

Biomechanical Report: Breaststroke Kick

1. INTRODUCTION

1.1 Context and Importance of Movement:

Breaststroke is unique among the four competitive swimming strokes, characterised by a symmetrical, cyclic lower-limb action to generate propulsion (Nicol *et al.*, 2024). While it is identified as the slowest stroke due to large deceleration in the leg recovery phase, the breaststroke leg kick is recognised as the largest force-producing movement in swimming and the main contributor to swimming velocity in this stroke (Koga *et al.*, 2025). The breaststroke kick is arguably more biomechanically complex and demanding compared to dolphin and flutter kick, with coordinated hip adduction and extension, knee flexion and extension and ankle eversion and plantarflexion being key components of a successful kick (Kippenhan, 2001).

1.2 Aims of Report:

The aim of this report is to investigate the biomechanics of the breaststroke kick in an elite swimmer using video-based kinematic analysis, with specific focus on movement efficiency and potential injury risk in the lower-limb joints.

1.3 Biomechanical Principles:

From a biomechanical perspective, breaststroke kick is primarily governed by kinematic variables, such as joint angular displacement and velocity and segmental timing (Nicol *et al.*, 2022). Effective execution requires precise coordination of the hip, knee and ankle joints to maximise propulsive surface area while minimising hydrodynamic drag (Santos, 2011). Mechanical principles, such as propulsion generation through action-reaction forces with the water and optimising mechanical efficiency by reducing drag, underpins these movements (McLachlan and Freeman, 2016).

1.4 Injury Risk and Relevance:

A significantly high incidence of lower limb injuries have been documented in breaststroke swimmers (Vizsolyi *et al.*, 1987). Excessive hip abduction and knee valgus during the propulsive phase of the kick can be linked to increased medial knee loading (Rovere and Nichols, 1985; Fernández-Galván *et al.*, 2025). This makes biomechanical analysis of this skill relevant for injury prevention and technique optimisation.

1.5 Report Overview:

Kinematic findings from video analysis will be presented and their implications discussed in relation to existing literature. Following this, evidence-based recommendations for performance optimisation and injury prevention will be suggested.

2. METHODOLOGY:

2.1 Study Design:

This study employed an observational, cross-sectional design to investigate the biomechanics of the breaststroke kick using video-based kinematic analysis. This allowed analysis of naturally occurring breaststroke technique. Video-based kinematic analysis is often relied on for swimming biomechanics due to aquatic constraints (Mooney *et al.*, 2015).

2.2 Participant:

One competitive level female swimmer, specialising in breaststroke, participated. The participants background made them an appropriate model for analysing breaststroke kick biomechanics at a high-performance level.

2.3 Data Collection and Equipment:

Underwater video footage was collected in a 25m pool using a waterproof '*Insta-360-GO*' camera. Filming was conducted from side on and posterior perspectives to allow observation of lower-limb kinematics throughout the kick cycle. Camera positions were fixed and aligned perpendicular to the swimmer where possible to minimise parallax errors (Hudson, 2015). Using underwater footage enabled visualisation of positioning that would not be observable using surface-based analysis.

2.4 Movement Tasks:

The participant completed 25m breaststroke swimming trials under two conditions: (1) slow pace (2) fast pace. This was to identify potential changes in kicking mechanics under different performance demands. Multiple kick cycles were recorded for each condition, with representative cycles selected for analysis.

2.5 Video Analysis Procedure:

Footage was analysed using Dartfish motion analysis software. Frame-by-frame playback was used to identify key phases of the breaststroke kick. Lower-limb joint kinematics were quantified by measuring hip, knee and ankle joint angles at predefined points within the kick cycle.

2.6 Limitations:

This study was limited by its use of two-dimensional (2D) video analysis and a single elite female participant, which restricts the generalisability of findings to wider swimming populations. Additionally, the methodology did not permit direct measurement of kinetic variables such as propulsive forces. Manual calculation of joint angles may have introduced measurement errors.

3. RESULTS

3.1 Overview of Kinematic Analysis:

Kinematic analysis of the breaststroke kick was conducted using 2D Dartfish motion analysis under slow and fast kicking conditions. Sagittal-plane joint angular displacement and angular velocity were quantified at the hip, knee and ankle across four stroke phases. In addition, rear-view footage was analysed qualitatively to assess frontal-plane hip and knee alignment.

