10 ± 1.80 movement units for moderate stroke. In contrast, healthy subjects consistently demonstrated 1.00 ± 0.00 movement units (Choi et al., 2023; Murphy et al., 2011). The reduction in spastic synergies is associated with a noticeable improvement in the smoothness of elbow angle transitions, as highlighted in the study by Pan, et al. (2018). Our investigation revealed that the ADIM-CT group exhibited a significant 20.94% decrease in movement units, while the CT-ADIM group demonstrated a corresponding increase of 25.80%. Importantly, a direct comparison between the groups showed that subjects undergoing ADIM exercise experienced a substantial improvement ($P < 0.02$). Notably, in the preliminary study, movement unit achieved through trunk control with trunk restraint experienced a decrease of 13.64% ($P < 0.001$) (Michaelsen et al., 2006b). This emphasized the efficacy of interventions targeting trunk control in enhancing overall movement quality.

As observed by previous studies, stroke survivors display extended deceleration phases featuring multiple peaks in hand velocity during movements, indicating disruptions in both feedforward and feedback control mechanisms and movement strategy (Murphy et al., 2011; Thrane et al., 2020). These insights contribute a deeper understanding of the complexities involved in motor control among individuals recovering from stroke. Our study further underscores the significance of sensorimotor control in neurorehabilitation, highlighting smoothness as a particular sensitive measure of progress. Given the superior effectiveness of ADIM exercise compared to conventional therapy in enhancing sensorimotor control across both intervention groups, there was strong justification for its incorporation into stroke rehabilitation programs. Building on Michaelsen & Levin. (2004a), restraining trunk displacement for trunk control resulted in a noteworthy reduction of -32mm ($P < 0.05$). Additionally, Woodbury, et al. (2009) reported a reliance on decrease trunk displacement ($P = 0.001$). These finding align with the results obtained in our study. Individuals severely affected by stroke may exhibit a concurrent deficit in controlling trunk, elbow, and shoulder movements (Thrane et al., 2018). In this preliminary study, the reaching coordination strategy is expected to demonstrate shoulder flexion and elbow extension rather than relying on trunk displacement (Woodbury et al., 2009). The combination of direction and beyond arm's length is considered through humeral flexion, scapular protraction, and trunk recruitment (Pain et al., 2015). In a study by Ferraro, et al. (2019), participants were categorized into age-specific healthy cohorts, and a 15-minute session of ADIM exercise was exhibited. In the results, there were no improvement in the functional reach task between-group ($P = 0.84$). However, there was a significant increase in sEMG values bilaterally for the transversus abdominis muscle in the between-group ($P = 0.004$). If the trunk muscles area weak, there may be an increased dependency on the elbow for stability. This is in contrast to situations where the upper limb struggles to effectively contribute to functional movement, prompting the trunk to naturally compensate. This dynamic is linked with heightened arm angular excursions and decrease in trunk recruitment (Levin et al., 2002). It suggests that the ADIM exercise may emphasize more controlled movement, relying less on compensatory motions and focusing on using the targeted muscle groups more effectively. Overall, these findings in forward direction contribute valuable insights into the potential benefits of ADIM exercises in enhancing functional movement and sensorimotor control for chronic stroke participants.

4.2.2. Consideration of Ipsilateral direction

Our findings indicate that the effectiveness of ADIM exercise in the ipsilateral direction did not surpass that of conventional therapy. Over time, a notable reduction in movement unit was observed across all groups, aligning with prior research indicating a decrease in multiple peak hand velocity with practice of reaching tasks. This particular direction led to heightened sensitivity in the stretching reflex, contributing to the development of an abnormal coordination pattern (Koh et al., 2023). Notably, Levin, et al. (2016) demonstrated that trunk recruitment was greater in the ipsilateral direction compared to the contralateral direction ($P < 0.001$), accompanied by a notable decrease in elbow extension ($P < 0.001$). Additionally, Robertson & Roby-Brami (2011) underscored a notable increase ($P < 0.01$) in trunk flexion, emphasizing its inclination towards the external target rather than the inner target.

Our study did not reveal a significant difference in intervention effectiveness between ADIM and CT intervention. The findings may not strongly support a significant impact of ADIM exercise on the heightened abnormal coordination of ipsilateral movement in the spastic upper extremity over a relatively short intervention period.

4.2.3. Consideration of Contralateral direction

After conducting a thorough analysis, we found no noticeable impact or effect in our results for this direction. Changes in kinematics may be attributed to reduced activation of agonist muscles and an improper engagement of antagonist muscles (Cirstea et al., 2003). In the study by Archambault, et al. (1999), individuals with chronic stroke exhibited reduced elbow extension ($P < 0.007$) compared to their healthy individuals when reaching toward the contralateral target, potentially destabilizing the endpoint trajectory. Raising the elbow may have been a means to bring the endpoint closer to the center of body, necessitating increased trunk involvement for precise targeting (Levin et al., 2016). The arrangement of the arm, involving horizontal adduction of the shoulder along with shoulder flexion and elbow extension, might have posed an instability challenge for individuals with stroke as the endpoint approached the target (Cirstea & Levin, 2000; Yoshioka et al., 2020). When movements are directed towards the contralateral target, afferent and efferent processes are coordinated across both cerebral hemispheres, potentially leading to a degradation of task-relevant information (Bagesteiro et al., 2020). Intricate biomechanical requirements could be responsible for the slower and less precise contralateral reaching (Carey et al., 1996). Our intervention did not demonstrate functional improvement by enhancing trunk control to increase accuracy in movements directed towards the contralateral direction.

4.3. Reaching beyond one's arm

When reaching for target beyond their arm, the trunk shifts from stabilizing posture to moving the hand (Kaminski et al., 1995). Extending the reaching beyond arm's length, necessitates active involvement of the trunk, particularly in the initial phase of reaching (Ma et al., 2017). Interestingly, the degree of trunk displacement or engagement is inversely correlated with the recruitment of shoulder and elbow joints (Levin et al., 2002; Wu et al., 2014). The trunk actively engages in the reaching process, collaborating with the redundant degrees of freedom (DoF) within the upper limb (Robertson & Roby-Brami, 2011). Specifically, it recruited more shoulder flexion, shoulder abduction, and elbow extension. The rise in shoulder abduction could potentially contribute to the reduction in elbow extension, as suggested by Lee, et al. (2009). Ma, et al. (2017) observed that positioning a target beyond arm's length might decrease the necessity for trunk flexion as a compensatory mechanism. This is attributed to an augmented contribution to endpoint displacement in the latter phase of the reaching motion. Nevertheless, other studies have documented instances where individuals exhibited excessive forward trunk displacement to bring their hand closer in various directions (Levin et al., 2016).

4.4. Consideration of the transversus abdominis muscle with connection tissue

It is evident that the ADIM exercise engages key deep core muscles, namely the Transversus Abdominis muscle and internal oblique muscles (Chon et al., 2012; Madokoro et al., 2020). These muscles collaboratively function to compress the abdominal cavity, thereby activating in direct mechanisms of the thoracolumbar fascia. This enhanced stability and posture can provide a more solid foundation for upper limb movements, including hand movements. It is evident that trunk and extremity muscles form a complex and dynamic system through fascial connections (Turan & Özyemişçi-Taşkıran, 2022), and this indicates that the Transversus Abdominis muscle has a limited capacity to stabilize on its own (Allison et al., 2008). A fundamental prerequisite for extremity movement is the stabilization of the pelvic and trunk regions (Endo & Sakamoto, 2014). Ferraro, et al. (2019) introduced the notion that while initial activation of the Transversus Abdominis muscle may facilitate forward-reaching movements, the act of reaching forward with the arm elevated to 90 degrees and the trunk gradually flexed triggers tension within the thoracolumbar fascia, leading to a limitation in further reach. Considering these foundational principles, our therapeutic strategy centered on the ADIM exercise aims to augment motor control and rectify movement compensation. Our findings strongly advocate that the ADIM exercise exerts a profoundly positive impact on the neurological dimension of feedforward trunk control. Additionally, it significantly enhances movement smoothness, demonstrating its pivotal role in promoting fluid and controlled motion. Beyond its contribution to overall upper limb movement, this dual effect on smoothness and stability highlights the exercise indispensable role in rehabilitation.

4.5. Limitations of this study

The main limitation in our study is related to the influence of a carryover effect and period effect. This phenomenon may be partially explained within the context of persistence of treatment, changes over time, and learned behavior (W. Y. Lim et al., 2021). The observed compound effect indicates that the impact of the intervention varies across directions and can may also be influenced by factors related to time. Secondly, four participants dropped out during the washout period, leading to a smaller sample size and uneven group distribution in period 2. Although initial sample size calculation was based on a total of 12 participants, it's important to recognize that when subjects drop out from the same group, this can affect the statistical power and the reliability of our results. Thirdly, we did not conduct various clinical assessments of Activities of Daily Living (ADL) at the baseline, such as the Barthel Index, functional Independence Measure, and Functional Reach Test. This omission limits our ability to compare and evaluate improvements in upper limb functionality for ADL. In the future, these findings may have important implications for designing interventions that can effectively assist patients with stroke in their rehabilitation. Understanding the specific compensatory movements required in each direction may contribute to the development of rehabilitation programs to address the unique needs of patients with stroke and promote their recovery.

