Postural control
in individuals with knee osteoarthritis
from patient-reported outcomes
to kinetic analysis

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"If I have seen further, it is by standing on the shoulders of giants."
— Isaac Newton—

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List of abbreviations

ACR	American College of Rheumatology
ADL	Activities of Daily Living
APA	Anticipatory Postural Adjustment
APA1	First anticipatory postural adjustment subphase
APA2a / APA2b	Second anticipatory adjustment subphases
COM	Centre of Mass
COP	Ground Reaction Force
CVI	Content Validity Index
EULAR	European League Against Rheumatism
FTSTS	Five-Times Sit-to-Stand Test
F_z	Vertical component of Ground Reaction Force
GI	Gait Initiation
HOA	Healthy Older Adults
HYA	Healthy Young Adults
I-CVI	Item-level Content Validity Index
ICC	Intraclass Correlation Coefficient
KOA	Individuals with Knee Osteoarthritis
KOOS	The Knee Injury and Osteoarthritis Outcome Score
KOOS-V	Vietnamese Version of the Knee Injury and Osteoarthritis Outcome Score
LOC	Locomotion Phase
MDC_{95}	Minimal Detectable Change at 95% Confidence
NICE	National Institute for Health and Care Excellence
NPRS	Numeric Pain Rating Scale
OLST	One-Leg Standing Test
QoL	Quality of Life
SEM	Standard Error of Measurement
SF-36	Short Form-36 Health Survey
SitTS	Sit-to-Stand
Sport/Rec	Sport and Recreation activities
StandTS	Stand-to-Sit
S-CVI/Ave	Scale-level Content Validity Index (Average agreement)
S-CVI/UA	Scale-level Content Validity Index (Universal agreement)

Abstract

Knee osteoarthritis is a prevalent musculoskeletal condition that substantially impairs functional mobility and postural control during everyday activities. Difficulties in rising from a chair, sitting down, and initiating gait often persist even when pain is relatively controlled, suggesting alterations in balance regulation that are not fully captured by conventional clinical assessments. A comprehensive understanding of these difficulties requires the integration of self-reported outcomes, functional performance tests, and objective biomechanical measures.

The overall aim of this thesis was to investigate postural control in individuals with knee osteoarthritis using a multi-dimensional approach combining patient-reported outcomes, clinical performance tests, and kinetic analyses of functional transitions.

Three complementary studies were conducted. The first study focused on the cross-cultural adaptation and psychometric validation of the Vietnamese version of the Knee Injury and Osteoarthritis Outcome Score (KOOS-V). The KOOS was translated and culturally adapted following established guidelines, and its measurement properties were evaluated in individuals with knee osteoarthritis. The KOOS-V demonstrated good to excellent internal consistency, test–retest reliability, and construct validity, supporting its use for clinical and research assessment of knee-related symptoms and function in Vietnam.

The second study examined postural control during bipodal transitions by analysing the kinetics of Sit-to-Stand and Stand-to-Sit tasks in individuals with knee osteoarthritis, age-matched healthy older adults, and healthy young adults. The vertical component of the ground reaction force recorded from dual force plates was used to identify key temporal events and movement phases. Compared with healthy participants, individuals with knee osteoarthritis exhibited longer movement durations, altered force modulation, and increased inter-limb asymmetry, particularly during phases requiring deceleration and stabilisation. Correlations were observed between kinetic variables, performance on the Five-Times Sit-to-Stand Test, and KOOS-V scores, highlighting links between objective balance control and perceived functional limitations. Stand-to-Sit emerged as a task with pronounced demands on eccentric control and postural regulation.

The third study investigated postural control during the bipodal-to-unipodal transition of gait initiation. Using a four-phase framework based on centre-of-pressure trajectories, anticipatory postural adjustments and loading patterns were analysed during gait initiation with both the preferred and non-preferred leading leg. Individuals with knee osteoarthritis demonstrated prolonged anticipatory phases, reduced loading dynamics, and altered asymmetry patterns compared with healthy older and young adults. These adaptations reflected a stability-oriented strategy and were associated with balance performance and self-reported function.

Together, these studies provide an integrated description of postural control modifications in knee osteoarthritis across key functional transitions. By combining validated patient-reported outcomes with kinetic analyses and clinical performance tests, this thesis highlights specific

phases and tasks that are particularly sensitive to balance impairments. These findings support the inclusion of both rising-up and going-down tasks, as well as gait initiation, in the assessment of postural control and may inform targeted rehabilitation strategies aimed at improving functional stability in individuals with knee osteoarthritis.

INTRODUCTION

The motivation for this thesis grew from a clinical question that has stayed with me for years: why do individuals with knee osteoarthritis struggle so much with everyday transitions such as standing up, sitting down, or taking a first step? These challenges often persist even when pain is reasonably controlled, suggesting that deeper mechanisms affecting functional performance. Understanding these difficulties requires more than a single type of measurement. Patient-reported outcomes highlight how individuals perceive their limitations, physical performance tests capture what they can accomplish in clinical conditions and kinetic analyses provide objective information on how forces and timing contribute to task performance. Each perspective provides only a partial view, but together they offer a more complete picture of why certain activities become challenging in knee osteoarthritis. This thesis was therefore conceived to clarify the mechanisms that underpin functional difficulties by integrating multiple outcome measures. The broader intent is to inform assessment and guide future rehabilitation strategies through a clearer understanding of the demands of these essential daily transitions.

1. General background

Functional mobility and postural control during dynamic transitions

Postural control is the ability to maintain or regain stability when the body position changes. It depends on the regulation of forces and timing that keeps the body's centre of mass (COM), which represents the average location of the body's mass, within the limits of stability (Horak, 2006; Winter, 1995) This control results from the continuous interaction between sensory input, motor output, and biomechanical constraints that preserve equilibrium under different conditions (Horak, 2006). Postural control is not limited to quiet standing but also needed to move from one posture to another and to adapt to changing environments (Horak, 2006; J. Massion, 1992).

Functional mobility refers to the ability to move independently and safely during daily activities, including posture transitions such as standing up or sitting down, and movements such as walking or turning (Shumway-Cook & Woollacott, 2007; WHO, 2007). These movements require precise control of the COM and of the centre of pressure (COP), which represents the point of application of the resultant of the ground reaction force. This involves close coordination between balance control and voluntary movement (Horak, 2006; Jean Massion, 1992; Winter, 1995). Changes in the regulation of the COM–COP relationship and the base of support have been reported with ageing and musculoskeletal disorders, emphasising the need to study how these factors influence dynamic postural control in daily life (Hinman et al., 2002; Horak, 2006; Winter, 1995).

When postural control is required before a voluntary movement, the body generates anticipatory postural adjustments (APA), small shifts of the COP and muscle activity that occur before movement onset to maintain stability (Bouisset & Zattara, 1981; J. Massion, 1992). These adjustments ensure that the body's COM remains within the limits of stability while enabling smooth transition into the intended movement.

Force plate analysis is a well-established method for quantifying postural control because it provides objective measures of how the body interacts with the support surface (Duarte & Freitas, 2010; Winter, 1995). Ground reaction forces and COP data describe the mechanical outcome of neuromuscular activity used to maintain balance. The vertical component of the ground reaction force is the main contributor to body motion in tasks which do not involve a large horizontal displacement like the Sit-to-Stand and Stand-to-Sit tasks. In such situations, the time-curve of the vertical forces provides reliable indicators of movement timing and balance control (Almonroeder et al., 2023; Hirschfeld et al., 1999). Compared with kinematic or observational assessments, force plate measurements allow subtle detection of instability, asymmetry, and temporal coordination (Prieto et al., 1996; Ruhe et al., 2010).

This approach is also suitable for the research environment in Vietnam, where such equipment is more affordable and can be used for both clinical and research purposes. Establishing standard procedures with force plates marked an important first step toward developing objective assessment in rehabilitation research.

Knee osteoarthritis and its impact on functional mobility and postural control

Among musculoskeletal disorders, knee osteoarthritis particularly challenges postural control because it affects both sensory and motor components of balance regulation (Hassan et al., 2001; Hinman et al., 2002; Sharma et al., 1997). Knee osteoarthritis is one of the most prevalent degenerative joint diseases, affecting about 375 million people worldwide in 2021 and predicted to reach approximately 658 million by 2045 (Ouyang & Dai, 2025). It is a leading cause of pain, mobility limitation, and loss of independence among older adults (Hunter & Bierma-Zeinstra, 2019; Vos, 2020).

Global estimates from the Global Burden of Disease 2019 show that the age-standardized prevalence of knee osteoarthritis has risen steadily over the past three decades, reaching approximately 4,376 per 100,000 population in 2019 (G. Yang et al., 2023). The global map of knee osteoarthritis prevalence highlights substantial geographical variation, with the highest rates observed in East Asia, high-income Asia Pacific, and Australasia, while Southeast Asia generally falls within a moderate-prevalence range of roughly 3,000–4,000 per 100,000 population **(Figure I1)**.

That finding is consistent with data showing that the burden of knee osteoarthritis is high in Asian countries, with an estimated prevalence of about 19% among adults aged 40 years and older, higher than that reported in Europe or North America (Cui et al., 2020). This difference may be partly related to lifestyle, occupational, and anatomical factors common in Asian populations. Deep knee-flexion postures such as squatting, kneeling, and sitting cross-legged are frequent in daily activities and create high compressive forces on the tibiofemoral joint (Dahlkvist et al., 1982; Han et al., 2021; Song et al., 2020). Prolonged squatting has been shown to increase the likelihood of tibiofemoral knee osteoarthritis among older Chinese adults, particularly in the medial compartment (Zhang et al., 2004). In addition to habitual postures, repetitive loading from physically demanding work, such as lifting, kneeling, squatting, or climbing, has been identified as an occupational contributor to increased knee joint loading and a higher risk of developing or worsening knee osteoarthritis (Ezzat & Li, 2014; Wang et al., 2020).

Similar seating and working habits are also common in Vietnam, where floor-based activities and occupations that require frequent kneeling or squatting are still widespread. Although these behaviours have not yet been studied in the Vietnamese population, they may partly explain the high prevalence of knee osteoarthritis, which is about 34% among adults aged 40 years and older, with women more frequently affected than men (Ho-Pham et al., 2014). In addition, the global map presented earlier places Vietnam in a moderate-prevalence band of approximately 3,000–4,000 per 100,000 population, yet the main text does not provide country-specific details **(Figure I1)**. The highest burden has been reported in high-income Asian countries such as Japan, Korea, and Singapore, where population ageing and longer life expectancy increase the number of cases (Ouyang & Dai, 2025). However, data from many low- and middle-income countries remain limited, especially regarding the functional and biomechanical features of knee osteoarthritis in daily activities.

Beyond cartilage degeneration, knee osteoarthritis involves a combination of structural, physiological, and neuromechanical alterations that compromise joint function and balance regulation. Progressive loss of articular cartilage reduces shock absorption and alters load distribution across the tibiofemoral joint (Andriacchi & Mündermann, 2006). Subchondral bone thickening and osteophyte formation further modify joint geometry, restricting motion and changing joint moments during weight-bearing (Felson, 2004; Hunter & Bierma-Zeinstra, 2019). Pain and inflammation contribute to muscle inhibition, particularly of the quadriceps, which decreases voluntary activation and dynamic joint stability (Bennell et al., 2013; Rice & McNair, 2010). These neuromuscular alterations lead to decreased knee flexion, reduced joint power, and compensatory strategies at the hip and ankle to maintain support and forward progression (Astephen et al., 2008; Bennell et al., 2013).

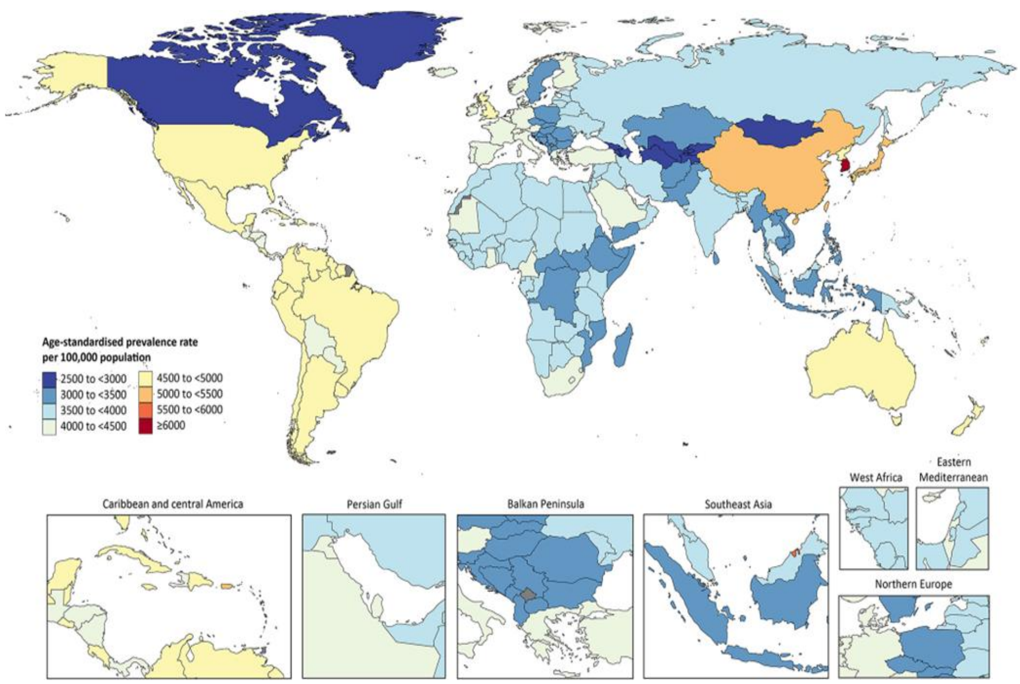

Figure I1. Global map of age-standardized prevalence rates of knee osteoarthritis in 2019 (Yang et al., 2023)

From a sensory perspective, reduced proprioceptive acuity impairs awareness of joint position and movement (Sharma et al., 1997), resulting in delayed or inaccurate postural adjustments. Pain, joint stiffness, and fear of movement further contribute to instability and decreased confidence during daily activities (Alaca, 2019; Gunn et al., 2017). Together, these sensory and motor impairments affect the ability to control the body's centre of mass within the base of support, increasing the risk of imbalance and falls (Manlapaz et al., 2019; Wilfong et al., 2023).