3.2 Stroke Phase Definition and Temporal Characteristics:

Table 1: Breaststroke Kick Phases

Phase	Description	Key Joint Actions
Recovery	Heels drawn towards hips	Knee flexion, hip abduction
Outsweep	Feet move laterally	Hip abduction, ankle eversion
Insweep (propulsion)	Feet accelerate medially	Knee extension, hip adduction
Glide	Legs extended	Minimal joint motion

The breaststroke kick cycle was divided into four phases based on observable kinematic events: recovery (knee flexion and heel draw-up), outsweep (external rotation of the feet and lateral displacement), insweep (knee and hip extension producing propulsion), and glide (full lower-limb extension) (Olstad *et al.*, 2014). Phase timings were extracted consistently across slow and fast conditions using Dartfish event markers to ensure comparability between trials.

3.3 Hip Joint Kinematics (Sagittal Plane)

Table 2: Hip Joint Angular Displacement Across Kick Phases (Slow vs Fast)

Phase	Hip Angle (°): Slow	Hip Angle (°): Fast

Recovery (Peak Flexion)	33.5	35.6
Outsweep	28.1	32.7
Insweep	14.9	18.6
Glide (Peak Extension)	4.9	6.8
Range of Motion (ROM)	28.6°	28.8°

Convention: 0° = neutral/standing position, higher values indicate greater flexion

Hip kinematics remained relatively consistent across conditions (Table 2). Peak hip flexion occurred during the recovery phase, reaching 33.5° in the slow condition and 35.6° in the fast condition. The hip approached a neutral position during the glide, with minimum flexion angles of 4.9° and 6.8° respectively. Total hip sagittal ROM was nearly identical between trials (~28.7°).

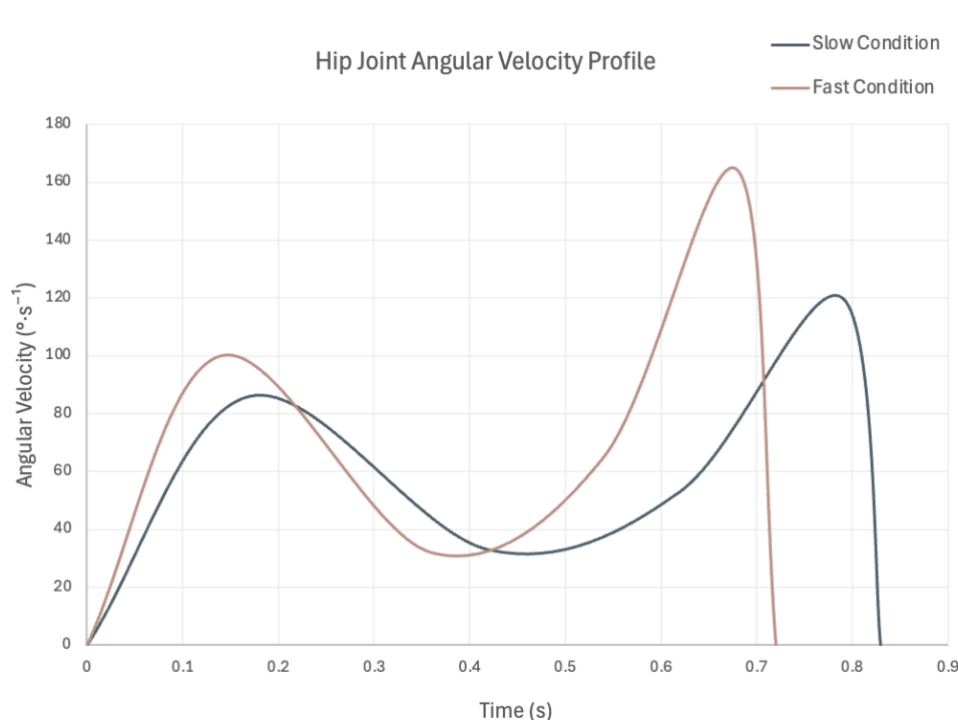


Figure 1: Hip Joint Angular Velocity-Time Profile (Slow vs Fast)

Hip joint angular velocity increased in the fast-kicking condition compared to slow-kicking, particularly during the transition from recovery to insweep (Figure 1). Peak angular velocities occurred during the insweep phase in both conditions, reflecting rapid hip extension. The velocity-time profile was steeper during fast-kicking, indicating increased angular acceleration across phases despite similar overall ranges of motion.