CONCLUSIONS

5. CONCLUSIONS

The ADIM exercise is highly effective in enhancing postural control and upper extremity function compared to conventional therapy.

1. Elbow extension exhibited improvement when the exercise was performed in a forward direction, but regrettably, there was no discernible impact on shoulder flexion.
2. Trunk compensation was effectively reduced, highlighting the potential of ADIM exercise for enhancing movement integrity.
3. The overall movement time during the reaching phase did not show significant improvement with the ADIM exercise
4. Hand velocity and acceleration did not experience noteworthy enhancements through ADIM exercise.
5. Elbow angular velocity and acceleration also yielded inconclusive results.
6. The ADIM exercise demonstrated overwhelming efficacy in improving movement units when performed in a forward direction.

REFERENCES

6. REFERENCES

Allison, G. T., Morris, S. L., & Lay, B. (2008). Feedforward responses of transversus abdominis are directionally specific and act asymmetrically: Implications for core stability theories. *Journal of Orthopaedic and Sports Physical Therapy*, *38*(5), 228–237. https://doi.org/10.2519/jospt.2008.2703

Archambault P, Pigeon P, Feldman AG, & Levin MF. (1999). Recruitment and sequencing of different degrees of freedom during pointing movements involving the trunk in healthy and hemiparetic subjects. *Experimental Brain Research*, *126*(1), 55–67. https://doi.org/10.1007/s002210050716

Bagesteiro, L. B., Balthazar, R. B., & Hughes, C. M. L. (2020). Movement Kinematics and Interjoint Coordination Are Influenced by Target Location and Arm in 6-Year-Old Children. *Frontiers in Human Neuroscience*, *14*. https://doi.org/10.3389/fnhum.2020.554378

Bailey, R. R., Klaesner, J. W., & Lang, C. E. (2015). Quantifying Real-World Upper-Limb Activity in Nondisabled Adults and Adults with Chronic Stroke. *Neurorehabilitation and Neural Repair*, *29*(10), 969–978. https://doi.org/10.1177/1545968315583720

Benaim, C., Dominique, ;, Pérennou, A., Villy, J., Rousseaux, M., Jacques, ;, & Pelissier, Y. (1999). Validation of a Standardized Assessment of Postural Control in Stroke Patients The Postural Assessment Scale for Stroke Patients (PASS). *Stroke*, *30*(9), 1862–1868. http://ahajournals.org

Brunnstrom, S. (1966). MOTOR TESTING PROCEDURES IN HEMIPLEGIA Based on Sequential Recovery Stages. *Phys Ther*, *46*(4), 357–375. https://academic.oup.com/ptj/article/46/4/357/4616501

Buma, F. E., van Kordelaar, J., Raemaekers, M., van Wegen, E. E. H., Ramsey,

N. F., & Kwakkel, G. (2016). Brain activation is related to smoothness of upper limb movements after stroke. *Experimental Brain Research*, *234*(7), 2077–2089. https://doi.org/10.1007/s00221-015-4538-8

Burns, M. K., Patel, V., Florescu, I., Pochiraju, K. V., & Vinjamuri, R. (2017). Low-dimensional synergistic representation of bilateral reaching movements. *Frontiers in Bioengineering and Biotechnology*, *5*(2). https://doi.org/10.3389/fbioe.2017.00002

Cabanas-Valdés, R., Boix-Sala, L., Grau-Pellicer, M., Guzmán-Bernal, J. A., Caballero-Gómez, F. M., & Urrútia, G. (2021). The effectiveness of additional core stability exercises in improving dynamic sitting balance, gait and functional rehabilitation for subacute stroke patients (Core-trial): Study protocol for a randomized controlled trial. *International Journal of Environmental Research and Public Health*, *18*(12). https://doi.org/10.3390/ijerph18126615

Carey, D. P., Hargreaves, E. L., Goodale, M. A., Carey, D. R., Hargreaves, E. L., & Goodale, M. A. (1996). Reaching to ipsilateral or contralateral targets: within-hemisphere visuomotor processing cannot explain hemispatial differences in motor control. *Exp Brain Res*, *112*, 496–504.

CASEY HENLEY. (2021). PLANNING OF MOVEMENT. In *FOUNDATIONS OF NEUROSCIENCE* (pp. 313–315).

Che-Nan, H., & Rambely, A. S. (2022). Kinematic Analysis of Daily Activity of Touching Lateral Shoulder for Normal Subjects. *Applied Sciences (Switzerland)*, *12*(4). https://doi.org/10.3390/APP12042069

Chien, C. W., Hu, M. H., Tang, P. F., Sheu, C. F., & Hsieh, C. L. (2007). A Comparison of Psychometric Properties of the Smart Balance Master System and the Postural Assessment Scale for Stroke in People Who Have Had Mild Stroke. *Archives of Physical Medicine and Rehabilitation*, *88*(3), 374–380. https://doi.org/10.1016/j.apmr.2006.11.019

Choi, H., Park, D., Rha, D. W., Nam, H. S., Jo, Y. J., & Kim, D. Y. (2023). Kinematic analysis of movement patterns during a reach-and-grasp task in stroke patients. *Frontiers in Neurology*, *14*. https://doi.org/10.3389/fneur.2023.1225425

Chon, S. C., You, J. H., & Saliba, S. A. (2012). Cocontraction of ankle dorsiflexors and transversus abdominis function in patients with low back pain. *Journal of Athletic Training*, *47*(4), 379–389. https://doi.org/10.4085/1062-6050-47.4.12

Chung, E., Lee, B. H., & Hwang, S. (2014). Core stabilization exercise with real-time feedback for chronic hemiparetic stroke: A pilot randomized controlled trials. *Restorative Neurology and Neuroscience*, *32*(2), 313–321. https://doi.org/10.3233/RNN-130353

Cirstea, M. C., & Levin, M. F. (2000). Compensatory strategies for reaching in stroke. *Brain*, *123*, 940–953.

Cirstea, M. C., Mitnitski, A. B., Feldman, A. G., & Levin, M. F. (2003). Interjoint coordination dynamics during reaching in stroke. *Experimental Brain Research*, *151*(3), 289–300. https://doi.org/10.1007/s00221-003-1438-0

Clarkson HM. (2013). *Musculoskeletal assessment: joint range of motion and manual muscle strength* (3rd ed.). Lippincott Williams & Wilkins.

Conwit, R. A., Stashuk, D., Tracy, B., Mchugh, M., Brown, W. F., & Metter, E. J. (1999). The relationship of motor unit size, firing rate and force. *Clinical Neurophysiology*, *110*(7), 1270–1275.

Current, M. E., & Cert Yi Chung-hwi, T. P. (1995). Concurrent Validity, Inter-Tester and Intra-Tester Reliability of Goniometric Measurement of Active Elbow Range of Motion Using 4 Different Types of Measuring Instruments. *Physical Therapy Korea*, *2*(2).

Database Center for Life Science(DBCLS). (2015, September 13). *BA17 primary visual cortex - posterior view*. BodyParts3D.

https://commons.wikimedia.org/wiki/File:BA17_Primary_visual_cortex_-_posterior_view.png

De Los Reyes-Guzmán, A., Dimbwadyo-Terrer, I., Trincado-Alonso, F., Monasterio-Huelin, F., Torricelli, D., & Gil-Agudo, A. (2014). Quantitative assessment based on kinematic measures of functional impairments during upper extremity movements: A review. *Clinical Biomechanics*, *29*(7), 719–727. https://doi.org/10.1016/j.clinbiomech.2014.06.013

Dean, C. M., Channon, E. F., & Hall, J. M. (2007). Sitting training early after stroke improves sitting ability and quality and carries over to standing up but not to walking: a randomised trial. *The Australian Journal of Physiotherapy*, *53*(2), 97–102. https://doi.org/10.1016/s0004-9514(07)70042-9

Demers, M., & Levin, M. F. (2017). Do Activity Level Outcome Measures Commonly Used in Neurological Practice Assess Upper-Limb Movement Quality? *Neurorehabilitation and Neural Repair*, *31*(7), 623–637. https://doi.org/10.1177/1545968317714576

Dos Santos, G. L., Moreira Da Silva, E. S., Desloovere, K., & Russo, T. L. (2019). Effects of elastic tape on kinematic parameters during a functional task in chronic hemiparetic subjects: A randomized sham-controlled crossover trial. *PLoS ONE*, *14*(1). https://doi.org/10.1371/journal.pone.0211332

Eliassen, J. C., Boespflug, E. L., Lamy, M., Allendorfer, J., Chu, W. J., & Szaflarski, J. P. (2008). Brain-mapping techniques for evaluating poststroke recovery and rehabilitation: A review. *Topics in Stroke Rehabilitation*, *15*(5), 427–450. https://doi.org/10.1310/tsr1505-427

Ellis, M. D., Schut, I., & Dewald, J. P. A. (2017). Flexion synergy overshadows flexor spasticity during reaching in chronic moderate to severe hemiparetic stroke. *Clinical Neurophysiology*, *128*(7), 1308–

1314. https://doi.org/10.1016/j.clinph.2017.04.028

Endo, Y., & Sakamoto, M. (2014). Correlation of Shoulder and Elbow Injuries with Muscle Tightness, Core Stability, and Balance by Longitudinal Measurements in Junior High School Baseball Players. *Physical Therapy Science*, *26*(5), 689–693.