Functionally, individuals with knee osteoarthritis (KOA) often demonstrate slower, less stable, and more asymmetric performance during tasks such as Sit-to-Stand, walking, and stair-climbing (Christiansen et al., 2011; Liikavainio et al., 2007). These mobility limitations are associated with reduced participation in daily activities and poorer self-reported quality of life (Pavel et al., 2025; Wojcieszek et al., 2022). Although numerous studies have examined biomechanical and functional impairments in knee osteoarthritis using both static and dynamic tasks, most have focused on performance outcomes such as strength, range of motion, or completion time (Mündermann et al., 2024; Thomas et al., 2022; Yang et al., 2024). Fewer have investigated how postural control and inter-limb coordination are regulated throughout functional transitions such as sitting down, standing up, or initiating gait. This highlights the need for analyses that describe balance regulation across the entire movement sequence rather than only its final outcome.

Clinical assessments related to postural control in knee osteoarthritis

Comprehensive assessment of knee osteoarthritis requires both self-reported and performance-based measures, as the condition affects pain, balance, and mobility (Dobson et al., 2013; Collins et al., 2016).

Self-reported questionnaire: Knee Injury and Osteoarthritis Outcome Score (KOOS)

The Knee Injury and Osteoarthritis Outcome Score (KOOS) is a self-administered questionnaire developed by Professor Ewa Roos (University of Southern Denmark) and is now recognized as one of the gold standard instruments for assessing patient-reported symptoms, pain, functional limitations, and knee-related quality of life in individuals with knee injury or osteoarthritis (Mapi Research Trust, 2024; Roos, 2024; Roos, Roos, Lohmander, et al., 1998). Since October 2023, the management and distribution rights of KOOS have been entrusted to the Mapi Research Trust (Lyon, France). This collaboration ensures controlled access and maintains the scientific integrity of the instrument while keeping it freely available for academic and non-commercial use.

KOOS contains five subscales: Symptoms (7 items), Pain (9 items), Activities of daily living (17 items), Sport and recreational activities (5 items), and Quality of life (4 items) (Roos, Roos, Lohmander, et al., 1998). Its validity has also been demonstrated in both post-injury and osteoarthritis populations (Roos & Lohmander, 2003). Each item in the KOOS is rated on a 5-point Likert scale ranging from 0 (“no problem”) to 4 (“extreme problem”). Responses for each subscale are then transformed to a 0–100 score, where 0 represents extreme problems and 100 represents no problems (Roos, 1998). Because the number of items differs between subscales, each subscale should be scored and reported separately to avoid unequal weighting (Roos, 2024). For clinical interpretation, KOOS subscale scores can be classified as follows: no difficulty (87.5–100), mild (62.5–87.4), moderate (37.5–62.4), severe (12.5–37.4), and extreme (0–12.4) (Roos, 2024).

The multi-subscale structure allows clinicians and researchers to examine specific aspects of knee function and to identify which domains are most affected. The pain and symptom subscales evaluate pain frequency, stiffness, and joint swelling in various situations such as stair climbing, standing, or resting. The Activities of Daily Living (ADL) subscale covers movements such as stair negotiation, Sit-to-Stand transitions, walking, transfers, self-care, and domestic tasks that require lower-limb strength, balance, and endurance during common weight-bearing conditions. The Sport and Recreation subscale includes more demanding tasks such as running, jumping, kneeling, squatting, and pivoting the knee The Quality of Life (QoL) subscale assesses the individual's perception of knee problems in daily life, including awareness of the knee during activities, confidence in the knee, and the extent to which knee-related limitations affect lifestyle, social participation, and future expectations (Roos, Roos, Lohmander, et al., 1998). Among the five subscales, Pain and ADL are the most frequently used for older individuals, as they reflect the symptoms and daily functional limitations most relevant to this population (Roos, 2024). In a comparison of nine commonly used knee outcome measures such as the International Knee Documentation Committee Subjective Knee Evaluation Form (IKDC), the Knee Injury and Osteoarthritis Outcome Score (KOOS), the KOOS Physical Function Short-Form (KOOS-PS), the Knee Outcome Survey–Activities of Daily Living Scale (KOS-ADL), the Lysholm Knee Scoring Scale, the Oxford Knee Score (OKS), the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), the Activity Rating Scale (ARS), and the Tegner Activity Score (TAS), Collins et al. (2011) found that the KOOS demonstrated strong internal consistency (Cronbach's α = 0.71–0.95) and test–retest reliability (ICC = 0.83–0.95), with minimal floor and ceiling effects and high responsiveness across both injury and osteoarthritis populations, making it one of the most comprehensive and responsive instruments compared with earlier tools (Collins et al., 2011). These findings were confirmed by a later systematic review by Collins et al. (2016), which analysed 37 studies showing that KOOS maintains good measurement properties across diverse populations and interventions, including both surgical and nonsurgical management of knee osteoarthritis (Collins et al., 2016). Together, these results indicate that KOOS captures a wider range of functional abilities and is more sensitive to clinical change than other instruments, such as Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), the International Knee Documentation Committee Subjective Knee Form (IKDC) or the Oxford Knee Score, making it a comprehensive tool for assessing outcomes across different stages and severities of knee osteoarthritis (Collins et al., 2011, 2016).

In Vietnam, no standardized patient-reported outcome measure for knee osteoarthritis had previously been available. Therefore, the cross-cultural adaptation and validation of the Vietnamese version of the KOOS represent an important step toward improving clinical assessment and ensuring comparability with international data. In this thesis, the Vietnamese version of the KOOS (KOOS-V) was first cross-culturally adapted and validated. The KOOS-V is then used together with performance-based tests to link selfperceived function with objective biomechanical findings, providing complementary perspectives on functional impairment in KOA.

Physical performance tests

Performance-based tests provide objective indicators of lower-limb function and postural control that complement self-reported outcomes such as the KOOS. They are particularly relevant in knee osteoarthritis, where pain, quadriceps weakness, reduced proprioception, and altered neuromuscular coordination contribute to functional decline and fall risk (Bennell et al., 2013; Hinman et al., 2002). In this thesis, two standardized clinical tests were used: the Five-Times Sit-to-Stand Test and the One-Leg Standing Test. These tests assess dynamic and static postural control, respectively, and have demonstrated good reliability and validity in KOA (Amano & Suzuki, 2019; Amano & Tamari, 2022; Amano et al., 2021; Dobson et al., 2013; Mostafaee et al., 2025).

The Five-Times Sit-to-Stand Test (FTSTS)

FTSTS evaluates dynamic balance, lower-limb strength, and movement coordination during repeated Sit-to-Stand transitions. The FTSTS measures the time required to rise from and sit down on a standard armless chair (seat height 43–45 cm) five consecutive times as quickly as possible without using the arms (Goldberg et al., 2012). A trial is valid if all five repetitions are completed continuously without arm support and with full knee and hip extension while maintaining balance; otherwise, the trial is repeated after rest.

A longer completion time reflects reduced lower-limb strength and/or impaired coordination (Goldberg et al., 2012). In KOA, FTSTS performance is typically slower, reflecting pain-related movement adaptations, reduced contribution from the affected leg, and asymmetrical weight bearing (Christiansen et al., 2011; Naili et al., 2018). Previous studies identified thresholds of approximately 7.9–9.0 seconds as predictive of increased fall risk in older adults with knee osteoarthritis (Amano & Suzuki, 2019; Amano & Tamari, 2022) although these values were derived from Japanese samples and may not be directly applicable to Vietnamese adults with different anthropometric characteristics. FTSTS requires movement patterns comparable to those observed during the Sit-to-Stand and Stand-to-Sit tasks analysed in this thesis.

The One-Leg Standing Test (OLST)

OLST measures static balance by recording the time an individual can maintain single-leg stance without support (Vellas et al., 1997). Timing begins when the foot leaves the floor and ends when it touches the ground, when the stance foot moves, or when balance is lost.

Two to three attempts were allowed, and the longest standing time is recorded in seconds (Oliveira et al., 2019; Springer et al., 2007).

This test reflects the ability to control the body's centre of mass over a narrow base of support, a key component of postural stability (Vellas et al., 1997). Research in older adults has documented side-to-side differences in OLST, suggesting that neither leg reliably outperforms the other in static balance tasks of this type (Inoue et al., 2025). Therefore, reporting an average of the right and left OLST results provides overall balance performance (Khanal et al., 2021).

Shorter stance time indicates reduced proprioceptive control and decreased confidence in the affected limb, which have been frequently reported in KOA (Hinman et al., 2002; Wilfong et al., 2023). In these individuals, OLST performance is influenced by impaired proprioception, quadriceps inhibition, altered sensory feedback, and pain-related adaptations (Rice & McNair, 2010; Sharma et al., 1997).

Relevance to the thesis

Together, FTSTS and OLST provide complementary insights into postural performance in knee osteoarthritis. The FTSTS reflects dynamic control during repetitive movement transitions, whereas the OLST assesses static stability during single-limb support. Both tests have been commonly applied in studies on KOA, where they demonstrated predictive value for identifying fall risk (Amano & Suzuki, 2019; Amano & Tamari, 2022; Amano et al., 2021). In this thesis, these two tests are used as global indicators of physical performance, providing a clinical reference to support the interpretation of biomechanical analyses of functional tasks presented in the following section.

Functional tasks for biomechanical evaluation

This thesis examined functional tasks involving bodyweight transfer to characterise postural control in KOA, they are common in daily life and place different demands on balance and coordination. While walking has been frequently studied, transitional movements such as rising from and sitting down on a chair or initiating gait also provide valuable insights into balance regulation. The following sections describe these tasks: bipodal transitions (Sit-to-Stand and Stand-to-Sit) and a unipodal transition (gait initiation).

Bipodal transitions: Sit-to-Stand

Sit-to-Stand: definitions and analytical frameworks

Sit-to-Stand is a mechanically demanding functional task requiring coordinated upward motion of the lower limb segments while maintaining balance. The primary goal is to raise the body's centre of mass from sitting to standing without loss of stability. To initiate rising, the trunk flexes forward to shift the centre of mass toward the feet as load transfers from the chair to the lower limbs, and at seat-off the resultant of the ground reaction force becomes slightly inclined backward, passing in front of the hip and ankle joints while remaining behind the knee, which generates extension moments at the hip and ankle and a flexion moment at the knee (Kerr et al., 1997; Roebroeck et al., 1994) **(Figure I2)**.

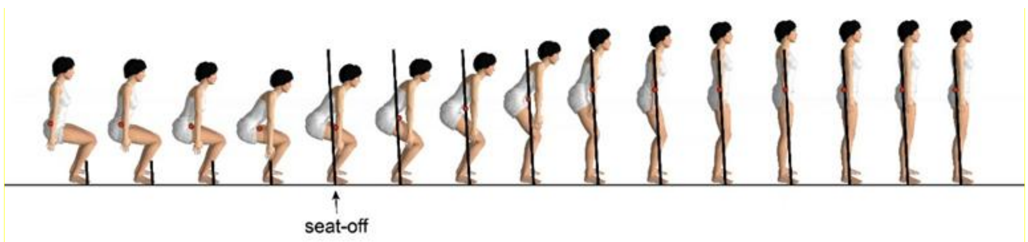

Figure I2. Illustration of the Sit-to-Stand transfer sequence. The quasi-vertical line represents the amplitude and orientation of the ground reaction force. Adapted from Roebroeck et al. (1994).