3.4. Knee Joint Kinematics (Sagittal Plane)

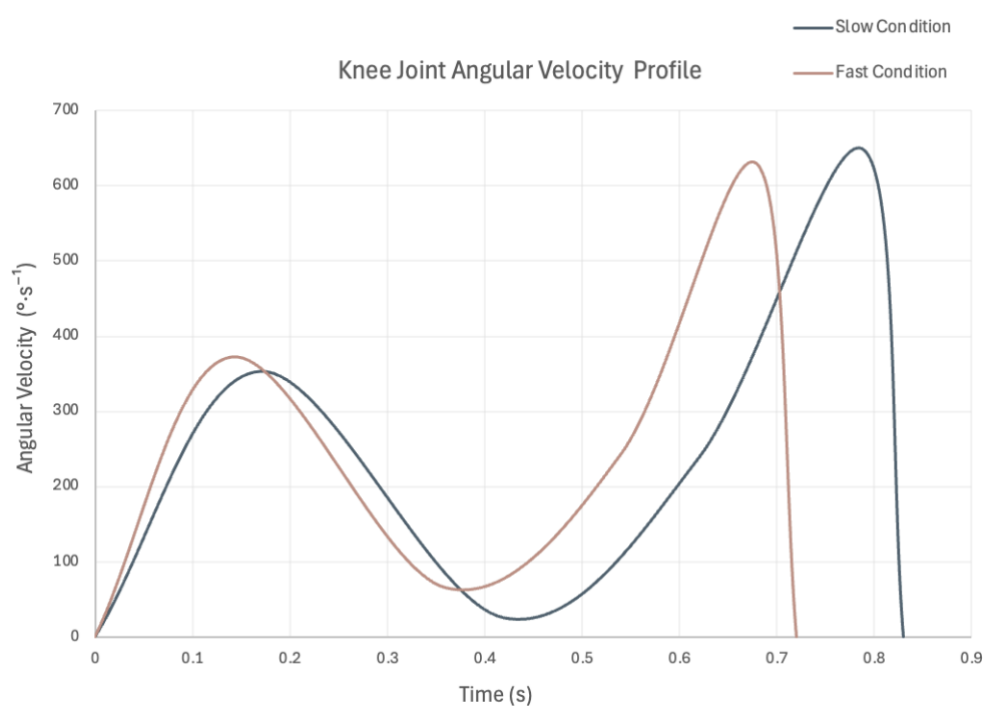
Table 3: Knee Joint Angular Displacement Across Kick Phases (Slow Vs Fast)

Phase	Knee Angle (°): Slow	Knee Angle (°): Fast
Recovery	128.7	122.0
Outsweep	124.5	112.6
Insweep	65.0	60.1
Glide	11.3	14.9
ROM	117.4°	107.1°

Convention: 0° = full extension (higher values = greater flexion)

Table 4: Knee Joint Angular Velocity Values (Slow vs Fast)

Condition	Angular Displacement (°)	Time (s)	Mean Angular Velocity (°·s ⁻¹)
Slow	117.4	0.83	141.4
Fast	107.1	0.72	148.8

**Figure 2: Knee Joint Angular Velocity-Time Profile (Slow vs Fast)**

Peak knee flexion occurred during the late recovery phase for both trials (Table 3). The slow condition exhibited a higher peak flexion (128.7°) compared to the fast condition (122.0°). Conversely, the fast condition maintained a slightly more flexed position during the glide (14.9° vs 11.3°). Consequently, total knee ROM was greater in the slow trial (117.4°) than the fast trial (107.1°). The fast trial produced a higher mean angular velocity of $148.8^\circ \cdot s^{-1}$ compared to $141.4^\circ \cdot s^{-1}$ in the slow trial (Table 4), attributed to the 0.11s reduction in phase duration despite reduced angular displacement.