Faries, M. D., Greenwood, M., & Fnsca, D. ; (2007). Core Training: Stabilizing the Confusion. © *National Strength and Conditioning Association*, *29*(2), 10–25.

Faul, F., Erdfelder, E., & Lang, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*, 175–191. https://doi.org/10.3758/BF03193146

Ferbert, A., Caramia, D., Priori, A., Bertolasi, L., & Rothwell, J. C. (1992). Cortical projection to erector spinae muscles in man as assessed by focal transcranial magnetic stimulation. In *Electroencephalography and clinical Neurophysiology* (Vol. 85).

Ferraro, R., Garman, S., Taylor, R., Parrott, J. S., & Kadlowec, J. (2019). The effectiveness of transverse abdominis training on balance, postural sway and core muscle recruitment patterns: a pilot study comparison across age groups. *Physical Therapy Science*, *31*(9), 729–737.

Filippo, T. R. M., Alfieri, F. M., Cichon, F. R., Imamura, M., & Battistella, L. R. (2015). Neuroplasticity and functional recovery in rehabilitation after stroke. *Acta Fisiátrica*, *22*(2). https://doi.org/10.5935/0104-7795.20150018

Floegel, M., Kasper, J., Perrier, P., & Kell, C. A. (2023). How the conception of control influences our understanding of actions. *Nature Reviews Neuroscience*, *24*(5), 313–329. https://doi.org/10.1038/s41583-023-00691-z

Fugl-Meyer AR, Jääskö L, Leyman I, Olsson S, & Steglind S. (1975). The post-stroke hemiplegic patient. 1. a method for evaluation of physical performance. *Scand J Rehabil Med*, *7*(1), 13–31.

Gajdosik, R. L., & Bohannon, R. W. (1987). Clinical measurement of range of motion. Review of goniometry emphasizing reliability and validity. *Physical Therapy*, *67*(12), 1867–1872. https://doi.org/10.1093/ptj/67.12.1867

Gera, G., McGlade, K. E., Reisman, D. S., & Scholz, J. P. (2016). Trunk muscle coordination during upward and downward reaching in stroke survivors. *Motor Control*, *20*(1), 50–69. https://doi.org/10.1123/mc.2014-0038

Gregson, J. M., Leathley, M., Moore, A. P., Sharma, A. K., Smith, T. L., & Watkins, C. L. (1999). Reliability of the Tone Assessment Scale and the Modified Ashworth Scale as Clinical Tools for Assessing Poststroke Spasticity. *Archives of Physical Medicine and Rehabilitation*, *80*(9), 1013–1016.

Haaland, K. Y., Mutha, P. K., Rinehart, J. K., Daniels, M., Cushnyr, B., & Adair, J. C. (2012). Relationship between arm usage and instrumental activities of daily living after unilateral stroke. *Archives of Physical Medicine and Rehabilitation*, *93*(11), 1957–1962.

Hallett, M., Aybek, S., Dworetzky, B. A., McWhirter, L., Staab, J. P., & Stone, J. (2022). Functional neurological disorder: new subtypes and shared mechanisms. *The Lancet Neurology*, *21*(6), 537–550. https://doi.org/10.1016/S1474-4422(21)00422-1

Hamilton, N., Weimar, W., & Luttgens, K. (2012). *Kinesiology : scientific basis of human motion.* McGraw-Hill.

Han, C. E., Kim, S., Chen, S., Lai, Y. H., Lee, J. Y., Osu, R., Winstein, C. J., & Schweighofer, N. (2013). Quantifying arm nonuse in individuals poststroke. *Neurorehabilitation and Neural Repair*, *27*(5), 439–447. https://doi.org/10.1177/1545968312471904

Hanna-Pladdy, B. (2007). Dysexecutive syndromes in neurologic disease. *Journal of Neurologic Physical Therapy*, *31*(3), 119–127. https://doi.org/10.1097/NPT.0b013e31814a63c2

Haruyama, K., Kawakami, M., & Otsuka, T. (2017a). Effect of Core Stability Training on Trunk Function, Standing Balance, and Mobility in Stroke Patients: A Randomized Controlled Trial. *Neurorehabilitation and Neural Repair*, *31*(3), 240–249. https://doi.org/10.1177/1545968316675431

Haruyama, K., Kawakami, M., & Otsuka, T. (2017b). Effect of Core Stability Training on Trunk Function, Standing Balance, and Mobility in Stroke Patients: A Randomized Controlled Trial. *Neurorehabilitation and Neural Repair*, *31*(3), 240–249. https://doi.org/10.1177/1545968316675431

Herbort, O., Butz, M. V, & Hoffmann, J. (2008, April). Multimodal Goal Representations and Feedback in Hierarchical Motor Control. *International Conference on Cognitive Systems*.

Hippisley-Cox, J., Fielding, K., & Pringle, M. (1998). General practice Depression as a risk factor for ischaemic heart disease in men: population based case-control study. *BMJ*, *316*, 1714–1719. www.bmj.com

Hodges, P. W., & Moseley, G. L. (2003). Pain and motor control of the lumbopelvic region: Effect and possible mechanisms. In *Journal of Electromyography and Kinesiology* (Vol. 13, Issue 4, pp. 361–370). Elsevier Ltd. https://doi.org/10.1016/S1050-6411(03)00042-7

Holmes, N. P., Calvert, G. A., & Spence, C. (2009). Multimodal Integration. In *Encyclopedia of Neuroscience* (pp. 2457–2461). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-29678-2_3640

Howe, T. E., Taylor, I., Finn, P., & Jones, H. (2005). Lateral weight transference exercises following acute stroke: A preliminary study of clinical effectiveness. *Clinical Rehabilitation*, *19*(1), 45–53. https://doi.org/10.1191/0269215505cr786oa

Hui C, Tadi P, & Patti L. (2023). Ischemic Stroke. In *StatPearls*. https://www.ncbi.nlm.nih.gov/books/NBK499997/?report=reader

International Classification of Diseases 11th Revision. (2023, January). *ICD-11 for Mortality and Morbidity Statistics*. World Health Organization. https://icd.who.int/browse11/l-m/en#/http://id.who.int/icd/entity/%20%20843843448?view=G1

Javed K, Reddy V, & Lui F. (2022). *Neuroanatomy, Lateral Corticospinal Tract*.

Javed K, Reddy V, & Lui F. (2023). Neuroanatomy, Lateral Corticospinal Tract. In *StatPearls* (StatPearls).

Johansson, B. B. (2000). Brain Plasticity and Stroke Rehabilitation The Willis Lecture. In *stroke* (Vol. 31, Issue 1). http://ahajournals.org

Jones, T. A. (2017). Motor compensation and its effects on neural reorganization after stroke. *Nature Reviews Neuroscience*, *18*(5), 267–280. https://doi.org/10.1038/nrn.2017.26

Jones, T. A., & Jefferson, S. C. (2011). Reflections of experience-expectant development in repair of the adult damaged brain. *Developmental Psychobiology*, *53*(5), 466–475. https://doi.org/10.1002/dev.20557

Karthikbabu, S., Chakrapani, M., Ganeshan, S., Rakshith, K. C., Nafeez, S., & Prem, V. (2012). A review on assessment and treatment of the trunk in stroke: A need or luxury. *Neural Regeneration Research*, *7*(25), 1974–1977. https://doi.org/10.3969/j.issn.1673-5374.2012.25.008

Kelli, A., Kellis, E., Galanis, N., Dafkou, K., Sahinis, C., & Ellinoudis, A. (2020). Transversus abdominis thickness at rest and exercise in individuals with poststroke hemiparesis. *Sports*, *8*(6). https://doi.org/10.3390/sports8060086

Kim, H., Her, J., Ko, J., Park, D.-S., Woo, J.-H., & Choi, Y. (2012). Reliability, Concurrent Validity, and Responsiveness of the Fugl-Meyer Assessment (FMA) for Hemiplegic Patients. *Journal of Physical Therapy Science*, *24*, 893–899.