To better capture postural control, these authors proposed three phases based on the velocity profile of the body centre of mass **(Figure I3)**. *The acceleration phase* is characterised by forward trunk flexion that increases horizontal velocity of the body centre of mass, *the transition phase* by the redirection of the body centre of mass near seat-off, where horizontal velocity decreases and vertical velocity increases, and *the deceleration phase* by slowing control into upright stance. This division emphasises not only the change in direction of body centre of mass motion at seat-off, but also the requirement to first accelerate and then decelerate the body centre of mass to reach upright stability, which makes it particularly relevant for analysing balance control (Roebroeck et al., 1994). However, because this approach defines acceleration and deceleration based on body centre of mass velocity rather than lower-limb force production, it does not show how the lower limbs generate the forces that produce these changes or how these forces are distributed between the legs throughout the movement.

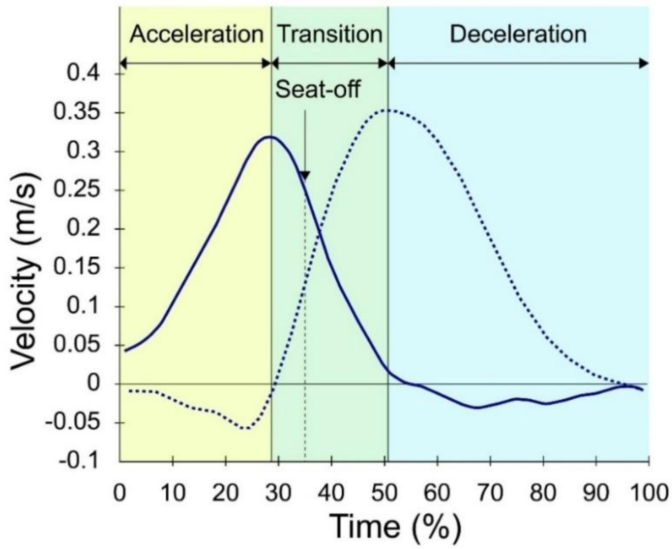

Figure I3. Horizontal (solid line) and vertical (dashed line) velocities of the centre of mass of the body during the Sit-to-Stand transfer, expressed as a percentage of movement time. The dotted vertical line marks the instant of seat-off, and the solid vertical lines indicate the boundaries between the three phases: acceleration (yellow), transition (green), and deceleration (blue). Adapted from Roebroeck et al. (1994)

Kerr et al. defined seven key events of the Sit-to-Stand movement kinematic measures of trunk displacement and knee joint angles: (1) *initiation of forward lean* (T_1), (2) *initiation of knee extension* (T_2), (3) *initiation of vertical displacement* (T_3), (4) *final forward lean* (T_4), (5) *final vertical displacement* (T_5), (6) *final knee extension* (T_6), and (7) *final backward lean* (T_7). And four phases are defined: *the forward lean* where the trunk flexes to shift the centre of mass anteriorly, generating horizontal momentum for rising; *the knee angular displacement phase* marked by the onset of knee extension and the production of vertical force through the lower limbs; *the vertical displacement phase* characterised by the upward motion of the trunk once seat contact is lost, marking the transfer from forward to vertical movement; and *the recovery phase* characterised by the realignment of the trunk over the pelvis to achieve upright stance (Kerr et al., 1997; Kerr et al., 1994) **(Figure I4)**. These phases overlap in time, reflecting continuous coordination between trunk flexion and lower-limb extension during rising (Kerr et al., 1997; Kerr et al., 1994).

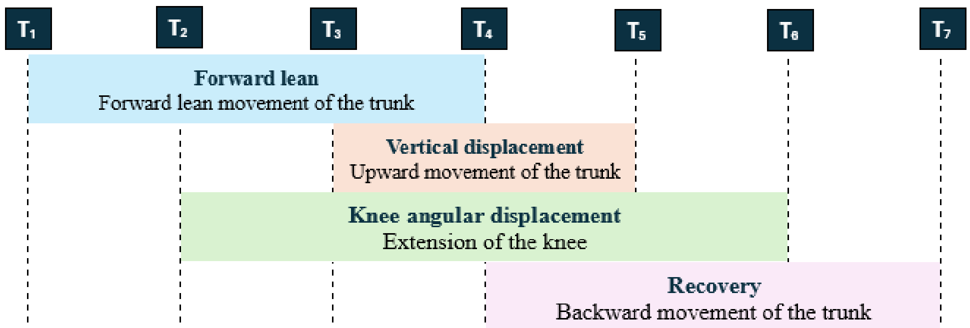

Figure I4. Phases, components, and temporal events of the Sit-to-Stand portion of the sit-stand-sit cycle. T_1: initiation of forward lean; T_2: initiation of knee extension; T_3: initiation of vertical displacement; T_4: final forward lean, T_5: final vertical displacement, T_6: final knee extension; T_7: final backward lean. Adapted from Kerr et al. (1994)

To enable phase analysis without requiring kinematic measurements, Etnyre and Thomas (2007) proposed to describe the task on three phases based on the vertical (F_z), fore-aft, lateral components of ground reaction forces and on a plate under the seat to mark the seat-off transition from preparation to rising when the seat force dropped below a 5 N threshold. The first phase is the flexion phase characterised by a preparatory reduction in F_z as the trunk flexes forward and load is partially transferred to the feet. The second phase is the extension phase, characterised by a rapid increase in F_z after seat-off when the lower limbs generate vertical force to elevate the body. The third and last phase is the stabilisation phase characterised by the gradual stabilisation of F_z at body weight once upright stance is achieved. Although their analysis included 3D force components, they demonstrated that F_z alone provides a reliable basis for defining the main phases of rising, supporting the practicality of approaches of using 1D-force plates under the feet in Sit-to-Stand studies (Etnyre & Thomas, 2007) **(Figure I5)**. Therefore, a force-plate-based approach focusing on vertical loading is both practical and compatible with the analytical framework of the present study.

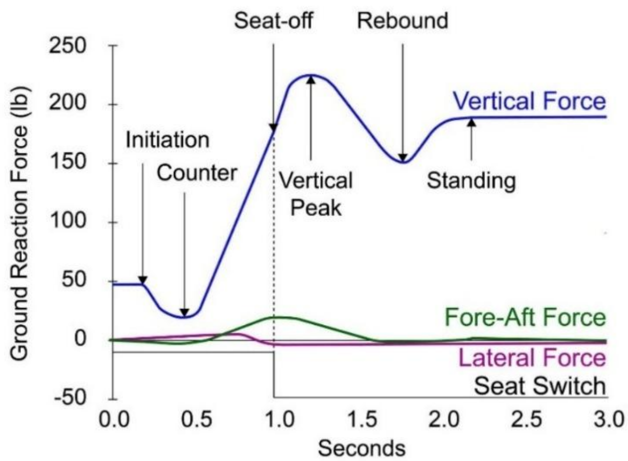

Figure I5. Ground reaction force recordings and event definitions during a Sit-to-Stand movement. The plot illustrates the vertical (F_z), fore–aft (F_y), and lateral (F_x) component of ground reaction forces during a Sit-to-Stand trial. The dotted trace represents the seat-switch signal (SS). Arrows indicate the six events identified from the F_z curve: initiation, counter movement, seat-off, vertical peak, rebound, and standing. Adapted from Etnyre and Thomas (2007).

Based on the event definitions proposed by Etnyre and Thomas (2007), the Sit-to-Stand task was divided into two phases. The rising phase corresponds to the transition from sitting to upright posture and comprises two parts: the first from initiation to the vertical peak of the ground reaction force, and the second from the vertical peak to the rebound. The stabilisation phase extends from the rebound to standing (Piano et al., 2020; Schenkman et al., 1990; Sipko et al., 2016).

In summary, Sit-to-Stand involves a rising period followed by stabilisation. Within this framework, the movement can be further described by acceleration and deceleration phases, which capture the mechanical characteristics analysed in this study.

Sit-to-Stand in healthy young adults

Sit-to-Stand (SitTS) in healthy young adults is performed as a continuous and well-coordinated action. After a brief forward lean that shifts the centre of mass toward the feet, bodyweight transfers smoothly from the chair to the lower limbs. Vertical force rises rapidly after seat-off as the hip and knee extensors elevate the body, while the trunk progressively realigns over the pelvis. Segmental movements occur with considerable temporal overlap, resulting in a fast and symmetrical rise with a short stabilisation period at the end (Roebroeck et al., 1994; Kerr et al., 1997).

Muscle activation occurs in a distal-to-proximal sequence involving the tibialis anterior, quadriceps, hamstrings, and gluteus maximus (Frykberg & Häger, 2015; Roebroeck et al., 1994). Extensor moments at the hip and knee are the main contributors to the upward acceleration of the COM, while ankle plantar flexors stabilise the body during the final stages of rising (Caruthers et al., 2016). The coordination of these muscle groups allows healthy young adults to perform the task rapidly and symmetrically, with overlapping segmental movements and efficient control of postural equilibrium.

Effect of ageing on Sit-to-Stand

Older adults tend to flex the trunk faster and further forward at the beginning of the movement to bring the body's centre of mass closer to the feet before rising. This forward inclination generates momentum that facilitates rising and improves stability at seat off, reflecting an adaptive strategy to maintain balance rather than a simple response to weakness (Kerr et al., 1997; Papa & Cappozzo, 2000; Van Der Kruk & Geijtenbeek, 2024). After seat off, the lower limbs extend more slowly and with less overlap between trunk flexion and leg extension, resulting in a slower and more phase-by-phase movement (Papa & Cappozzo, 2000). Owing to this strategy, their relative muscular effort during Sit-to-Stand is similar to that of young adults while stability is better preserved (Ahn et al., 2024). However, this pattern takes longer to complete, produces lower peak vertical force and velocity, shows less overlap between trunk flexion and lower-limb extension, and requires more time to stabilise once upright (Papa & Cappozzo, 2000; Piano et al., 2020). The stabilisation phase is the most distinct feature of older adults, being markedly longer than in young adults (Akram & McIlroy, 2011; Piano et al., 2020). In summary, older adults prioritise stability over mechanical efficiency when performing the Sit-to-Stand task.

Bipodal transition: Stand-to-Sit

Stand-to-Sit: definitions and analytical frameworks

Although Stand-to-Sit is often assumed to be the opposite of Sit-to-Stand, it relies on different neuromechanical demands (Ashford & De Souza, 2000). Sitting down requires forward trunk flexion while maintaining the body's centre of mass within the base of support before descent begins. Then, the lower limbs generate eccentric muscle activity, particularly at the hip and knee, to decelerate the vertical downward motion of the body and avoid a hard landing on the chair (Ashford & De Souza, 2000; Kerr et al., 1997).

Kerr et al. divided the Stand-to-Sit as a sequence of seven kinematic events: (1) initiation of forward lean (T_8), (2) *initiation of knee flexion* (T_9), (3) *initiation of vertical displacement* (T_{10}), (4) *final forward lean* (T_{11}), (5) *final knee flexion* (T_{12}), (6) *final vertical displacement* (T_{13}), and (7) *final backward lean (recovery)* (T_{14}) **(Figure I6)**. The movement starts with forward trunk inclination and knee flexion, followed by controlled vertical lowering and backward trunk motion to stabilise the sitting posture. This framework provides a detailed reference for analysing Stand-to-Sit performance and shows that the task relies on coordinated eccentric control of the lower limb extensors to regulate body descent and ensure a smooth transition to sitting (Kerr et al., 1997; Kerr et al., 1994) **(Figure I6).**

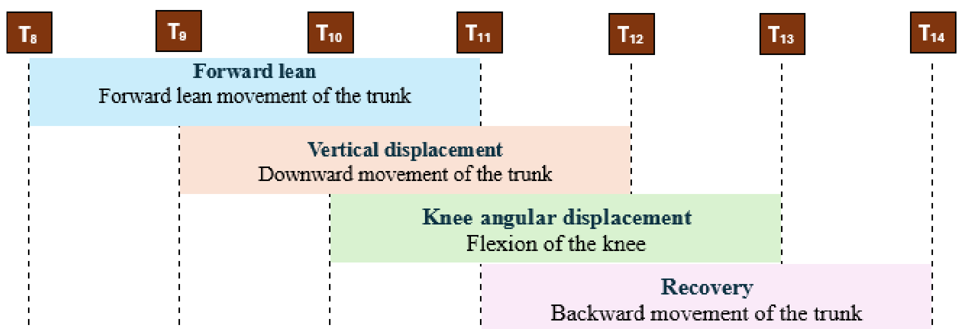

Figure I6. Phases, components, and temporal events of the Stand-to-Sit portion of the sit-stand-sit cycle. T_8: initiation of forward lean; T_9: initiation of knee flexion; T_{10}: initiation of vertical displacement; T_{11}: final forward lean, T_{12}: final knee flexion, T_{13}: final vertical displacement; T_{14}: final backward lean. Adapted from Kerr et al. (1994)

More recently, Jeon et al. (2024) analysed the Stand-to-Sit task using an event-based approach derived from combined force-plate, motion-capture, and EMG measurements. They identified four temporal events: (A) *onset of Stand-to-Sit*; (B) *initiation of vertical ground reaction force descent*; (C) *start of seat contact*; and (D) *completion of the movement.* Yet, these events were reported only in figure legends, without any definitions or detection criteria provided in the Methods. The authors defined the descending phase of the task as the period from the onset of movement (A) to just before seat contact (C), and the segment from A to B was described as a controlled descent, during which knee extensor eccentric activation increased and reached its maximum at the initiation of vertical component of the ground reaction force decrease (B) (Jeon et al., 2024) **(Figure I7)**.