3.5. Ankle Joint Kinematics (Sagittal Plane)

Table 5: Ankle Joint Angular Displacement Across Kick Phases (Slow Vs Fast)

Phase	Ankle Angle ($^\circ$): Slow	Ankle Angle ($^\circ$): Fast
Recovery	10.6 (PF)	27.6 (PF)
Outsweep	23.6 (PF)	-12.3 (DF)
Insweep	26.3 (PF)	9.4 (PF)
Glide	68.2 (PF)	74.6 (PF)
ROM	57.6°	86.9°

Convention 0° = neutral (90-degree foot). Positive = plantarflexion (PF), negative (-) = dorsiflexion (DF)

Significant differences were observed in ankle positioning (Table 5). In the slow condition, the ankle remained plantarflexed throughout all phases, peaking at 68.2° in the glide. In the fast condition, the participant achieved a dorsiflexed position of -12.3° during the outsweep, representing a total ROM of 86.9° compared to 57.6° in the slow trial.

3.6 Inter-Joint Coordination and Frontal-Plane Observations (Rear View)

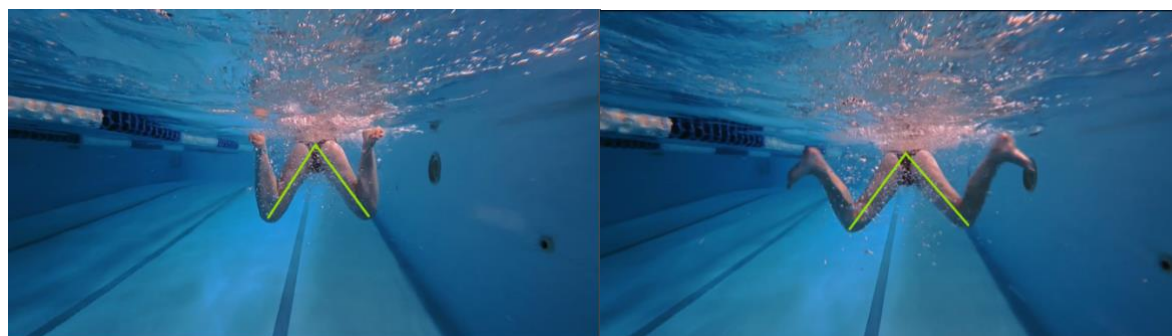


Figure 3: Hip Abduction Rear-View

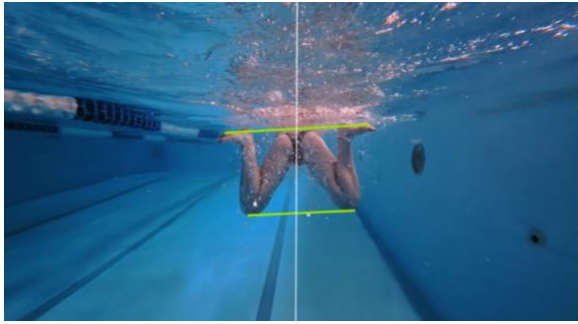


Figure 4: Knee Valgus Rear-View

Frontal plane analysis (Figure 3 & 4) identified hip abduction and medial knee displacement during the transition from recovery to outswEEP. These movement patterns appeared more pronounced in the fast condition, coinciding with the increased angular velocities recorded in the sagittal plane.

Summary of Key Kinematic Findings:

In summary, fast-kicking was characterised by increased angular velocity across joints, reduced phase durations and altered joint positioning during recovery and outswEEP. Hip and knee joints exhibited consistent phase-dependent patterns across conditions, while ankle kinematics demonstrated greater variability. Rear-view analysis highlighted coordinated hip abduction and knee valgus during kick preparation.

4. Discussion

4.1 Interpretation of Kinematics and Mechanical Efficiency

The kinematic data revealed a proximal-to-distal kinematic chain, characterised by condition dependent changes in joint coordination (Almansoof, Nuhmani and Muaidi, 2023). During the fast-trial, the hip joint functioned as a proximal stabilizer, maintaining a restricted sagittal ROM ($\sim 35^\circ$) (Siegel, Kepple and Stanhope, 2007). Biomechanically, this is a form of streamlining, by limiting hip flexion and abduction, the swimmer minimised the frontal surface area, effectively reducing drag and preserving horizontal momentum during the non-propulsive recovery phase (Alves, Barbosa and Paulo Vilas-Boas, 2024; Tanaka, Hayashi and Isaka, 2024; Koga *et al.*, 2025).