Ko, E. J., Chun, M. H., Kim, D. Y., Yi, J. H., Kim, W., & Hong, J. (2016). The additive effects of core muscle strengthening and trunk nmes on trunk balance in stroke patients. *Annals of Rehabilitation Medicine*, *40*(1), 142–151. https://doi.org/10.5535/arm.2016.40.1.142

Koh, K., Oppizzi, G., Kehs, G., & Zhang, L. Q. (2023). Abnormal coordination of upper extremity during target reaching in persons post stroke. *Scientific Reports*, *13*(1). https://doi.org/10.1038/s41598-023-39684-4

Kołcz, A., Urbacka-Josek, J., Kowal, M., Dymarek, R., & Paprocka-Borowicz, M. (2020). Evaluation of postural stability and transverse abdominal muscle activity in overweight post-stroke patients: A prospective, observational study. *Diabetes, Metabolic Syndrome and Obesity*, *13*, 451–462. https://doi.org/10.2147/DMSO.S235015

Kuriakose, D., & Xiao, Z. (2020). Pathophysiology and treatment of stroke: Present status and future perspectives. *International Journal of Molecular Sciences*, *21*(20), 1–24. https://doi.org/10.3390/ijms21207609

Kwakkel, G., Van Wegen, E. E. H., Burridge, J. H., Winstein, C. J., van Dokkum, L. E. H., Alt Murphy, M., Levin, M. F., & Krakauer, J. W. (2019). Standardized measurement of quality of upper limb movement after stroke: Consensus-based core recommendations from the Second Stroke Recovery and Rehabilitation Roundtable. *International Journal of Stroke*, *14*(8), 783–791. https://doi.org/10.1177/1747493019873519

Lalonde, R., & Strazielle, C. (2007). Brain regions and genes affecting postural control. In *Progress in Neurobiology* (Vol. 81, Issue 1, pp. 45–60). https://doi.org/10.1016/j.pneurobio.2006.11.005

Lang, C. E., Bland, M. D., Bailey, R. R., Schaefer, S. Y., & Birkenmeier, R. L. (2013). Assessment of upper extremity impairment, function, and activity after stroke: Foundations for clinical decision making. *Journal of Hand Therapy*, *26*(2), 104–115. https://doi.org/10.1016/j.jht.2012.06.005

Lee, G., An, S., Lee, Y., Lee, D., & Park, D.-S. (2015). Predictive factors of hypertonia in the upper extremity of chronic stroke survivors. *Journal of Physical Therapy Science*, *27*(8), 2545–2549.

Lee, S., Yao, J., Acosta, A. M., & Dewald, J. A. (2009). The Effects of Asymmetric Tonic Neck Reflex during Reaching Movement following Stroke: Preliminary Results. *Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Annual International Conference*, 1581–1584.

Levin, M. F. (1996). Interjoint coordination during pointing movements is disrupted in spastic hemiparesis. *Brain: A Journal off Neurology*, *119*, 281–293. https://academic.oup.com/brain/article/119/1/281/338168

Levin, M. F., Kleim, J. A., & Wolf, S. L. (2009). What do motor “recovery” and “compensationg” mean in patients following stroke? *Neurorehabilitation and Neural Repair*, *23*(4), 313–319. https://doi.org/10.1177/1545968308328727

Levin, M. F., Liebermann, D. G., Parmet, Y., & Berman, S. (2016). Compensatory Versus Noncompensatory Shoulder Movements Used for Reaching in Stroke. *Neurorehabilitation and Neural Repair*, *30*(7), 635–646. https://doi.org/10.1177/1545968315613863

Levin, M. F., Michaelsen, S. M., Cirstea, C. M., & Roby-Brami, A. (2002). Use of the trunk for reaching targets placed within and beyond the reach in adult hemiparesis. *Experimental Brain Research*, *143*(2), 171–180. https://doi.org/10.1007/s00221-001-0976-6

Li, T., Yu, T., Hawkins, B. S., & Dickersin, K. (2015). Design, analysis, and reporting of crossover trials for inclusion in a meta-analysis. *PLoS ONE*, *10*(8). https://doi.org/10.1371/journal.pone.0133023

Lim, C. Y., & In, J. (2021). Considerations for crossover design in clinical study. *Korean Journal of Anesthesiology*, *74*(4), 293–299. https://doi.org/10.4097/KJA.21165

Lum, P. S., Patten, C., Kothari, D., & Yap, R. (2004). Effects of velocity on maximal torque production in poststroke hemiparesis. *Muscle and Nerve*, *30*(6), 732–742. https://doi.org/10.1002/mus.20157

Ma, H. I., Lin, K. C., Hsieh, F. H., Chen, C. L., Tang, S. F., & Wu, C. Y. (2017). Kinematic Manifestation of Arm-Trunk Performance during Symmetric Bilateral Reaching after Stroke: Within vs. beyond Arm's Length. *American Journal of Physical Medicine and Rehabilitation*, *96*(3), 146–151. https://doi.org/10.1097/PHM.0000000000000554

Madokoro, S., Yokogawa, M., & Miaki, H. (2020). Effect of the abdominal draw-in maneuver and bracing on abdominal muscle thickness and the associated subjective difficulty in healthy individuals. *Healthcare (Switzerland)*, *8*(4). https://doi.org/10.3390/healthcare8040496

Marshall, P., & Murphy, B. (2003). The validity and reliability of surface EMG to assess the neuromuscular response of the abdominal muscles to rapid limb movement. *Journal of Electromyography and Kinesiology*, *13*(5), 477–489. https://doi.org/10.1016/S1050-6411(03)00027-0

McMorland, A. J. C., Runnalls, K. D., & Byblow, W. D. (2015). A neuroanatomical framework for upper limb synergies after stroke. *Frontiers in Human Neuroscience*, *9*(FEB). https://doi.org/10.3389/fnhum.2015.00082

Messier, S., Bourbonnais, D., Desrosiers, J., & Roy, Y. (2005). Weight-bearing on the lower limbs in a sitting position during bilateral movement of the upper limbs in post-stroke hemiparetic subjects.

Journal of Rehabilitation Medicine, *37*(4), 242–246. https://doi.org/10.1080/16501970510026007

Michaelsen, S. M., Dannenbaum, R., & Levin, M. F. (2006a). Task-specific training with trunk restraint on arm recovery in stroke: Randomized control trial. *Stroke*, *37*(1), 186–192. https://doi.org/10.1161/01.STR.0000196940.20446.c9

Michaelsen, S. M., Dannenbaum, R., & Levin, M. F. (2006b). Task-specific training with trunk restraint on arm recovery in stroke: Randomized control trial. *Stroke*, *37*(1), 186–192. https://doi.org/10.1161/01.STR.0000196940.20446.c9

Michaelsen, S. M., Jacobs, S., Roby-Brami, A., & Levin, M. F. (2004). Compensation for distal impairments of grasping in adults with hemiparesis. *Experimental Brain Research*, *157*(2), 162–173. https://doi.org/10.1007/s00221-004-1829-x

Michaelsen, S. M., & Levin, M. F. (2004a). Short-term effects of practice with trunk restraint on reaching movements in patients with chronic stroke: A controlled trial. *Stroke*, *35*(8), 1914–1919. https://doi.org/10.1161/01.STR.0000132569.33572.75

Michaelsen, S. M., & Levin, M. F. (2004b). Short-term effects of practice with trunk restraint on reaching movements in patients with chronic stroke: A controlled trial. *Stroke*, *35*(8), 1914–1919. https://doi.org/10.1161/01.STR.0000132569.33572.75

Miyake, Y., Kobayashi, R., Kelepecz, D., & Nakajima, M. (2013). Core exercises elevate trunk stability to facilitate skilled motor behavior of the upper extremities. *Journal of Bodywork and Movement Therapies*, *17*(2), 259–265. https://doi.org/10.1016/j.jbmt.2012.06.003

Monjo, H., Fukumoto, Y., Asai, T., & Shuntoh, H. (2018). Muscle thickness and echo intensity of the abdominal and lower extremity muscles in stroke survivors. *Journal of Clinical Neurology (Korea)*, *14*(4), 549–

554. https://doi.org/10.3988/jcn.2018.14.4.549

Montaño, A., Hanley, D. F., & Hemphill, J. C. (2021). Hemorrhagic stroke. In *Handbook of Clinical Neurology* (Vol. 176, pp. 229–248). Elsevier B.V. https://doi.org/10.1016/B978-0-444-64034-5.00019-5

Murphy, M. A., Willén, C., & Sunnerhagen, K. S. (2011). Kinematic variables quantifying upper-extremity performance after stroke during reaching and drinking from a glass. *Neurorehabilitation and Neural Repair*, *25*(1), 71–80. https://doi.org/10.1177/1545968310370748

Nakayama, H., Jørgensen, H. S., Raaschou, H. O., & Olsen, T. S. (1994). Compensation in recovery of upper extremity function after stroke: the Copenhagen Stroke Study. *Archives of Physical Medicine and Rehabilitation*, *75*(8), 852–857.

Navarro-Orozco, D., & Sánchez-Manso, J. C. (2023). Neuroanatomy, Middle Cerebral Artery. In *StatPearls* (StatPearls).