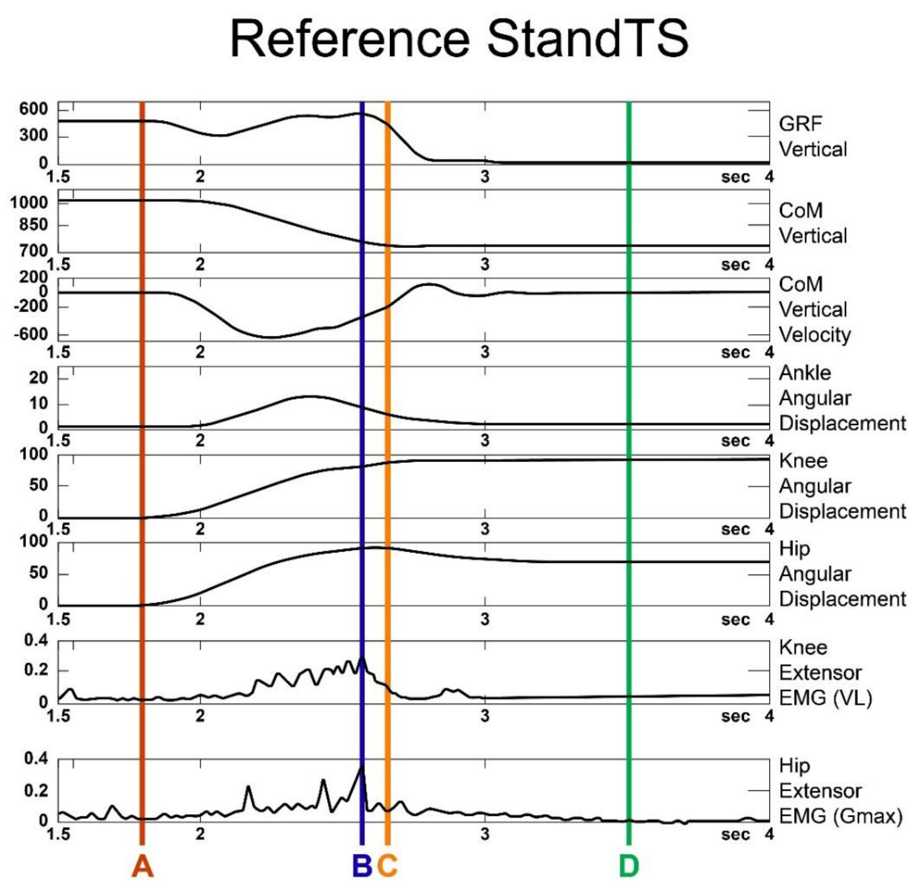

Figure I7. Kinematic, kinetic, EMG profiles and temporal events of the Stand-to-Sit task. A: Onset of Stand-to-Sit (red vertical line); B: Initiation of vertical ground reaction force descent (purple vertical line); C: Start of seat contact (orange vertical line); D: Completion of the movement (green vertical line). Modified from Jeon et al. (2024).

Stand-to-Sit in healthy young adults

In healthy young adults, Stand-to-Sit is performed as a smooth, well-coordinated movement that prioritises control of the body's downward motion. The task begins with forward trunk flexion that shifts the centre of mass forward over the feet, followed by hip and knee flexion in which the lower-limb extensors act eccentrically to decelerate the descent. As the body approaches the seat, vertical velocity decreases and load is gradually transferred from the feet to the seat, ending with small postural adjustments to achieve stable sitting (Kerr et al., 1997; Kerr et al., 1994; Kralj et al., 1990). Movement smoothness is associated with greater eccentric work at the hip and knee joints and reduced postural sway at seat contact, reflecting precise control of balance and momentum (Jeon et al., 2024).

Effect of ageing on Stand-to-Sit

In older adults, the total duration of descent is similar to that of young adults. However, they perform the movement with greater trunk flexion, slower trunk velocity, and reduced coordination between the trunk and lower limbs, reflecting a more cautious and segmented pattern (Kerr et al., 1997). The hip and knee extensors act less synchronously, leading to a less smooth transfer of load to the seat and greater reliance on gravity rather than active eccentric control, indicating reduced braking capacity of the lower limbs and increased dependence on passive dynamics (Akram & McIlroy, 2011; Jeon et al., 2024; Kondo et al., 2022). In general, ageing affects both the eccentric control and intersegmental coordination components of the Stand-to-Sit task, leading to less controlled descent and reduced postural stability after sitting.

Bipodal to unipedal transition: Gait initiation

Gait initiation: definitions and analytical frameworks

Gait initiation is the transition from quiet standing to steady walking. It requires the body to generate forward momentum while maintaining balance as support shifts from both feet to one foot (Breniere & Do, 1986; Yiou et al., 2017). The movement begins with anticipatory postural adjustments (APAs), which slightly shift the COM forward relative to the feet to prepare for stepping. During these adjustments, the COP first moves backward and slightly toward the leading leg. This backward shift changes the direction of the ground reaction force, causing the COM to move toward the trailing leg and transferring weight to that leg to prepare for stepping (Brenière & Do, 1991; Cau et al., 2014). As the COP then shifts under the trailing leg, it moves behind the COM and generates a forward-directed force that propels the body into stepping. Adjustments along the anteroposterior axis predict motor performance through forward propulsion, whereas those along the mediolateral axis predict postural stability through weight transfer control (Yiou et al., 2017).

Several divisions have been proposed to describe the sequence. Early investigations divided gait initiation into two broad phases: an anticipatory phase during which postural adjustments generate instability to initiate movement, and a locomotor phase when the COM follows an inverted pendulum trajectory over the trailing foot (Breniere & Do, 1986; Brenière & Do, 1991). Later divisions, based on COP trajectories, refined this description by identifying three phases: a backward–lateral COP shift toward the leading leg (*APA1*), a lateral shift toward the trailing leg (*APA2*), and a forward progression during the locomotor phase (*LOC*). These frameworks captured the main temporal features of balance control but did not describe the detailed load transfer between limbs (Breniere & Do, 1986; Brenière & Do, 1991; Halliday et al., 1998).

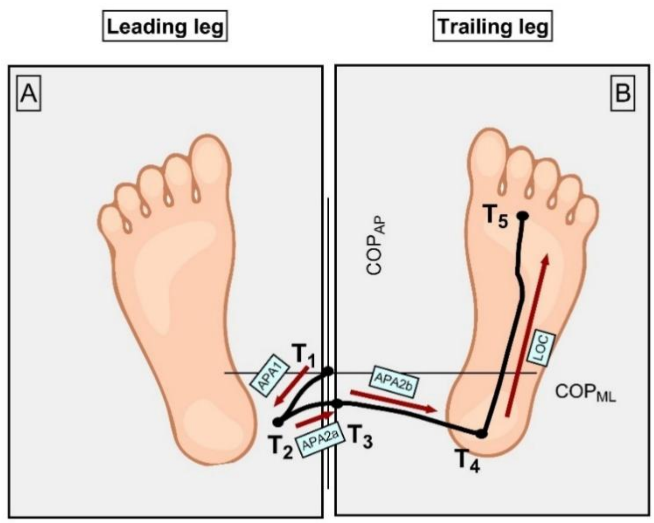

Figure I8. Schematic of the COP trajectory during gait initiation. T1: onset of centre of pressure net in antero-posterior direction (COP_{AP}); T2: the time of the minimum of COP_{AP}, T_3: the time of the maximum of COP_{AP} between T2 and T4; T_4 the last moment before step-off of the leading leg; T_5 the last moment before step-off of the trailing leg. Adapted from Cau et al. 2014.

To address this limitation, a four-phase division (*APA1, APA2a, APA2b*, and *LOC*) was later proposed, based on COP trajectories measured from dual force plates (Cau et al., 2014) **(Figure I8)**. It distinguishes two subphases (APA2a and APA2b) within APA2, allowing a more detailed representation of the mechanical transitions between postural control and locomotor propulsion. It has since been applied under different experimental conditions, becoming a reference framework for analysing gait initiation (Cau et al., 2014; da Silva Soares et al., 2020; Signorelli et al., 2025).

The four phases/subphases are illustrated in **Figure I8** and defined as follows:

- *APA1 subphase* which corresponds to the interval between the initial backward (T_1) and the first minimum anteroposterior displacement value of the COP toward the leading leg (T_2) (Cau et al., 2014). During this subphase, the COP shifts backward toward the leading leg heel. This motion, produced by the inhibition of the soleus and the activation of the tibialis anterior, shifts the COP posteriorly, while hip abductor–adductor activity generates a mediolateral displacement (Breniere & Do, 1986).
- *APA2a subphase* which begins when the COP reverses direction and moves laterally toward the trailing leg, corresponding to the interval between T_2 and the first maximum anteroposterior displacement value of the COP (T_3). During this subphase, COP shifts forward towards the trailing leg, with an increasing load transfer to that leg. Heel-off of the leading leg typically occurs during this phase, while F_z under the leading leg continues to decrease (Cau et al., 2014; Yiou et al., 2017).
- *APA2b subphase* which corresponds to the subsequent anticipatory movement between T_3 and the second minimum anteroposterior displacement value of the COP (Cau et al., 2014). During this subphase, the COP shifts further backward toward the trailing leg heel, reaching its most lateral and posterior position just before toe-off of the leading leg. This backward placement of the COP creates an anteriorly directed ground reaction force that propels the COM forward (Brenière & Do, 1991; Cau et al., 2014). At the same time, F_z under the trailing leg increases sharply as it bears nearly the entire body weight, while F_z under the leading leg approaches zero at toe-off (Cau et al., 2014).
- *LOC phase* which begins once the leading leg leaves the ground. Then, the COP moves forward under the trailing leg as the COM accelerates ahead. At this stage, the body behaves like an inverted pendulum pivoting over the ankle of the trailing leg. The COM moves forward around the ankle joint, and the ground reaction force acts upward and slightly backward to control the body and transform it into forward

propulsion. The F_z under the trailing leg peaks during this period, representing the vertical push that propels the body upward. The phase ends when the leading heel contacts the ground, restoring a broader base of support and completing the transition to steady walking (Brenière & Do, 1991).

This four-phase model integrates both the horizontal COP displacement and F_z modulation that together ensure a smooth and stable transition from posture to locomotion. Because the present study analyses kinetic data recorded from dual force plates, this division provides a suitable analytical framework for identifying phases and quantifying vertical loading during gait initiation (Cau et al., 2014).

Gait initiation in healthy young adults

In healthy young adults, gait initiation is a rapid and well-coordinated transition that efficiently converts postural stability into forward progression. The anticipatory adjustments occur in a smooth and symmetrical pattern, reflecting precise control of both balance and propulsion (Yiou et al., 2017; Zhao et al., 2021). Previous study showed that the hip extensors of the leading leg and the ankle plantar flexors of the trailing leg provide most of the forward propulsive work, ensuring a smooth transfer of momentum between legs (Zhao et al., 2021). The amplitude of the initial COP displacement and the forward COM velocity at toe-off are strongly correlated with step length and walking velocity, illustrating the fine coordination between stability and propulsion achieved in young adults (Yiou et al., 2017; Zhao et al., 2021).

Effect of ageing on gait initiation

Ageing affects both the timing and magnitude of anticipatory postural adjustments during gait initiation. Older adults typically exhibit smaller and slower COP displacements and reduced COM forward velocity at step onset, reflecting cautious control of stability (Kimijanová et al., 2021; Polcyn et al., 1998). The amplitude of the backward COP shift in the anteroposterior direction is reduced, and its duration is prolonged, suggesting a prioritisation of balance maintenance over forward propulsion (Polcyn et al., 1998). Compared with young adults, the lateral COP displacement toward the trailing leg is smaller and slower, resulting in less effective unloading of the leading leg and a longer time to achieve toe-off (Kimijanová et al., 2021). Consequently, older adults spend more time in the anticipatory subphase, with reduced COM acceleration and smaller momentum generation during the transition to the first step (Polcyn et al., 1998). Recent evidence also suggests age-related differences in motor inhibition that may contribute to slower movement onset (Kwag et al., 2024). These changes lead to a more gradual and conservative transition from posture to locomotion, with shorter step length and slower gait initiation velocity (Kimijanová et al., 2021; Polcyn et al., 1998).

Overall, older adults appear to adopt a stability-prioritising strategy, characterised by prolonged APAs, smaller COP and COM excursions, and lower propulsive forces. This strategy may help compensate for age-related declines in lower-limb strength and sensory integration, but at the cost of slower and less dynamic movement.

Effects of Knee Osteoarthritis on Sit-to-Stand and Stand-to-Sit

Sit-to-Stand in Knee Osteoarthritis

It is unclear if knee osteoarthritis modifies the duration of the Sit-to-Stand task. Some studies report a longer total duration and a longer deceleration–stabilisation period in KOA (Anan et al., 2015; Duffell et al., 2013; Pan et al., 2024; Sonoo et al., 2019; Turcot et al., 2012), while others found no differences (Bouchouras et al., 2015; Sagawa et al., 2017; Verlaan et al., 2018).