The knee joint acted as the primary engine of the kick, exhibiting a clear bimodal angular velocity profile (Ward, 2018). An important observation was the inverse relationship between knee displacement and velocity, the fast-condition utilised a reduced ROM (107.1°) to achieve a significantly higher mean angular velocity ($148.8^\circ \cdot s^{-1}$) (Strzala *et al.*, 2012). This shift

represents temporal optimization, however, when compared with research by Sanders *et al.*, (2015) and Koga *et al.*, (2025), where knee angular velocity commonly exceeded $180^{\circ}\cdot\text{s}^{-1}$ in world-class breastroke populations, the current findings ($148^{\circ}\cdot\text{s}^{-1}$ and $141.4^{\circ}\cdot\text{s}^{-1}$) seem relatively modest. This discrepancy could be due to skill level differences or a consequence of 2D video analysis, where limitations, such as parallax errors, may lead to underestimated velocities compared to 3D analysis which both studies utilise. According to the impulse-momentum principle, a shorter kick cycle (0.72s) requires greater acceleration to produce the same change in momentum (Hamm, 2020). Higher angular accelerations at the joints imply larger internal joint torques (since $\tau = I\alpha$) and if the foot produces larger reaction forces on the water this can increase propulsive impulse during the insweep, which is a fundamental determinant of velocity in breaststroke performance (Rushall, 2013; Schnitzler, Seifert and Button, 2021; Ling, Sanny and Moebs, 2016; Schilling, Falvo and Chiu, 2008; Houlton *et al.*, 2025).

The effectiveness of the knee extension and power of the kick was based on the distal positioning of the ankle (Koga *et al.*, 2025). While the slow-trial remained in propulsively-inefficient plantarflexion, the fast-trial transitioned to dorsiflexion (-12.3°) during the outstroke. This sagittal plane adjustment maximizes the propulsive surface area of the foot, ensuring that the high angular momentum generated by the knee is converted into forward thrust rather than being lost to 'foot slip' (Koga *et al.*, 2025; Suito, Teramoto and Ozeki, 2025). This supports research identifying ankle flexibility as a key determinant in generating above-average propulsive force (Strzala *et al.*, 2012; Jagomägi and Jürimäe, 2005).

4.2 Injury and Safety Risk

While the adaptations in the fast-kicking condition facilitate greater propulsive impulse, they increase mechanical load on the lower-limb joints. Research suggests that breaststroke swimmers have a five-fold higher risk of knee pain than other strokes, with 86% of competitive breaststrokers reporting kick-related pain (Rupp, Berninger and Hopf, 1995). A concern identified in this analysis is knee medial deviation during the transition from recovery to insweep. In the fast-trial the combination of high angular velocity ($148.8^{\circ}\cdot\text{s}^{-1}$) and significant hip abduction creates a valgus moment at the knee, placing excessive tension on the medial collateral ligament (MCL) while causing lateral compartment compression (Richardson, 1986; Keskinen, Eriksson and Komi, 1980; Kennedy, Hawkins and Krissoff, 1978; Wanivenhaus *et al.*, 2012). These factors align with 'breaststroker's knee', a condition characterised by repetitive tension, found in 47% of symptomatic swimmers (Keskinen, Eriksson and Komi, 1980; Rovere and Nichols, 1985).

Furthermore, the ‘whip kick’ motion required for an effective catch involves increased external tibial rotation, which Stulberg *et al.*, (1980) and Wanivenhaus *et al.*, (2012) identify as a trigger for medial patellar facet tenderness and increased patellofemoral contact stress. Additionally, the explosive adduction of the insweep increases the risk of strain injuries to the hip flexors and adductors (Rodeo, 1999).