Nejati, V., Majdi, R., Salehinejad, M. A., & Nitsche, M. A. (2021). The role of dorsolateral and ventromedial prefrontal cortex in the processing of emotional dimensions. *Scientific Reports*, *11*(1). https://doi.org/10.1038/s41598-021-81454-7

Pain, L. M., Baker, R., Richardson, D., & Agur, A. M. R. (2015). Effect of trunk-restraint training on function and compensatory trunk, shoulder and elbow patterns during post-stroke reach: A systematic review. *Disability and Rehabilitation*, *37*(7), 553–562. https://doi.org/10.3109/09638288.2014.932450

Palmer, E., & Ashby, P. (1992). CORTICOSPINAL PROJECTIONS TO UPPER LIMB MOTONEURONES IN HUMANS. In *Journal of Physiology* (Vol. 448).

Pan, B., Sun, Y., Xie, B., Huang, Z., Wu, J., Hou, J., Liu, Y., Huang, Z., & Zhang, Z. (2018). Alterations of muscle synergies during voluntary arm reaching movement in subacute stroke survivors at different levels of impairment. *Frontiers in Computational Neuroscience*, *12*. https://doi.org/10.3389/fncom.2018.00069

Park, D.-J., & Lee, S.-K. (2013). What is a Suitable Pressure for the Abdominal Drawing-in Maneuver in the Supine Position Using a Pressure Biofeedback Unit? *J.Phys.Ther.Sci*, *25*, 527–530.

Park, S.-D., & Yu, S.-H. (2013). The effects of abdominal draw-in maneuver and core exercise on abdominal muscle thickness and Oswestry disability index in subjects with chronic low back pain. *Journal of Exercise Rehabilitation*, *9*(2), 286–291. https://doi.org/10.12965/jer.130012

Pomeroy, V. M., Kennedy, N. C., Roh, J., Hussain, N., Murphy, M. A., & Sunnerhagen, K. S. (2018). Upper limb Kinematics in stroke and healthy controls Using Target-to-Target Task in Virtual reality. *Frontiers in Neurology*, *9*(300), 1. https://doi.org/10.3389/fneur.2018.00300

Poole, J. L., Sadek, J., & Haaland, K. Y. (2009). Ipsilateral Deficits in 1-Handed Shoe Tying After Left or Right Hemisphere Stroke. *Archives of Physical Medicine and Rehabilitation*, *90*(10), 1800–1805. https://doi.org/10.1016/j.apmr.2009.03.019

Raghavan, P. (2015). Upper Limb Motor Impairment After Stroke. *Physical Medicine and Rehabilitation Clinics of North America*, *26*(4), 599–610. https://doi.org/10.1016/j.pmr.2015.06.008

Ressman, J., Grooten, W. J. A., & Rasmussen-Barr, E. (2021). Visual assessment of movement quality: a study on intra- and interrater reliability of a multi-segmental single leg squat test. *BMC Sports Science, Medicine and Rehabilitation*, *13*(1). https://doi.org/10.1186/s13102-021-00289-x

Rinehart, J. K., Singleton, R. D., Adair, J. C., Sadek, J. R., & Haaland, K. Y. (2009). Arm use after left or right hemiparesis is influenced by hand preference. *Stroke*, *40*(2), 545–550.

https://doi.org/10.1161/STROKEAHA.108.528497

Robertson, J. V. G., & Roby-Brami, A. (2011). The trunk as a part of the kinematic chain for reaching movements in healthy subjects and hemiparetic patients. *Brain Research*, *1382*, 137–146. https://doi.org/10.1016/j.brainres.2011.01.043

Roh, J., Rymer, W. Z., Perreault, E. J., Yoo, S. B., & Beer, R. F. (2013). Alterations in upper limb muscle synergy structure in chronic stroke survivors. *J Neurophysiol*, *109*, 768–781. https://doi.org/10.1152/jn.00670.2012.-Previous

Saes, M., Mohamed Refai, M. I., van Beijnum, B. J. F., Bussmann, J. B. J., Jansma, E. P., Veltink, P. H., Buurke, J. H., van Wegen, E. E. H., Meskers, C. G. M., Krakauer, J. W., & Kwakkel, G. (2022). Quantifying Quality of Reaching Movements Longitudinally Post-Stroke: A Systematic Review. *Neurorehabilitation and Neural Repair*, *36*(3), 183–207. https://doi.org/10.1177/15459683211062890

Saeys, W., Vereeck, L., Truijen, S., Lafosse, C., Wuyts, F. P., & Van De Heyning, P. (2012). Randomized controlled trial of truncal exercises early after stroke to improve balance and mobility. *Neurorehabilitation and Neural Repair*, *26*(3), 231–238. https://doi.org/10.1177/1545968311416822

Sczesny-Kaiser, M., Trost, R., Aach, M., Schildhauer, T. A., Schwenkreis, P., & Tegenthoff, M. (2019). A Randomized and Controlled Crossover Study Investigating the Improvement of Walking and Posture Functions in Chronic Stroke Patients Using HAL Exoskeleton – The HALESTRO Study (HAL-Exoskeleton STROke Study). *Frontiers in Neuroscience*, *13*. https://doi.org/10.3389/fnins.2019.00259

Singh, R. E., Iqbal, K., White, G., & Hutchinson, T. E. (2018). A systematic review on muscle synergies: From building blocks of motor behavior to a neurorehabilitation tool. *Applied Bionics and Biomechanics*, *2018*.

https://doi.org/10.1155/2018/3615368

Sorinola, I. O., Powis, I., & White, C. M. (2014). Does additional exercise improve trunk function recovery in stroke patients? A meta-analysis. *NeuroRehabilitation*, *35*(2), 205–213. https://doi.org/10.3233/NRE-141123

Soto-Cámara, R., González-Bernal, J. J., González-Santos, J., Aguilar-Parra, J. M., Trigueros, R., & López-Liria, R. (2020). Age-related risk factors at the first stroke event. *Journal of Clinical Medicine*, *9*(7), 1–12. https://doi.org/10.3390/jcm9072233

Sternad, D., & Schaal, S. (1999). Segmentation of endpoint trajectories does not imply segmented control. *Experimental Brain Research*, *124*(1), 118–136. https://doi.org/10.1007/s002210050606

Sterr, A., Freivogel, S., & Schmalohr, D. (2002). Neurobehavioral aspects of recovery: assessment of the learned nonuse phenomenon in hemiparetic adolescents. *Archives of Physical Medicine and Rehabilitation*, *83*(12), 1726–1731.

Sturdevant, S. G., & Lumley, T. (2021). Statistical methods for testing carryover effects: A mixed effects model approach. *Contemporary Clinical Trials Communications*, *22*. https://doi.org/10.1016/j.conctc.2021.100711

Subramaniam, S., Varghese, R., & Bhatt, T. (2019). Influence of Chronic Stroke on Functional Arm Reaching: Quantifying Deficits in the Ipsilesional Upper Extremity. *Rehabilitation Research and Practice*, *2019*. https://doi.org/10.1155/2019/5182310

Subramanian, S. K., Yamanaka, J., Chilingaryan, G., & Levin, M. F. (2010). Validity of movement pattern kinematics as measures of arm motor impairment poststroke. *Stroke*, *41*(10), 2303–2308. https://doi.org/10.1161/STROKEAHA.110.593368

Suvada, K. C., Deol, J., Dewald, J. P. A., & Acosta, A. M. (2020). A Method for Quantifying Trunk Motor Control During Reaching in Individuals Post Hemiparetic Stroke. *Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Annual International Conference*, 3743–3746.

Takakusaki, K. (2013). Neurophysiology of gait: From the spinal cord to the frontal lobe. In *Movement Disorders* (Vol. 28, Issue 11, pp. 1483–1491). https://doi.org/10.1002/mds.25669

Taub, E., Uswatte, G., & Mark, V. W. (2014). The functional significance of cortical reorganization and the parallel development of CI therapy. *Frontiers in Human Neuroscience*, *8*(JUNE). https://doi.org/10.3389/fnhum.2014.00396

Thrane, G., Alt Murphy, M., & Sunnerhagen, K. S. (2018). Recovery of kinematic arm function in well-performing people with subacute stroke: A longitudinal cohort study. *J Neuroeng Rehabil*, *15*, 67. https://doi.org/10.1186/s12984-018-0409-4

Thrane, G., Sunnerhagen, K. S., Persson, H. C., Opheim, A., & Alt Murphy, M. (2019). Kinematic upper extremity performance in people with near or fully recovered sensorimotor function after stroke. *Physiotherapy Theory and Practice*, *35*(9), 822–832. https://doi.org/10.1080/09593985.2018.1458929

Thrane, G., Thrane, G., Sunnerhagen, K. S., & Murphy, M. A. (2020). Upper limb kinematics during the first year after stroke: The stroke arm longitudinal study at the University of Gothenburg (SALGOT). *Journal of Neuroengineering and Rehabilitation*, *17*(1). https://doi.org/10.1186/s12984-020-00705-2

Turan, Z., & Özyemişçi-Taşkıran, Ö. (2022). The effect of activation of thoracolumbar fascia on the thickness of abdominal muscles: An ultrasonographic study. *Turkish Journal of Physical Medicine and*