KOA are reported to show greater forward trunk flexion during the early forward-leaning segment of Sit-to-Stand, where the trunk inclines to bring the centre of mass toward the feet (Duffell et al., 2013; Petrella et al., 2019; Sagawa et al., 2017; Sonoo et al., 2019). Hip and knee range of motion is reduced, whereas ankle motion is less consistently affected (Bouchouras et al., 2015; Pan et al., 2024; Verlaan et al., 2018).

Peak vertical ground reaction force is generally similar between KOA and healthy older adults (Anan et al., 2015; Sonoo et al., 2019; Verlaan et al., 2018). In unilateral KOA, the vertical component of the ground reaction force - including integrals, peak and average- has been reported to be lower on the symptomatic side, indicating an asymmetrical contribution between legs (Christiansen et al., 2011; Duffell et al., 2013; Petrella et al., 2021).

Stand-to-Sit in Knee Osteoarthritis

Although less studied, the Stand-to-Sit task also provides valuable information on postural control and dynamic stability. The total duration of descent is longer than in healthy adults, particularly during the deceleration phase before seat contact (Fu et al., 2021; Pan et al., 2023). KOA also reduce the speed of descent and require more time to stabilise once seated, accompanied by larger anterior–posterior and mediolateral centre-of-pressure excursions, indicating reduced control during the terminal part of the movement (Fu et al., 2021; Lim & Lee, 2012). Kinematic and kinetic changes have also been reported, including reduced hip and knee range of motion, lower knee extensor moments, and less smooth segmental coordination during descent, while ankle mechanics appear less affected (Pan et al., 2023).

Effects of Knee Osteoarthritis on Gait initiation

KOA show altered anticipatory and locomotor patterns compared with healthy older adults. The total duration of the movement is prolonged, mainly due to longer anticipatory postural adjustment phases, while the amplitude and velocity of the COP displacement are reduced (da Silva Soares et al., 2020; Esfandiari et al., 2020). These changes reflect a cautious strategy that prioritises stability over forward propulsion, possibly influenced by pain, altered muscle activation, and the need to protect the affected joint (da Silva Soares et al., 2020; Esfandiari et al., 2020). The backward COP displacement during APA1 is typically smaller, and the lateral shift toward the trailing leg during APA2 occurs more slowly and over a shorter distance, resulting in delayed toe-off and reduced forward acceleration of the COM. Consequently, the push of the trailing leg is reduced and the transition from standing to locomotion becomes slower. These adaptations are observed even in early-stage KOA, indicating that altered postural strategies may develop before marked structural impairment occurs (da Silva Soares et al., 2020; Esfandiari et al., 2020).

Generally, gait initiation in KOA is characterised by prolonged APA duration, smaller CoP displacement, reduced forward propulsion, and a stability-oriented movement strategy (da Silva Soares et al., 2020; Esfandiari et al., 2020; Signorelli et al., 2025).

Knowledge Gaps

Across Sit-to-Stand, Stand-to-Sit, and gait initiation tasks, individuals with knee osteoarthritis show a consistent alteration of postural control. Movements are slower, COP excursions smaller, and vertical force patterns less dynamic, showing a tendency toward more stability-prioritised control.

Previous kinetic studies have mainly focused on simple temporal or global force parameters, such as total movement time, peak vertical force, or overall COP displacement, without analysing how postural control evolves throughout each phase. As a result, the mechanisms underlying this alteration remain to be explored. Second, most studies examine each task separately and reports mechanical findings in isolation, without linking them to patients' perceived function or performance outcomes. Third, most comparisons have also been limited to age matched controls, making it difficult to distinguish disease related adaptations from those associated with normal ageing.

Kinetic assessment represents a feasible and informative approach for studying postural control in Vietnam, where simplified and portable one-dimensional force-plate systems offer an affordable yet sufficiently sensitive tool for capturing key kinetics features. These measurements provide clinically meaningful insight when combined with functional and self-reported outcomes. Comparing individuals with knee osteoarthritis, healthy older adults, and young adults helps distinguish disease-related adaptations from age-related changes. These findings may also support rehabilitation for individuals with knee osteoarthritis by highlighting specific aspects of postural control that can inform assessment and guide targeted intervention.

2. Aims and structure of the present thesis

The overall aim of this thesis is to investigate postural control in KOA through a combination of kinetic, self-reported, and performance-based approaches.

- **Study 1** investigates the cross-cultural adaptation and validation of the Vietnamese version of the KOOS (KOOS-V).
- **Study 2** investigates the kinetics of the Sit-to-Stand and Stand-to-Sit tasks (bipodal control) and explores their relationships with FTSTS performance and KOOS-V scores.
- **Study 3** investigates gait initiation (unipodal control), focusing on anticipatory postural adjustments and asymmetry patterns and relating these findings to clinical outcomes.

Together, these studies provide an integrated view of postural control in KOA and its relation to pain and function. Each study forms one chapter of the thesis, followed by a general discussion summarizing the main findings, clinical implications, and perspectives for future work.

CHAPTER 1

General methods

This thesis comprises two distinct methodological components. The first component (Chapter 2) focuses on the translation, cultural adaptation, and psychometric validation of the Vietnamese version of the Knee injury and Osteoarthritis Outcome Score (KOOS-V). The second component (Chapters 3 and 4) consists of experimental studies using force-plate recordings to examine the kinetic characteristics of Sit-to-Stand, Stand-to-Sit, and gait initiation. Detailed task procedures and outcome definitions are provided within each chapter, while the present section outlines the general methodological principles common to the experimental studies.

1.1. Methods for the cross-cultural adaptation and validation study

Permission to translate and update the Vietnamese version of the KOOS was obtained from Mapi Research Trust (https://eprovide.mapi-trust.org), the official distributor of the instrument. A formal request was submitted and approved, followed by the signing of a Master User License Agreement. The approval record and license agreement are shown in **Figure 1.1**.

This component followed a cross-sectional design and comprised two phases:

- Translation and cross-cultural adaptation of the KOOS into Vietnamese, and
- Psychometric evaluation of the adapted version in individuals with knee osteoarthritis.

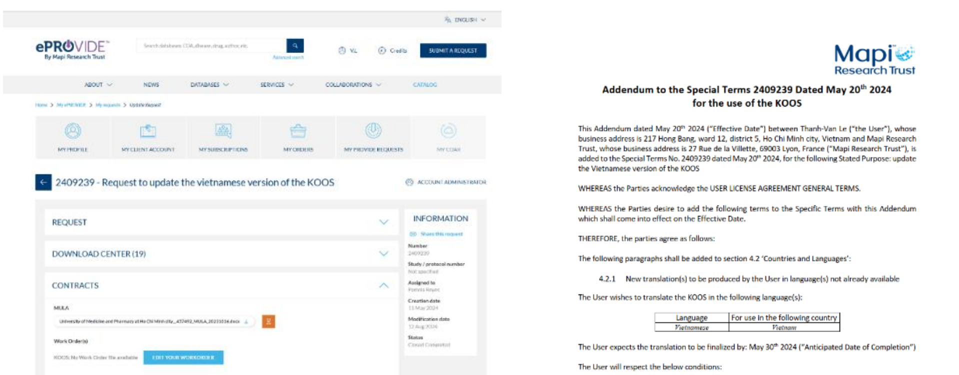

Figure 1.1. Documentation of translation permission for the Vietnamese KOOS.

Translation and cross-cultural adaptation

The KOOS was translated and culturally adapted into Vietnamese following the five-step procedure recommended by Beaton et al. (2000) **(Figure 1.2)**. The steps were as follows:

Step 1. Forward translation (English to Vietnamese)

Two independent forward translations were produced. The first was completed by an occupational therapist who has been studying abroad in English for six years and familiar with the terminology, and the second by an English teacher. These two versions (T1 and T2) formed the initial Vietnamese drafts.

Step 2. Synthesis of the forward translations

The two forward translators and one investigator met to review T1 and T2 item by item. All discrepancies in wording and interpretation were discussed until consensus was reached. This process generated a single Vietnamese version, referred to as T12.

Step 3. Back translation (Vietnamese to English)

The T12 version was independently back-translated into English by two bilingual individuals who were not involved in the previous steps and were unaware of the original KOOS. One back translator was a Canadian-Vietnamese office worker, and the other was an American-Vietnamese physiotherapist. The two back-translated versions (BT1 and BT2) were used to verify conceptual correspondence with the original questionnaire.

Step 4. Expert committee review

An expert committee consisting of seven members, including the four translators from earlier steps, a language professional, a methodologist, and a physiotherapist, reviewed the original KOOS, the T12 version, and the two back translations. The committee evaluated semantic, idiomatic, experiential, and conceptual equivalence, and made revisions where necessary. This process resulted in the pre-final KOOS-V.

Step 5. Pretesting

The pre-final KOOS-V was administered to 30 individuals with knee osteoarthritis. Participants were asked about the clarity and relevance of each item. Any issues raised during pretesting were incorporated into the instrument.

Content validity of the final KOOS-V was then evaluated by a separate panel of seven experts who were not involved in the translation steps. Each expert independently rated the relevance and clarity of every item. Item-level Content Validity Index (I-CVI) values were calculated as the proportion of experts rating an item as relevant. Scale-level indices were also computed: the average scale-level CVI (S-CVI/Ave), representing the average of all I-CVI values, and the universal agreement CVI (S-CVI/UA), reflecting the proportion of items receiving unanimous agreement across all experts.

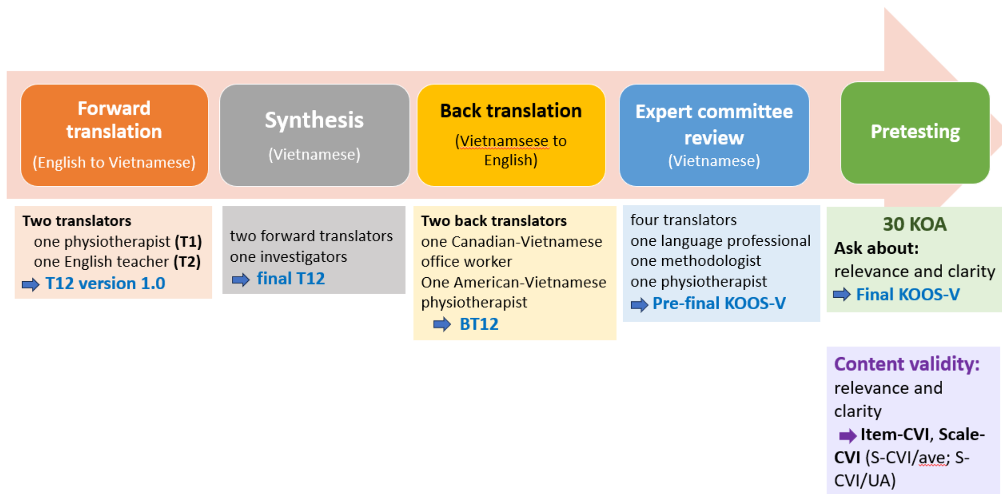

Figure 1.2. Overview of the translation and cross-cultural adaptation procedure for the KOOS-V

Psychometric evaluation

The psychometric evaluation of the Vietnamese version of the KOOS (KOOS-V) included the assessment of internal consistency, test–retest reliability, construct validity, and cultural validity. The procedures are summarised in **Figure 1.3**.

Participants and study design

A cross-sectional design was used for the validity analyses. Individuals with clinically diagnosed knee osteoarthritis were recruited from outpatient clinics and community settings in Ho Chi Minh City. A total of 133 participants completed the first assessment. Of these, 67 participants returned for a second assessment after 7–14 days to evaluate score stability. Participants were excluded if they had neurological, vestibular, cardiovascular, or acute musculoskeletal conditions affecting lower-limb function or balance, or if they were unable to stand or walk independently.

All participants provided written informed consent. The study was approved by the Ethics Committee of the University of Medicine and Pharmacy at Ho Chi Minh City (Approval No. 642/HDDD-DHYD, dated 03/07/2023).

Internal consistency

Internal consistency of each KOOS-V subscale (Pain, Symptoms, Activities of Daily Living, Sport/Recreation, and Quality of Life) was examined using Cronbach's alpha, with values ≥ 0.70 considered acceptable, ≥ 0.80 good, and ≥ 0.90 excellent.

Test–retest reliability

Test–retest reliability was assessed in the subsample of 67 participants using the two-way mixed-effects intraclass correlation coefficient ($ICC_{3,1}$; absolute agreement). ICC values were interpreted as follows: <0.50 = poor; 0.50–0.75 = moderate; 0.75–0.90 = good; >0.90 = excellent reliability.

The Standard Error of Measurement (SEM) and Minimal Detectable Change at 95% confidence (MDC_{95}) were also computed.

Construct validity

Construct validity was examined through convergent and discriminant validity hypotheses.