The valgus related stress identified aligns with the foundational work of Rovere and Nichols (1985) regarding ‘breaststrokers knee’. However, it is important to highlight this study is over 40 years old and focussed on the high-volume training sessions typical of that era. Modern coaching often prioritises ‘quality’ over extreme volumes, which may reduce cumulative overuse stress (Nicol *et al.*, 2024; Nugent, Comyns and Warrington, 2017).

4.4 Implications for Practice and Training Recommendations:

Given that a large percentage of breaststrokers report knee pain, training programmes must balance the performance demands of high angular velocity with musculoskeletal preservation. The peak angular velocity in conjunction with hip abduction identifies a valgus moment at the knee, suggesting the athlete requires a ‘proximal stability for distal mobility’ approach (Moreside and McGill, 2012). Strength and conditioning interventions should prioritise the eccentric and isometric strength of the hip abductors and external rotators, such as the gluteus medius (Rodeo, 1999). By improving the capacity of the gluteals to stabilise the femur, the athlete can better control the medial path of the knee during the insweep, therefore reducing load on the MCL (Wilczyński, Wąż and Zorena, 2021; Ambrus *et al.*, 2026).

Additionally, while the ankle’s transition to dorsiflexion in the fast-kick is technically efficient, it places strain on the distal kinetic chain (Rao *et al.*, 2024). Improving ankle joint mobility would increase the available range of dorsiflexion, ensuring that the required ‘catch’ surface area can be achieved without resorting to excessive external tibial rotation (Tourillon, M'Baye and Smith, 2025; Jeon *et al.*, 2015).

Greater hip abduction in the recovery phase could increase the medial torque and stress acting on the knee joint (Rodeo, 1999). A ‘narrow-kick’ technique should be implemented to ensure joint safety without compromising propulsion (Vizsolyi *et al.*, 1987).

A common training recommendation to avoid ‘breaststroker’s knee’ is to increase breaststroke training distances gradually during early season, alongside an adequate warm-up distance before any high-intensity kicking (Rovere and Nichols, 1985).

4.5 Limitations

The primary limitation is the reliance on 2D kinematic analysis. While 2D video provided temporal data suitable for identifying bimodal velocity profiles, it is limited by parallax error (Matúš *et al.*, 2025). The breaststroke kick is a complex, multiple-plane movement that involves internal and external rotation of the tibia and femur, a 2D sagittal plane camera fails to fully capture out of plane joint excursions (Keskinen, Eriksson and Komi, 1980; Mezêncio *et al.*, 2024). This could explain why peak angular velocities recorded ($148.8^{\circ}\cdot\text{s}^{-1}$) were lower than 3D tracked data from Sanders *et al.*, (2015) and Koga *et al.*, (2025). With 3D analysis the true velocity would be calculated across all three planes which 2D analysis underestimates (Slawinski *et al.*, 2010).

The footage analysed was compromised by environmental artifacts commonly seen in underwater videography. Specifically, the presence of cavitation (bubbles) generated during the insweep and motion-induced blur during high velocity phases hindered the precise identification of joint markers (Dubois, Thiel and James, 2012; Mooney *et al.*, 2015). These artifacts increase risk of inaccuracies when calculating variables.

Additionally, the analysis included no kinetic data, such as force production or electromyography. Without electromyography, the conclusions regarding kick efficiency are based solely on joint angles rather than the muscular cost of the movement (Puce *et al.*, 2021). Integrating 3D motion capture with wearable pressure sensors would provide the most holistic understanding of true mechanical work performed against the water (Pascual, 2024; Tanaka, Hayashi and Isaka, 2024).

5. Conclusion and Recommendations

In conclusion, this kinematic analysis demonstrates that elite breaststroke performance is a strategic trade off between mechanical efficiency and joint safety. The data revealed that high-velocity kicking is achieved through temporal optimisation, specifically, the fast-condition presenting a reduction in knee ROM paired with an increase in angular velocity and a transition into dorsiflexion for an effective ankle catch (Koga *et al.*, 2025). While this coordination maximises propulsion and minimises hydrodynamic drag, it also subjects the knee joint to substantial valgus-related stress. The findings suggest that the kinematic adaptations that maintain horizontal velocity, including the explosive insweep and external tibia rotation, could be primary causes of the 86% injury prevalence recorded in competitive populations (Wanivenhaus *et al.*, 2012).

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