Rehabilitation, *68*(2), 169–174. https://doi.org/10.5606/tftrd.2022.7877

Van Criekinge, T., Truijen, S., Schröder, J., Maebe, Z., Blanckaert, K., van der Waal, C., Vink, M., & Saeys, W. (2019). The effectiveness of trunk training on trunk control, sitting and standing balance and mobility post-stroke: a systematic review and meta-analysis. *Clinical Rehabilitation*, *33*(6), 992–1002. https://doi.org/10.1177/0269215519830159

Van Dokkum, L., Hauret, I., Mottet, D., Froger, J., Métrot, J., & Laffont, I. (2014). The contribution of kinematics in the assessment of upper limb motor recovery early after stroke. *Neurorehabilitation and Neural Repair*, *28*(1), 4–12. https://doi.org/10.1177/1545968313498514

Verheyden, G., Nieuwboer, A., Mertin, J., Preger, R., Kiekens, C., & De Weerdt, W. (2004). The Trunk Impairment Scale: A new tool to measure motor impairment of the trunk after stroke. *Clinical Rehabilitation*, *18*(3), 326–334. https://doi.org/10.1191/0269215504cr733oa

Verheyden, G., Vereeck, L., Truijen, S., Troch, M., Lafosse, C., Saeys, W., Leenaerts, E., Palinckx, A., & De Weerdt, W. (2009). Additional exercises improve trunk performance after stroke: A pilot randomized controlled trial. *Neurorehabilitation and Neural Repair*, *23*(3), 281–286. https://doi.org/10.1177/1545968308321776

Wang, C.-H., Hsueh, I.-P., Sheu, C.-F., Yao, G., & Hsieh, C.-L. (2004). Psychometric Properties of 2 Simplified 3-Level Balance Scales Used for Patients With Stroke. *Physical Therapy*, *84*(5), 430–438. https://academic.oup.com/ptj/article/84/5/430/2805329

Wellek, S., & Blettner, M. (2012). Vom richtigen Umgang mit dem Crossover-Design in klinischen Studien: Teil 18 der Serie zur Bewertung wissenschaftlicher Publikationen. *Deutsches Arzteblatt International*, *109*(15), 276–281. https://doi.org/10.3238/arztebl.2012.0276

Woodbury, M. L., Howland, D. R., McGuirk, T. E., Davis, S. B., Senesac, C.

R., Kautz, S., & Richards, L. G. (2009). Effects of trunk restraint combined with intensive task practice on poststroke upper extremity reach and function: A pilot study. *Neurorehabilitation and Neural Repair*, *23*(1), 78–91. https://doi.org/10.1177/1545968308318836

World Health Organization Eastern Mediterranean Region. (2024, January). *Stroke cerebrovascular accident*. World Health Organization. https://www.emro.who.int/health-topics/stroke-cerebrovascular-accident/index.html

Wr, H., & Newton Bw. (2023). Neuroanatomy, Prefrontal Cortex. In *StatPearls*. https://www.ncbi.nlm.nih.gov/books/NBK499919/?report=reader

Wu, C.-Y., Liing, R.-J., Chen, H.-C., Chen, C.-L., & Lin, K.-C. (2014). Arm and Trunk Movement Kinematics During Seated Reaching Within and Beyond Arm's Length in People With Stroke: A Validity Study. *Physical Therapy*, *94*(6), 845–856. https://academic.oup.com/ptj/article/94/6/845/2735624

Yoon, M.-R., Choi, H.-S., & Shin, W.-S. (2015). Effects of the Abdominal Drawing-in Maneuver and the Abdominal Expansion Maneuver on Grip Strength, Balance and Pulmonary Function in Stroke Patients. *The Journal of Korean Physical Therapy*, *27*(3), 147–153. https://doi.org/10.18857/jkpt.27.3.147

Yoshioka, K., Watanabe, T., Yoshioka, M., Iino, K., Honda, K., Hayashida, K., & Kuninaka, Y. (2020). Direction-specific Disruption of Paretic Arm Movement in Post-stroke Patients. *Progress in Rehabilitation Medicine*, *5*(0), n/a. https://doi.org/10.2490/prm.20200009

APPENDIX

7. Appendix

Appendix 1. Institutional Review Boards (IRBs) approval

울산과학기술원 생명윤리위원회 Ulsan National Institute of Science and Technology Institutional Review Board	#Form10 (version 2.0, 2015.12)

Notice of Review Result

File No.	2022-43		**IRB Approval No.**	UNISTIRB-22-43-A
Project Name	(Korean) 선택적 체간 운동을 통한 뇌졸중의 reaching task 효과 분석			
	(English) The effects of reaching task following selective trunk stability exercise in chronic stroke survivors			
Principal Investigator	**Name**	Aenon Lee	**Position**	Student (Doctors course)
	Affiliation	UNIST/ Department of Mechanical Engineering		
Review Type	■ Initial Review ☐ Re-Review(Supplement, Objection, etc.) ☐ Interim Report ☐ Revision Review ☐ Other :			
Research Type	■ Human Subject Research ☐ Human Materials Research ☐ Other ( )			
Reveiwed Documents	■ Protocol Review Application ☐ Request for Protocol Revision ☐ Interim of Research Report ☐ End of Research Report ☐ Waiver of Informed Consent Explanatory Statement ☐ Waiver or Alternation of Documentation of Informed Consent Explanatory ■ Research Proposal (Version: 1.0) ■ Certificate of completion of bioethics training(All researchers) ■ Principal Investigator CV ■ Informed Consent and explanation (Version: 1.0) ☐ CRF(Case Report Form)/experiment daily record/Laboratory research note, etc ☐ Research funds detailed statement ☐ Compensation rule for the damage ■ Subjects recruitment documents ■ Research Tools ((Interview) Questionnaire, etc.) ☐ Information or materials provided to subjects except questionnaire ☐ MTA(Material Transfer Agreement) related to human materials ☐ IRB approval document(other institution) ☐ Response to Review Opinion ☐ Change Comparison Table ☐ Written oath of Academic advisor ☐ Other ( )			
Review Result	■ Approval ☐ Conditional Approval ☐ Review after revision ☐ Rejection ☐ Suspension or Holding			

울산과학기술원 생명윤리위원회 Ulsan National Institute of Science and Technology Institutional Review Board	#Form10 (version 2.0, 2015.12)

Approval Period	2022.07.19. ~ 2023.01.31.		
Review Opinion	-		
Review Date	2022.07.18.	**Interim Report Period**	N/A

★ All researchers should comply with the followings.

< Identified as review exemption research >

1. **In the case that identified as review exemption research, after confirmation date from the Committee research project can be performed according to the research protocol.**
2. **Even the review exemption research, if changes occur in research protocol to such an extent as to further review exemption is not possible, you must report to the Committee for review.**
3. **If Committee investigate or direct the research, you should actively cooperate and if Committee requires other matters related to research, you should report.**
4. **If the research is terminated, early termination of research, or suspending, research results are derived, please report to the Committee.**
5. **The result of review exemption check should not be used for any purpose other than scientific research without the prior permission of the Committee.**
6. **The following records relating to research should be kept for at least three years from the time of research termination.**
   - **(1) Research protocol and related review exemption confirmation.**
   - **(2) Written consent received from the subjects or Committee approval related to waiver of informed consent**
   - **(3) Collection, use and provision status of personal information**
   - **(4) Research completion report that includes research results**
   - **(5) Committee supervision and investigation results on the progress and results of research**

< Identified as review nonexempt research >

In the case that identified as review nonexempt research, research should be performed after achieving review from the Committee. You should submit Protocol Review Application and related documents to the Committee.

- **Ulsan Institute of Science and Technology Institutional Review Board is in compliance with Bioethics and Safety Act, and other relevant laws and respect Bioethics and research ethics, international norms and national norms.**

울산과학기술원 생명윤리위원회 Ulsan National Institute of Science and Technology Institutional Review Board	#Form10 (version 2.0, 2015.12)

- The information contained in this notice proves to be the same as the contents written and kept in Ulsan Institute of Science and Technology Institutional Review Board.
- Ulsan Institute of Science and Technology Institutional Review Board keep the copy of this notice.
- If you have objection to the result of Committee review described in this notice, you can submit an appeal by writing within the first two weeks from the date of notification of results. However, two or more times for the same issue should not appeal.
- Committee contact: 052)217-5214(Stem Cell Research Bldg. 109), leeyj0926@unist.ac.kr

UNIST Institutional Review Board notify that it determined as above on your request for confirmation.

2022. 07. 18.

U N I S T Institutional Review Board Chairperson Hyug Moo Kwon

Appendix 2. Informed consent form

Research Project Title :	Compensatory Kinematic Movements in Various Directions After Stroke
IRB Approval Number:	UNISTIRB-22-43-A

Do you consent to the secondary use of your research data (samples) or specimens for purp oses other than those stated in this informed consent form?