Convergent validity

Two external measures were used:

- SF-36, for correlations with conceptually related subscales (e.g., KOOS-ADL with SF-36 Physical Functioning; KOOS-QoL with SF-36 Emotional or Social domains).
- Numeric Pain Rating Scale (NPRS), for expected moderate correlations with the KOOS Pain subscale.

Pearson or Spearman coefficients were used depending on score distribution and interpreted as: <0.25 weak or none; 0.25–0.50 weak to moderate; 0.50–0.75 moderate; >0.75 strong.

Discriminant validity

Lower correlations were expected between KOOS-V subscales and SF-36 domains that measure unrelated constructs (e.g., KOOS Symptoms vs SF-36 Mental Health), supporting discriminant validity.

Cultural validity

Cultural validity was explored by comparing KOOS-V subscale scores with published data from other countries where the KOOS has been validated. Similar patterns of subscale hierarchy and dispersion across versions were interpreted as evidence that the Vietnamese version performs consistently with international KOOS datasets and does not display cultural response distortion.

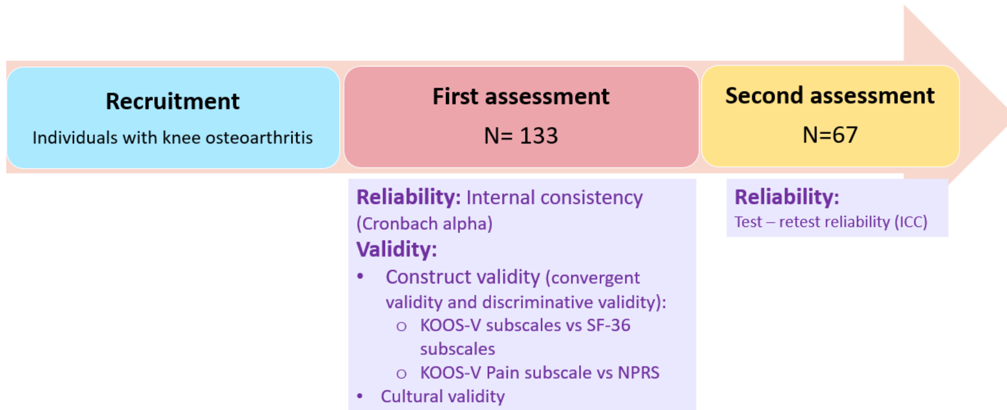

Figure 1.3. Overview of the psychometric evaluation procedures for the KOOS-V

1.2. Methods for the experimental study

Experiment setup

All experimental recordings were carried out in the laboratory established at the Department of Rehabilitation, School of Nursing and Medical Technology, University of Medicine and Pharmacy at Ho Chi Minh City (UMP).

The vertical component of ground reaction forces was measured using a pair of one-dimensional force plates (TwinPlates® 1D-Twin Plates 400300, Arsalis SRL, Belgium), each equipped with a four vertical load cell. Signals were sampled at 1000 Hz and low-pass filtered using an 8th-order Bessel filter with a 25 Hz cutoff. Data acquisitions were performed in TwinPlates® software. The two plates were aligned side-by-side with one cm apart, allowing separate measurement of the vertical component of the ground reaction force under each foot. Participants stood with each foot entirely within the boundaries of one plate. For Sit-to-Stand and Stand-to-Sit, a height-adjustable chair without armrests was used. Chair height was individually adjusted to create a 90° knee angle, following recommendations for kinetic analysis of Sit-to-Stand tasks (Anan et al., 2015; Bouchouras et al., 2015; Petrella et al., 2021; Sagawa et al., 2017; Turcot et al., 2012; Verlaan et al., 2018).

Participants

Three groups were included: individuals with knee osteoarthritis (KOA), age matched healthy older adults (HOA), and healthy young adults (HYA). KOA were recruited from community sources and from outpatient departments of the University Medical Center, An Binh Hospital, the Hospital of Traditional Medicine, and Le Van Thinh Hospital. Diagnosis of knee osteoarthritis followed the clinical criteria of the National Institute for Health and Care Excellence: adults aged ≥ 45 years with activity-related knee pain and either no morning stiffness or morning stiffness lasting ≤ 30 minutes (NICE, 2020). These criteria identified most symptomatic cases in community-treated samples, detecting 89% of individuals with knee osteoarthritis compared with 48–52% using EULAR (European League Against Rheumatism) or ACR (American College of Rheumatology) criteria (Skou et al., 2020). HOA were recruited through public advertisements, were age- and sex-matched with KOA, and reported no history of knee pain. HYA were recruited from the student population of the Department of Rehabilitation Sciences.

Exclusion criteria for all groups included neurological, vestibular, cardiovascular conditions that could affect balance or ability to walk or stand independently, as well as any current or previous painful or symptomatic musculoskeletal disorders of the lower-limb or lumbar spine (Kim et al., 2011; Kostro et al., 2024). Group-specific characteristics are provided in each chapter.
All participants gave written informed consent. The studies were approved by the Ethics Committee of the University of Medicine and Pharmacy in Ho Chi Minh City (approval number 389/ DHYD-HDDD and 3347/ĐHYD-HDDD).

Sample size

Sample size considerations were based on published kinetic studies of Sit-to-Stand and gait initiation in individuals with knee osteoarthritis, which reported between-group effect sizes of around 0.75 for Sit-to-Stand (Bouchouras et al., 2015) and 0.5–0.9 for anticipatory postural adjustments and early loading variables during gait initiation (da Silva Soares et al., 2020; Esfandiari et al., 2020; Katoh, 2019; Viton et al., 2000).

An a priori power analysis using G*Power ($\alpha = 0.05$, power ≥ 0.80) indicated that detecting effects within this range requires approximately 10–12 participants per group. All experimental chapters therefore targeted sample sizes at or above this threshold.

General Procedures

Data collection procedure is summarized in **Figure 1.4**. Before data collection, each participant changed into shorts and barefoot. After providing written informed consent, demographic information was obtained. The experimental session then followed a standardized sequence for all groups (see description below).

Functional performance tests

For individuals with knee osteoarthritis and healthy older adults, two functional performance tests were administered before the experimental tasks.

One-Leg Standing Test (OLST)

Single-leg balance was assessed separately for each leg. Participants stood upright with their arms by their sides and lifted one foot off the ground without touching the stance leg. Timing began when the foot left the floor and ended when the lifted foot touched the floor, the stance foot moved, the arms left the sides. Three trials were conducted for each leg and the best performance (longest standing time) was recorded. Longer durations reflected better single-leg balance.

Five-Time Sit-to-Stand Test (FTSTS)

Participants sat on a backless, armless chair adjusted to achieve approximately 90° of knee flexion, with their feet flat on the floor and their arms crossed over the chest. At the verbal cue "Go," they stood up and sat down five consecutive times as quickly as possible. Timing started at the cue and ended when the participant reached full standing after the fifth repetition. Trials were repeated if the participant used the arms for support, did not perform all five repetitions, or did not complete each stand and sit fully.

Self-reported measures

Individuals with knee osteoarthritis additionally completed the Vietnamese Knee Injury and Osteoarthritis Outcome Score (KOOS-V), including all subscales, and rated knee pain for each leg using the Numeric Pain Rating Scale, a validated and widely used measure of pain intensity (Jensen et al., 1999).

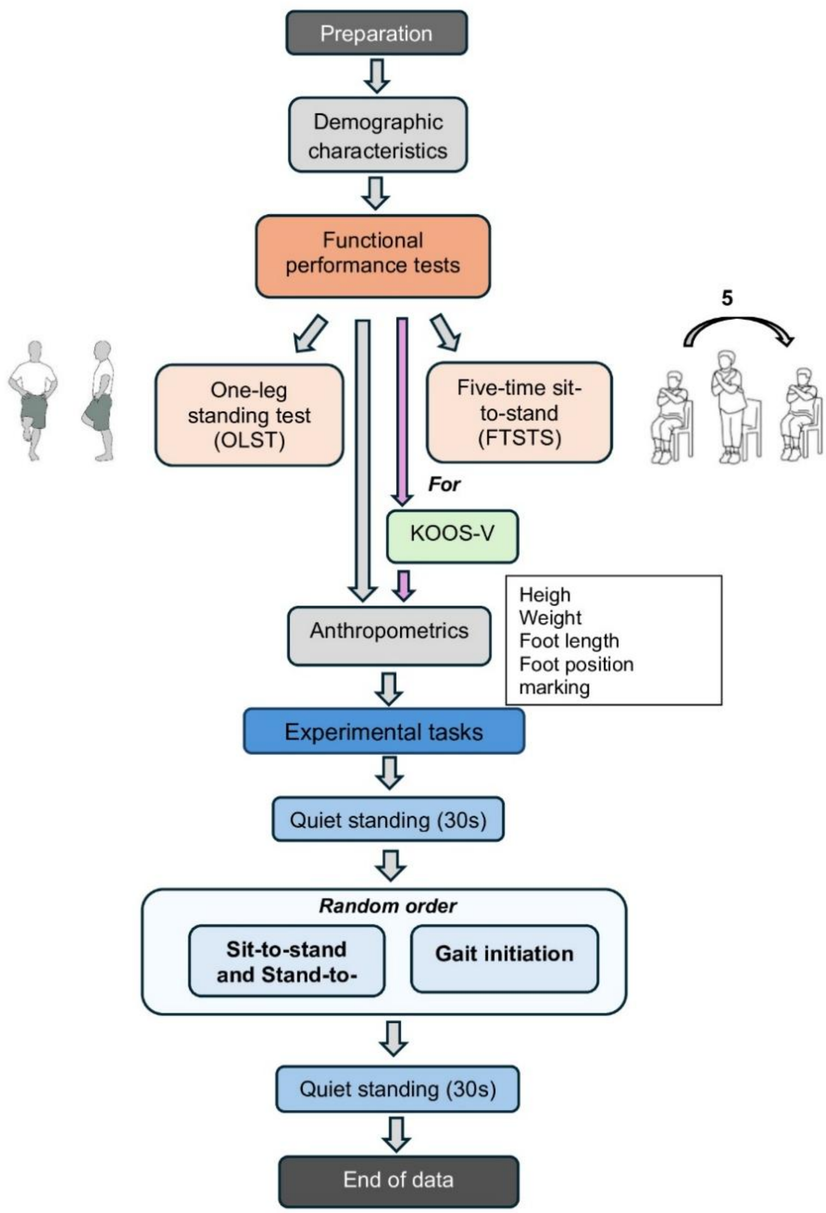

Figure 1.4. Overview of the data collection procedure

Anthropometric measurements

Height and foot length were measured before the experimental tasks. Body weight was recorded using the force plates. While standing quietly on the plates, participants were instructed to adopt a comfortable position **(Figure 1.5A)**. The foot outlines were marked and maintained throughout the session to ensure consistent foot placement across tasks **(Figure 1.5B)**.

[A] **[B]**

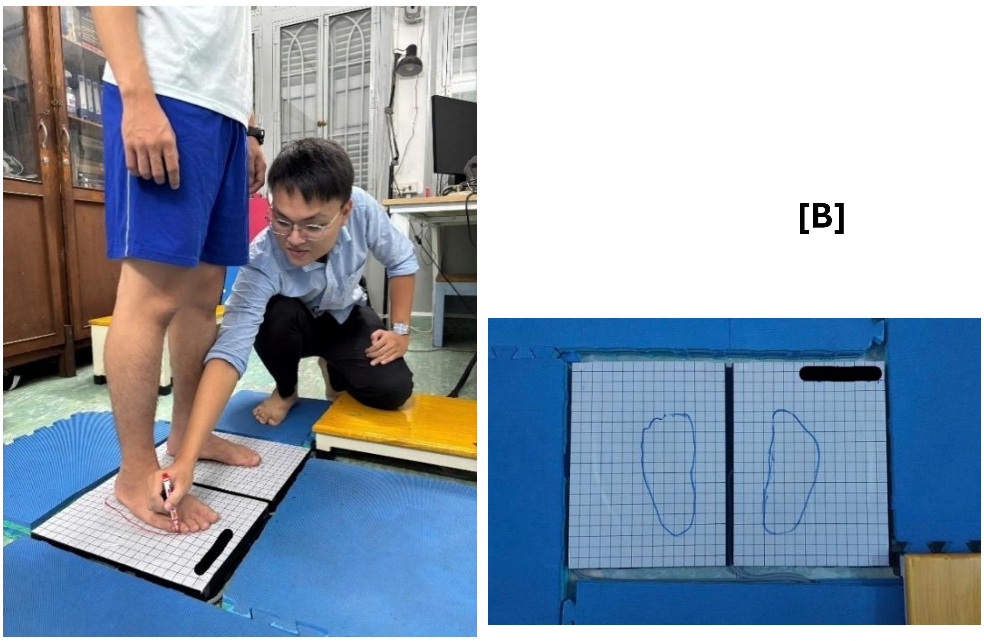

Figure 1.5. Standing posture for anthropometric measurements [A] and marked foot outlines to standardize foot placement across tasks [B]

Experimental tasks

All participants performed quiet standing for 30 seconds at both the beginning and end of the session. During quiet standing, participants kept their arms by their sides and looked straight ahead. The experimental tasks, Sit-to-Stand, Stand-to-Sit, and gait initiation, were randomised for each participant **(Figure 1.4)**. Before each task, the investigator demonstrated the movement and the participant performed practice trials. During data acquisition, the investigator stood beside the participant to provide assistance if necessary and to prevent falls.