	Without additional consent, the data (samples) will be used in a state that includes personally identifiable information
	Without additional consent, the personally identifiable information in the data (samples) will be encoded, allowing for the possibility of tracing and identifying the research participants
	Without additional consent, the personally identifiable information in the data (samples) will be completely removed and utilized in a state where individual identification is not possible
	If the data (samples) are to be used for a different type of research, please proceed with obtaining my additional informed consent before proceeding
	I agree. I confirm that you do not consent to the use of the data (samples) for purposes other than those stated in the informed consent

I hereby confirm that I have no relationships that could influence my decision to participate in the research, between myself, the researchers, and UNIST

I affirm that I have received an explanation of this consent form from the research personnel, have personally read and understood it, and have received satisfactory answers to all my questions. I voluntarily and without any coercion sign this consent form to confirm my participation in this research

(The date and signature must be handwritten)

Participant	(Name)________	(Signature)_______________	(The date)___________
Legal Guardian (If necessary)	(Name)____________	(Signature)__________	(The date)___________
	(Relationship with legal guardian) ___________		
Applicant (If necessary)	(Name)____________	(Signature)__________	(The date)___________
Principal Investigator	(Name)____________	(Signature)__________	(The date)___________
Co-Investigator	(Name)____________	(Signature)__________	(The date)___________

This research will only utilize consent forms that have been reviewed and approved by the UNIST IRB(Institutional Review Board)

Appendix 3. Pre-interview

PRE-INTERVIEW

1	Name		
2	Birth date		
3	Height		
4	Weight		
5	Infarction / Hemorrhage		
6	Onset		
7	Arm length (affected side)		

Appendix 4. Fugl-Meyer Assessment Upper Extremity (FMA-UE)

FUGL-MEYER ASSESSMENT UPPER EXTREMITY (FMA-UE) Assessment of sensorimotor function

ID:
Date:
Examiner:

Fugl-Meyer AR, Jaasko L, Leyman I, Olsson S, Steglind S: The post-stroke hemiplegic patient. A method for evaluation of physical performance. Scand J Rehabil Med 1975, 7:13-31.

A. UPPER EXTREMITY, sitting position

I. Reflex activity	**none**	**can be elicited**
Flexors: biceps and finger flexors (at least one)	0	2
Extensors: triceps	0	2
Subtotal I (max 4)		

II. Volitional movement within synergies, without gravitational help			**none**	**partial**	**full**
Flexor synergy: Hand from contralateral knee to ipsilateral ear. From extensor synergy (shoulder adduction/ internal rotation, elbow extension, forearm pronation) to flexor synergy (shoulder abduction/ external rotation, elbow flexion, forearm supination).	Shoulder	retraction	0	1	2
		elevation	0	1	2
		abduction (90°)	0	1	2
		external rotation	0	1	2
	Elbow	flexion	0	1	2
	Forearm	supination	0	1	2
Extensor synergy: Hand from ipsilateral ear to the contralateral knee	Shoulder	adduction/internal rotation	0	1	2
	Elbow	extension	0	1	2
	Forearm	pronation	0	1	2
Subtotal II (max 18)					

III. Volitional movement mixing synergies, without compensation		**none**	**partial**	**full**
Hand to lumbar spine hand on lap	cannot perform or hand in front of ant-sup iliac spine hand behind ant-sup iliac spine (without compensation) hand to lumbar spine (without compensation)	0	1	2
Shoulder flexion 0°- 90° elbow at 0° pronation-supination 0°	immediate abduction or elbow flexion abduction or elbow flexion during movement flexion 90°, no shoulder abduction or elbow flexion	0	1	2
Pronation-supination elbow at 90° shoulder at 0°	no pronation/supination, starting position impossible limited pronation/supination, maintains starting position full pronation/supination, maintains starting position	0	1	2
Subtotal III (max 6)				

IV. Volitional movement with little or no synergy		**none**	**partial**	**full**
Shoulder abduction 0 - 90° elbow at 0° forearm neutral	immediate supination or elbow flexion supination or elbow flexion during movement abduction 90°, maintains extension and pronation	0	1	2
Shoulder flexion 90° - 180° elbow at 0° pronation-supination 0°	immediate abduction or elbow flexion abduction or elbow flexion during movement flexion 180°, no shoulder abduction or elbow flexion	0	1	2
Pronation/supination elbow at 0° shoulder at 30°- 90° flexion	no pronation/supination, starting position impossible limited pronation/supination, maintains start position full pronation/supination, maintains starting position	0	1	2
Subtotal IV (max 6)				

V. Normal reflex activity assessed only if full score of 6 points is achieved in part IV; compare with the unaffected side		**hyper**	**lively**	**normal**
Biceps, triceps, finger flexors	2 of 3 reflexes markedly hyperactive 1 reflex markedly hyperactive or at least 2 reflexes lively maximum of 1 reflex lively, none hyperactive	0	1	2
Subtotal V (max 2)				
Total A (max 36)				

B. WRIST support may be provided at the elbow to take or hold the starting position, no support at wrist, check the passive range of motion prior testing		none	partial	full
Stability at 15° dorsiflexion elbow at 90°, forearm pronated shoulder at 0°	less than 15° active dorsiflexion dorsiflexion 15°, no resistance tolerated maintains dorsiflexion against resistance	0	1	2
Repeated dorsifexion / volar flexion elbow at 90°, forearm pronated shoulder at 0°, slight finger flexion	cannot perform volitionally limited active range of motion full active range of motion, smoothly	0	1	2
Stability at 15° dorsiflexion elbow at 0°, forearm pronated slight shoulder flexion/abduction	less than 15° active dorsiflexion dorsiflexion 15°, no resistance tolerated maintains dorsiflexion against resistance	0	1	2
Repeated dorsifexion / volar flexion elbow at 0°, forearm pronated slight shoulder flexion/abduction	cannot perform volitionally limited active range of motion full active range of motion, smoothly	0	1	2
Circumduction elbow at 90°, forearm pronated shoulder at 0°	cannot perform volitionally jerky movement or incomplete complete and smooth circumduction	0	1	2
	Total B (max 10)			

C. HAND support may be provided at the elbow to keep 90° flexion, no support at the wrist, compare with unaffected hand, the objects are interposed, active grasp		none	partial	full
Mass flexion from full active or passive extension		0	1	2
Mass extension from full active or passive flexion		0	1	2
GRASP				
a. Hook grasp flexion in PIP and DIP (digits II-V), extension in MCP II-V	cannot be performed can hold position but weak maintains position against resistance	0	1	2
b. Thumb adduction 1-st CMC, MCP, IP at 0°, scrap of paper between thumb and 2-nd MCP joint	cannot be performed can hold paper but not against tug can hold paper against a tug	0	1	2
c. Pincer grasp, opposition pulpa of the thumb against the pulpa of 2-nd finger, pencil, tug upward	cannot be performed can hold pencil but not against tug can hold pencil against a tug	0	1	2
d. Cylinder grasp cylinder shaped object (small can) tug upward, opposition of thumb and fingers	cannot be performed can hold cylinder but not against tug can hold cylinder against a tug	0	1	2
e. Spherical grasp fingers in abduction/flexion, thumb opposed, tennis ball, tug away	cannot be performed can hold ball but not against tug can hold ball against a tug	0	1	2
	Total C (max 14)			

D. COORDINATION/SPEED, sitting, after one trial with both arms, eyes closed, tip of the index finger from knee to nose, 5 times as fast as possible		marked	slight	none
Tremor		0	1	2
Dysmetria	pronounced or unsystematic slight and systematic no dysmetria	0	1	2
		≥ 6s	**2 - 5s**	**< 2s**
Time start and end with the hand on the knee	6 or more seconds slower than unaffected side 2-5 seconds slower than unaffected side less than 2 seconds difference	0	1	2
	Total D (max 6)			

TOTAL A-D (max 66)	

Appendix 5. Trunk Impairment Scale (TIS)

Item			
	Static sitting balance		
1	Starting position	Patient falls or cannot maintain starting position for 10 seconds without arm support	☐ 0
		Patient can maintain starting position for 10 seconds	☐ 2
		If score = 0, then TIS total score = 0	
2	Starting position Therapist crosses the unaffected leg over the hemiplegic leg	Patient falls or cannot maintain sitting position for 10 seconds without arm support	☐ 0
		Patient can maintain sitting position for 10 seconds	☐ 2
3	Starting position Patient crosses the unaffected leg over the hemiplegic leg	Patient falls	☐ 0
		Patient cannot cross the legs without arm support on bed or table	☐ 1
		Patient crosses the legs but displaces the trunk more than 10 cm backwards or assists crossing with the hand	☐ 2
		Patient crosses the legs without trunk displacement or assistance	☐ 3
		Total static sitting balance	/7
	Dynamic sitting balance		
1	Starting position Patient is instructed to touch the bed or table with the hemiplegic elbow (by shortening the hemiplegic side and lengthening the unaffected side) and return to the starting position	Patient falls, needs support from an upper extremity or the elbow does not touch the bed or table	☐ 0
		Patient moves actively without help, elbow touches bed or table	☐ 1
		If score = 0, then items 2 and 3 score 0	
2	Repeat item 1	Patient demonstrates no or opposite shortening/lengthening	☐ 0
		Patient demonstrates appropriate shortening/lengthening	☐ 1
		If score = 0, then item 3 scores 0	
3	Repeat item 1	Patient compensates. Possible compensations are: (1) use of upper extremity, (2) contralateral hip abduction, (3) hip flexion (if elbow touches bed or table further then proximal half of femur), (4) knee flexion, (5) sliding of the feet	☐ 0
		Patient moves without compensation	☐ 1
4	Starting position Patient is instructed to touch the bed or table with the unaffected elbow (by shortening the unaffected side and lengthening the hemiplegic side) and return to the starting position	Patient falls, needs support from an upper extremity or the elbow does not touch the bed or table	☐ 0
		Patient moves actively without help, elbow touches bed or table	☐ 1
		If score = 0, then items 5 and 6 score 0	
5	Repeat item 4	Patient demonstrates no or opposite shortening/lengthening	☐ 0
		Patient demonstrates appropriate shortening/lengthening	☐ 1
		If score = 0, then item 6 scores 0	

Item			
6	Repeat item 4	Patient compensates. Possible compensations are: (1) use of upper extremity, (2) contralateral hip abduction, (3) hip flexion (if elbow touches bed or table further then proximal half of femur), (4) knee flexion, (5) sliding of the feet	☐ 0
		Patient moves without compensation	☐ 1
7	Starting position Patient is instructed to lift pelvis from bed or table at the hemiplegic side (by shortening the hemiplegic side and lengthening the unaffected side) and return to the starting position	Patient demonstrates no or opposite shortening/lengthening	☐ 0
		Patient demonstrates appropriate shortening/lengthening If score = 0, then item 8 scores 0	☐ 1
8	Repeat item 7	Patient compensates. Possible compensations are: (1) use of upper extremity, (2) pushing off with the ipsilateral foot (heel loses contact with the floor)	☐ 0
		Patient moves without compensation	☐ 1
9	Starting position Patient is instructed to lift pelvis from bed or table at the unaffected side (by shortening the unaffected side and lengthening the hemiplegic side) and return to the starting position	Patient demonstrates no or opposite shortening/lengthening	☐ 0
		Patient demonstrates appropriate shortening/lengthening If score = 0, then item 10 scores 0	☐ 1
10	Repeat item 9	Patient compensates. Possible compensations are: (1) use of upper extremities, (2) pushing off with the ipsilateral foot (heel loses contact with the floor)	☐ 0
		Patient moves without compensation	☐ 1
		Total dynamic sitting balance	/10
	Co-ordination		
1	Starting position Patient is instructed to rotate upper trunk 6 times (every shoulder should be moved forward 3 times), first side that moves must be hemiplegic side, head should be fixated in starting position	Hemiplegic side is not moved three times	☐ 0
		Rotation is asymmetrical	☐ 1
		Rotation is symmetrical If score = 0, then item 2 scores 0	☐ 2
2	Repeat item 1 within 6 seconds	Rotation is asymmetrical	☐ 0
		Rotation is symmetrical	☐ 1
3	Starting position Patient is instructed to rotate lower trunk 6 times (every knee should be moved forward 3 times), first side that moves must be hemiplegic side, upper trunk should be fixated in starting position	Hemiplegic side is not moved three times	☐ 0
		Rotation is asymmetrical	☐ 1
		Rotation is symmetrical If score = 0, then item 4 scores 0	☐ 2
4	Repeat item 3 within 6 seconds	Rotation is asymmetrical	☐ 0
		Rotation is symmetrical	☐ 1
		Total co-ordination	/6
		Total Trunk Impairment Scale	/23

Appendix 6. Postural Assessment Scale (PASS)

Maintaining a Posture

Give the subject instructions for each item as written below. When scoring the item, record the lowest response category that applies for each item.

1. Sitting Without Support

Examiner: Have the subject sit on a bench/mat without back support and with feet flat on the floor.

____(3) Can sit for 5 minutes without support
____(2) Can sit for more than 10 seconds without support
____(1) Can sit with slight support (for example, by 1 hand)
____(0) Cannot sit

2. Standing With Support

Examiner: Have the subject stand, providing support as needed. Evaluate only the ability to stand with or without support. Do not consider the quality of the stance.

____(3) Can stand with support of only 1 hand
____(2) Can stand with moderate support of 1 person
____(1) Can stand with strong support of 2 people
____(0) Cannot stand, even with support

3. Standing Without Support

Examiner: Have the subject stand without support. Evaluate only the ability to stand with or without support. Do not consider the quality of the stance.

____(3) Can stand without support for more than 1 minute and simultaneously perform arm movements at about shoulder level
____(2) Can stand without support for 1 minute or stands slightly asymmetrically
____(1) Can stand without support for 10 seconds or leans heavily on 1 leg
____(0) Cannot stand without support

4. Standing on Nonparetic Leg

Examiner: Have the subject stand on the nonparetic leg. Evaluate only the ability to bear weight entirely on the nonparetic leg. Do not consider how the subject accomplishes the task.

____(3) Can stand on nonparetic leg for more than 10 seconds
____(2) Can stand on nonparetic leg for more than 5 seconds
____(1) Can stand on nonparetic leg for a few seconds
____(0) Cannot stand on nonparetic leg

5. Standing on Paretic Leg

Examiner: Have the subject stand on the paretic leg. Evaluate only the ability to bear weight entirely on the paretic leg. Do not consider how the subject accomplishes the task.

____(3) Can stand on paretic leg for more than 10 seconds
____(2) Can stand on paretic leg for more than 5 seconds
____(1) Can stand on paretic leg for a few seconds
____(0) Cannot stand on paretic leg

Maintaining Posture SUBTOTAL ______

Changing a Posture

6. Supine to Paretic Side Lateral

Examiner: Begin with the subject in supine on a treatment mat. Instruct the subject to roll to the paretic side (lateral movement). Assist as necessary. Evaluate the subject's performance on the amount of help required. Do not consider the quality of performance.

____(3) Can perform without help
____(2) Can perform with little help
____(1) Can perform with much help
____(0) Cannot perform

7. Supine to Nonparetic Side Lateral

Examiner: Begin with the subject in supine on a treatment mat. Instruct the subject to roll to the nonparetic side (lateral movement). Assist as necessary. Evaluate the subject's performance on the amount of help required. Do not consider the quality of performance.

____(3) Can perform without help
____(2) Can perform with little help
____(1) Can perform with much help
____(0) Cannot perform

8. Supine to Sitting Up on the Edge of the Mat

Examiner: Begin with the subject in supine on a treatment mat. Instruct the subject to come to sitting on the edge of the mat. Assist as necessary. Evaluate the subject's performance on the amount of help required. Do not consider the quality of performance.

____(3) Can perform without help
____(2) Can perform with little help
____(1) Can perform with much help
____(0) Cannot perform

9. Sitting on the Edge of the Mat to Supine

Examiner: Begin with the subject sitting on the edge of a treatment mat. Instruct the subject to return to supine. Assist as necessary. Evaluate the subject's performance on the amount of help required. Do not consider the quality of performance.

____(3) Can perform without help
____(2) Can perform with little help
____(1) Can perform with much help
____(0) Cannot perform

10. Sitting to Standing Up

Examiner: Begin with the subject sitting on the edge of a treatment mat. Instruct the subject to stand up without support. Assist if necessary. Evaluate the subject's performance on the amount of help required.
Do not consider the quality of performance.

____(3) Can perform without help
____(2) Can perform with little help
____(1) Can perform with much help
____(0) Cannot perform

11. Standing Up to Sitting Down

Examiner: Begin with the subject standing by the edge of a treatment mat. Instruct the subject to sit on edge of mat without support. Assist if necessary. Evaluate the subject's performance on the amount of help required. Do not consider the quality of performance.

____(3) Can perform without help
____(2) Can perform with little help
____(1) Can perform with much help
____(0) Cannot perform

12. Standing, Picking Up a Pencil from the Floor

Examiner: Begin with the subject standing. Instruct the subject to pick up a pencil from the floor without support. Assist if necessary. Evaluate the subject's performance on the amount of help required. Do not consider the quality of performance.

____(3) Can perform without help
____(2) Can perform with little help
____(1) Can perform with much help
____(0) Cannot perform

Changing Posture SUBTOTAL ______ **TOTAL _________**

Appendix 7. Modified Ashworth Scale (MAS)

Grade	Definition
0	No increase in muscle tone
1	Slight increase in muscle tone, with a catch and release or minimal resistance at the end of the range of motion when an affected apart (s) is moved in flexion or extension
1^+	Slight increase in muscle tone, manifested as a catch, followed by minimal resistance through the remainder (less than half) of the range of motion
2	A marked increase in muscle tone throughout most of the range of motion, but affected part(s) are still easily moved
3	Considerable increase in muscle tone, passive movement difficult
4	Affected part(s) rigid in flexion or extension