Sit-to-Stand and Stand-to-Sit tasks

For the Sit-to-Stand and Stand-to-Sit tasks, participants began each trial seated quietly for five seconds. At the verbal cue "Stand up," they rose as fast as possible and then remained standing for 10 seconds. They then received the cue "Sit down" and returned to the seated position as fast as possible, followed by five seconds of quiet sitting. Each task was performed three times with one-minute rest between trials **(Figure 1.6)**.

Figure 1.6. Illustration of the Sit-to-Stand and Stand-to-Sit sequence performed during a trial.

Gait initiation task

For the gait initiation task, participants stood quietly on the force plate for five seconds. At the verbal cue "Go," they initiated walking as fast as comfortable using their preferred stepping leg and continued forward for around one m. Three trials were performed. The procedure was then repeated for the non-preferred leg, with three additional trials. Participants were allowed to rest between trials if needed **(Figure 1.7)**.

Figure 1.7. Illustration of the gait initiation task: quiet standing before the cue (left), stepping with the preferred leg (middle), and stepping with the non-preferred leg (right)

CHAPTER 2

Cross-cultural adaptation and validation of the Vietnamese version of the Knee Injury and Osteoarthritis Outcome Score (KOOS) in patients with knee osteoarthritis

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This chapter addresses the need for a culturally appropriate patient-reported outcome measure to complement the performance-based and kinetic assessments used in this thesis. Because individuals with knee osteoarthritis often report limitations that cannot be fully explained by objective measures alone, a validated instrument is essential for capturing their perceived symptoms, functional difficulties, and quality of life. This chapter therefore presents the development of the Vietnamese version of the Knee Injury and Osteoarthritis Outcome Score (KOOS-V), including its translation, cultural adaptation, and evaluation of key measurement properties. Establishing a reliable self-reported measure provides the foundation for integrating subjective and objective perspectives in the subsequent chapters.

Introduction

Knee osteoarthritis (KOA) is a degenerative disease leading to pain, stiffness and reduced mobility. It is ranked as the fourth leading cause of disability and affects over 600 million people globally in 2020 (Cui et al., 2020). Assessing the functional status of people with KOA is crucial for determining the disease's impact, planning treatment and evaluating intervention effectiveness. Several instruments are commonly used to assess the functional impact of KOA, including the Knee Injury and Osteoarthritis Outcome Score (KOOS) or its short form, the Knee Outcome Survey Activities of Daily Living Scale (KOS-ADL), the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) and the Activity Rating Scale (Collins et al., 2011). Among these instruments, most only focus on specific aspects of knee function and/or pain level, while the KOOS stands out as a comprehensive patient-reported outcome measure covering pain, symptoms, activities of daily living and quality of life (Collins et al., 2011).

The original KOOS exhibited good test-retest reliability (ICC= 0.75-0.93) and internal consistency (Cronbach's α= 0.71-0.95) (Roos, Roos, Lohmander, et al., 1998). Construct validity is demonstrated by significant correlations with SF-36 subscales, with the KOOS showing stronger correlations with the SF-36 physical function (r = 0.68), bodily pain (r = 0.69) and role physical (r = 0.55) than with mental health subscales, indicating good convergent and divergent validity (Roos, Roos, Lohmander, et al., 1998). Moreover, the KOOS is widely used for patients with KOA, having been employed in clinical and research settings for over 30 years and translated into 57 languages since its development (Roos, 2024).

The KOOS is currently distributed by the Mapi Research Trust (Mapi Research Trust, 2024; Roos, 2024). To date, 26 translations have undergone formal validation with 18 studies including patients with KOA (Alfadhel et al., 2018; Almeida et al., 2022; Cheng et al., 2019; Cheung et al., 2016; de Groot et al., 2008; Fatima et al., 2021; Goldhahn et al., 2017; Gonçalves et al., 2009; Jha et al., 2021; Moutzouri et al., 2015; Multanen et al., 2018; Ornetti et al., 2008; Phatama et al., 2021; Roos, Roos, Ekdahl, et al., 1998; Xie et al., 2006; L. Yang et al., 2023; Zulkifli et al., 2017). The psychometric properties of the KOOS translations which were done on KOA population showed satisfactory internal consistency (Cronbach's α = 0.70-0.98) and good to excellent test-retest reliability (ICC= 0.76-0.94) (Alfadhel et al., 2018; Cheng et al., 2019; Roos, Roos, Ekdahl, et al., 1998; L. Yang et al., 2023). The construct validity of KOOS has been evaluated using various convergent and divergent assessments. Convergent validity was shown by moderate to strong correlation between the KOOS subscales and the Physical Functioning related subscales of the SF-36 (r = 0.49-0.83) (Alfadhel et al., 2018; Almeida et al., 2022; Cheung et al., 2016; de Groot et al., 2008; Goldhahn et al., 2017; Gonçalves et al., 2009; Multanen et al., 2018; Phatama et al., 2021; Roos, Roos, Ekdahl, et al., 1998; Xie et al., 2006; L. Yang et al., 2023) and between the KOOS Pain subscale and the NPRS (r= 0.51- 0.79) (Alfadhel et al., 2018; Cheng et al., 2019; de Groot et al., 2008; Gonçalves et al., 2009; Multanen et al., 2018), highlighting the ability of the KOOS to capture the various functional consequences of knee health problems. When compared with the Mental Health related subscales of the SF-36, the KOOS subscales display weak to moderate correlations (r = 0.02-0.43), underscoring the distinct domains assessed by both instruments (Alfadhel et al., 2018; Goldhahn et al., 2017; Roos, Roos, Ekdahl, et al., 1998). The reliability and validity assessments of the KOOS underscore its current acceptance as a valuable tool for evaluating KOA across different languages and cultural adaptations (Alfadhel et al., 2018; Almeida et al., 2022; Cheung et al., 2016; de Groot et al., 2008; Goldhahn et al., 2017; Gonçalves et al., 2009; Multanen et al., 2018; Phatama et al., 2021; Xie et al., 2006; L. Yang et al., 2023)

While KOA affects an average of 23% of the global population (Cui et al., 2020), its prevalence is even higher in certain countries, such as Vietnam, where its affects 34% of individuals aged 40 years or more (Ho-Pham et al., 2014). However, to date, there is no validated Vietnamese version of the KOOS, limiting its use in clinical and research settings. Therefore, a cross-sectional study was conducted to translate the KOOS into Vietnamese and assess the psychometric properties of the translation (KOOS-V) on patients with knee osteoarthritis in Vietnam.

Material and methods

Main outcome measure

KOOS is a self-administered survey including 42 items that cover five subscales: Pain (P, 9 items), Symptom (S, 7 items), Function in daily living (ADL, 17 items), Function in sports and recreational activities (Sport/Rec, 5 items) and Quality of Life (QoL, 4 items). A 5-level Likert scale is used to rate each item (e.g. 0= None, 1= Mild, 2= Moderate, 3= Severe, 4= Extreme). Subscale scores are calculated as 100 – (mean of subscale items scores)/4 x 100, with higher scores indicating better condition (Roos, Roos, Lohmander, et al., 1998).

Translation and cross-cultural adaptation

Approval for the translation was obtained from the original developer, Professor Ewa Maria Roos, as well as from the official distributor via www.eprovide.mapi-trust.org, following the linguistic validation procedure outlined by Mapi Research Trust (Mapi Research Trust, 2024). A translation contract was signed between the distributor and the author prior to the translation process.

The translation of the KOOS into Vietnamese included five stages according to the guidelines of the American Academy of Orthopaedic Surgeons (Beaton et al., 2000): forward translation (Stage I) by two independent native Vietnamese speakers, synthesis (Stage II) with one investigator together with the translators to reconcile both forward translations, back translation (Stage III) of the reconciled version by two native English speakers unfamiliar with the KOOS concepts, expert committee review (Stage IV) including seven experts to reconcile both back translations, produce the pre-final version and pretestand then cognitive interviews (Stage V) that involved 30 Vietnamese patients with KOA to assess and adjust the prefinal version to produce the final Vietnamese version of the KOOS (KOOS-V). The final version is now available at: https://eprovide.mapi-trust.org/instruments/knee-injury-and-osteoarthritis-outcome-score.

A group of experts was formed with seven physiotherapists to provide independent ratings on the relevance and clarity of the final KOOS-V questionnaire. Content validity, ensuring a comprehensive content representation, was assessed using a Content Validity Index (CVI). To compute the Item-CVI (I-CVI), the experts were asked to score each of the 113 translated parts of text, including the instructions, titles, item labels, response categories and scoring instructions. A 4-point scale was used to rate each translated text for relevance ("Not relevant"/ “Somewhat relevant”/ “Quite relevant”/ “Highly relevant” scored as 1 to 4) and for clarity ("Not clear"/ “Somewhat clear”/ “Quite clear”/ “Highly clear” scored as 1 to 4). The I-CVI was calculated for each translated text as the proportion of experts who scored the Vietnamese translations either 3 or 4; with scores above 0.79 indicating excellent content validity (Zamanzadeh et al., 2015). To compute an aggregate content validity index for the whole translation, a Scale-level CVI (S-CVI) was computed to assess either average agreement (S-CVI/Ave) or universal agreement (S-CVI/UA). The S-CVI/Ave was computed as the average of all I-CVI for each translated text and the S-CVI/UA as the proportion of the 113 translated texts that were scored 3 or 4 by all experts.

Participants

Participants diagnosed with KOA and undergoing medical or physiotherapy treatment was recruited in Vietnam, from 12 hospitals in Ho Chi Minh City, Dang Nang city and Hanoi city, between July and November 2023. The participants needed to be Vietnamese residents proficient in the Vietnamese language. The study adhered to the ethical standards delineated in the Declaration of Helsinki and approved by the Ethical Committee of the University of Medicine and Pharmacy at Ho Chi Minh City, Vietnam (Approval number: 642/HDDD-DHYD, dated 03/07/2023). Written informed consent was obtained from all participants.

Validation questionnaires

The Vietnamese version of the SF-36 and the Numeric Pain Rating Scale (NPRS) were used to assess the construct validity of the KOOS-V. The SF-36 is a widely-used self-reported health questionnaire covering eight domains: physical functioning (PF, 10 items), physical role limitations (PR, 4 items), bodily pain (BP, 2 items), general health perception (GH, 5 items), energy/vitality (VT, 4 items), social functioning (SF, 2 items), emotional role limitations (ER, 3 items), mental health (MH, 5 items) and perceived health change (HC, 1 item). Each subscale score (0-100) is calculated as the average item score, with higher scores reflecting better health (Ware, 2000). The NPRS, a generic pain assessment tool, was used to evaluate general knee pain. Participants were asked to rate their overall knee pain intensity on an 11-point scale (0-10), with higher scores indicating more pain. Scores of 1-3 denoted mild pain, 4-6 denoted moderate pain and scores of 7 or higher denoted severe pain (Boonstra et al., 2016).

Procedures

The KOOS-V, SF-36 and NPRS were administered in a face-to-face interview. All 133 participants completed these three outcome measures at baseline. The participants were re-contacted by telephone after 5-8 days following the interview to assess the test-retest reliability of the KOOS-V. This time interval was selected to prevent any functional change and recall of the first assessment answers (Collins et al., 2016).

Cross-cultural validation

The cross-cultural validity of the KOOS-V was evaluated by comparing the mean scores in Vietnam with the scores reported in other validated translations of the KOOS either in Asian or in European countries. Studies were included in the comparison only if the original subscales were unchanged as compared to the original KOOS. The Asian versions included Arabic-Saudi Arabi (Alfadhel et al., 2018), Cantonese-Hong Kong (Cheng et al., 2019), Chinese-China (L. Yang et al., 2023), Chinese–Singapore (Xie et al., 2006), English-Singapore (Xie et al., 2006), Hindi-India (Jha et al., 2021), Japanese-Japan (Goldhahn et al., 2017), Indonesian-Indonesia (Phatama et al., 2021), and Urdu-Pakistan (Fatima et al., 2021). The European versions included French-France (Ornetti et al., 2008), Portuguese-Portugal (Gonçalves et al., 2009), Finnish – Finland (Multanen et al., 2018), Dutch – Netherland (de Groot et al., 2008), Greek-Greece (Moutzouri et al., 2015), and Swedish–Sweden (Roos, Roos, Ekdahl, et al., 1998).

Statistical analysis

For each subscale of the KOOS-V, SF-36 and NPRS, the mean score and standard deviation were computed and these scores were treated as continuous variables. For reliability evaluation, the internal consistency of the initial administration was assessed for each subscale of the KOOS-V using Cronbach's alpha and was considered to be acceptable if greater than 0.70 (Collins et al., 2016; Terwee et al., 2007). Test-retest reliability for each subscale of the KOOS-V was evaluated with the intraclass correlation coefficient ($ICC_{3,1}$) for each subscale of the KOOS-V using a two-way mixed effect model for absolute agreement (Koo & Li, 2016). The ICC values were interpreted as follows: < 0.5: poor reliability; 0.5-0.75: moderate reliability; 0.75-0.9: good reliability; > 0.9: excellent reliability (Koo & Li, 2016). The standard error of measurement (SEM) for each subscale of the KOOS-V was computed as SEM= $s_p \times \sqrt{1-ICC}$ where $s_p = \sqrt{0.5 * (s_1^2 + s_2^2)}$ with s_1 being the standard deviation of the first test and s_2 being the standard deviation of the re-test(Portney & Watkins, 2017). The minimum detectable change (MDC_{95}) for each subscale of the KOOS-V, denoting the smallest change in a score that can be considered a 'real' change beyond measurement error, was computed as $MDC_{95} = 1.96 \times \sqrt{2} \times$ SEM (Portney & Watkins, 2017). For validity evaluation, the floor and ceiling effects were determined based on the number of participants scoring zero or 100, respectively. Construct validity was assessed as the relationship between the KOOS-V, the SF-36 and the NPRS using Spearman's correlation coefficients (ρ), interpreted as follows: ≤ 0.25: weak relation; 0.25–0.50: weak to moderate; 0.50 to 0.75: moderate and ≥ 0.75: strong relation (Portney & Watkins, 2017). All the results were presented with 95% confidence intervals (CI). Two-tailed tests were used to assess statistical significance, with a p-value threshold of 0.05. All statistical analyses were performed using SPSS 29.0.1.0 (IBM, New York, USA).

Results

Translation and cross-cultural adaptation of the KOOS-V

Minor modifications were made to adapt the KOOS to the Vietnamese context. Indeed, item "Getting in/out of car" was adapted as "Getting in/out of vehicle" to better reflect the transportation context in Vietnam, where car usage is less common. Item "Getting in/out of bath" was changed to "Getting in/out of places where you clean yourself" based on participants' feedback and item "How much are you troubled with lack of confidence in your knee?" was changed to "How much are you troubled with lack of reassurance in your knee". Additionally, during the pretest of the ADL and Sport/Rec subscales, most participants misinterpreted the response "None" as not being able to perform the activity while this response intends to indicate that the patient perceives no difficulty. Therefore, the response label was changed from "None" to "No difficulty" for the final KOOS-V questionnaire.

All items were rated with an I-CVI score of 1.00 for clarity, leading to a scale-level content validity index of 1.00 for both S-CVI/ave and S-CVI/UA. For relevance, I-CVI scores ranged from 0.86 to 1.00, with corresponding S-CVI/ave and S-CVI/UA values of 1.00 and 0.99, respectively, indicating excellent content validity for the final KOOS-V (see the supplementary table at the end of the chapter: Content validity index of the KOOS-V).

Psychometric properties of the KOOS-V

A total of 133 patients with KOA were enrolled in this study. The demographic and clinical data of the participants are presented in **Table 2.1**. No missing values were observed for the KOOS-V, SF-36, or the NPRS. The average score of the five KOOS-V subscales ranged from a maximum of 65.8 for ADL to a minimum of 32.7 for Sport/Recreation, as shown in **Table 2.2**. This indicates that participants generally reported the most difficulty with Sport/Recreation activities and the ADL activities were considered the least challenging. Among the participants, 18.1% scored the lowest possible score (zero) on the Sport/Recreation subscale indicating a floor effect of this subscale. For the other subscale, the percentage of participants scoring zero ranged from 0 to 2.3%. Additionally, the percentage of participants achieving the highest score (100) on any subscale ranged from 0 to 5.3%. The internal consistency was acceptable in all subscales with Cronbach's α ranging from 0.70 – 0.98.

Table 2.1. Demographic and clinical characteristics of the participants (n= 133)

Parameter	Value
Age (years), mean ± SD**, min-max**	63.7 ± 9.7, 41-84
Gender, n (%)	
Female	110 (83 %)
Male	23 (17 %)
Body weight (kg), mean ± SD, min-max	58.2 ±9.1, 36-88
Body Mass Index (kg/m^2), mean (SD), min-max	23.9 (3.3), 16.4 - 32.4
Duration of KOA, n (%)	
<1 year	28 (21 %)
1-3 years	38 (29 %)
3-5 years	15 (11 %)
5-7 years	13 (10 %)
>7 years	39 (29 %)
Level of pain, n (%)	
Mild (NPRS 1-3)	15 (11 %)
Moderate (NPRS 4-6)	65 (49 %)
Severe (NPRS 7-10)	53 (40 %)
Limb affected, n (%)	
Unilateral	48 (36 %)
Bilateral	85 (64 %)
Use of walking aid, n (%)	
No	115 (86 %)
Yes	18 (14 %)

KOA: Knee osteoarthritis, **NPRS=** Numeric Pain Rating Scale

Table 2.2. Descriptive statistics and internal consistency for KOOS-V (n= 133)

KOOS-V subscale	Mean ± SD	Floor effect (%)	Ceiling effect (%)	Cronbach's α
Symptom	64.2 ± 21.1	0	5.3	0.82
Pain	57.4 ± 23.2	1.5	0	0.93
ADL	65.8 ± 25.4	2.3	1.5	0.98
Sport/Recreation	32.7 ± 27.6	18.1	1.5	0.91
Quality of life	45.6 ± 19.2	0.8	0	0.70

KOOS-V: the Vietnamese version of the Knee Injury and Osteoarthritis Outcome Score

Test-retest reliability of the KOOS-V

A total of 71 participants were re-assessed. Four participants with a non-similar pain condition compared to the first assessment, as shown by a NRPS score change higher than 2 points, were excluded to ensure consistency in condition between the two assessments (Jensen et al., 2003). Hence, a total of 67 participants were retained for the test-retest reliability analysis. According to the COSMIN guidelines, this sample size is considered adequate for reliability studies, ensuring the validity of the reliability assessment (Mokkink et al., 2019). A good reliability was observed for each subscale ($ICC_{3,1}$ from 0.77 to 0.90, **Table 2.3**). Additionally, the standard error of measurement (SEM) ranged from 6.4 to 10.1 and the minimum detectable change (MDC_{95}) ranged from 17.7 to 27.9 **(Table 2.3)**.

Table 2.3. Average scores and test-retest reliability for KOOS-V subscale (n= 67)

KOOS-V subscale	Test Mean±SD	Retest Mean±SD	SEM	MDC_{95}	$ICC_{3,1}$ (95%CI)
Symptom	61.5 ± 20.5	62.1 ± 19.3	6.4	17.7	0.90
Pain	54.4 ± 21.6	57.2 ± 20.2	9.0	25.0	0.81
ADL	64.6 ± 24.0	66.1 ± 21.6	7.6	21.0	0.89
Sport/Recreation	31.0 ± 28.2	31.9 ± 26.3	10.1	27.9	0.86
Quality of life	43.4 ± 17.6	45.8 ± 17.3	8.4	23.3	0.77

KOOS-V: the Vietnamese version of the Knee Injury and Osteoarthritis Outcome Score, SEM: standard error of measurement; MDC_{95}: minimum detectable change; $ICC_{3,1}$: intraclass correlation coefficient.

Construct validity of the KOOS-V

The correlations of the subscale scores of the KOOS-V with the SF-36 and NPRS are presented in **Table 2.4**. All subscales had a moderate to strong correlation with the SF-36 Physical Functioning subscale ($\rho = 0.66 - 0.82$), a moderate correlation with the Bodily Pain ($\rho = 0.56 - 0.71$) and with the Energy/vitality ($\rho = 0.53 - 0.58$) subscales, a weak to moderate correlation with the Physical role limitations ($\rho = 0.40 - 0.59$), General health perception ($\rho = 0.33 - 0.50$), Social functioning ($\rho = 0.32 - 0.57$), Emotional role limitations ($\rho = 0.35 - 0.47$) and Mental health ($\rho = 0.38 - 0.49$) subscales of the SF-36. All subscales of the KOOS-V also showed a moderate negative correlation with the NPRS (rho = -0.49 to -0.62). The p-values for all correlation coefficients were less than 0.001.

Cross-cultural validity of the KOOS-V

The mean score to the KOOS-V subscales demonstrated a pattern that is consistent with translations in other languages, indicating that the KOOS subscales followed a parallel trend across different countries **(Figure 2.1)**. Three subscales, Symptom, Pain and ADL consistently showed higher scores, indicating that these domains display lower or less frequent functional limitations. The Sport/Rec and Quality of life subscales consistently showed lower scores, indicating that these domains are relatively more challenging for patients with KOA whatever their country.

Table 2.4. Spearman's correlation coefficients between the KOOS-V, SF-36 and NPRS

	KOOS-V				
	Sympto m	Pain	ADL	Sport/ Recreation	Quality of life
SF-36					
Physical functioning	**0.66**	**0.71**	**0.82**	**0.78**	**0.69**
Physical role limitations	0.44	**0.50**	**0.59**	0.49	0.40
Bodily pain	**0.60**	**0.64**	**0.71**	**0.61**	**0.56**
General health perception	0.33	0.42	**0.50**	0.44	0.47
Energy/Vitality	**0.54**	**0.57**	**0.58**	**0.56**	**0.53**
Social functioning	0.47	0.49	**0.57**	0.45	0.32
Emotional role limitations	0.39	0.47	0.42	0.35	0.35
Mental health	0.44	0.49	0.49	0.38	0.39
NPRS	**-0.62**	**-0.59**	**-0.58**	-0.49	**-0.57**

All correlations were statically significant (p <0.001, 2-tailed). Correlation coefficients greater than |0.50|, indicating a moderate or strong relationship, are highlighted in bold.

The Vietnamese scores to the KOOS subscales were in the top half of all Asian countries, indicating a smaller challenge in Vietnam as compared to most other Asian countries **(Figure 2.1, upper panel)**. Compared to other European countries, the Vietnamese scores were close to the top of the score range, indicating that the KOOS subscales represent a higher challenge in Europe than in Vietnam **(Figure 2.1, lower panel)**. Together these observations indicate that the KOOS-V subscales follow the same trend in all studied European and Asian countries, even if KOA patients in Asian countries tend to report higher scores than in European countries and if the scores to the Sport/Rec subscale are relatively lower in some countries (e.g. Singapore).

Discussion

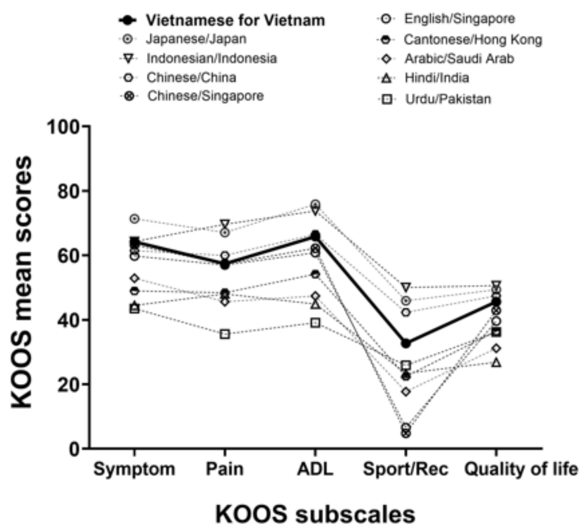
The aim of this study was to translate the KOOS to Vietnamese and to evaluate the psychometric properties of the Vietnamese version (KOOS-V). The translation demonstrated strong psychometric properties, including high content validity, satisfactory internal consistency and good test-retest reliability. Construct and cross-cultural validity were also confirmed, showing that assessments with the KOOS-V in Vietnam convey the same clinical content as in other countries.

The translation process followed a comprehensive process recommended by Beaton and colleagues, encompassing forward and backward translations, synthesis, expert committee reviews and pretesting (Beaton et al., 2000). Similar challenges to those reported in prior studies were encountered. First, terminology related to transportation and bathing activities required further adjustments for cultural adaptation, as observed in the Finnish and Brazilian translation (Almeida et al., 2022; Multanen et al., 2018). Second, the inclusion of the term "none" in the responses for the ADL and Sport/Recreation subscales aimed to improve clarity, aligning with adaptations made in the Saudi Arabian version of the KOOS (Alfadhel et al., 2018). These adjustments resulted in excellent content validity, with content validity indices ranging from 0.86 to 1.00, underscoring the relevance and clarity of the KOOS-V to assess KOA in the Vietnamese population. Among previous versions, only the Chinese version conducted a content validity analysis and similar results were reported (Cheng et al., 2019). The reliability of the KOOS-V was assessed through internal consistency and test-retest analysis. The KOOS-V showed high internal consistency across the Symptoms (0.82), Pain (0.93), ADL (0.98) and Sport/Recreation (0.91) subscales compared to the original Swedish version (0.74, 0.84, 0.95 and 0.85 respectively) as other translated versions (Cheng et al., 2019; Cheung et al., 2016; Gonçalves et al., 2009; Jha et al., 2021; Moutzouri et al., 2015; Multanen et al., 2018; Ornetti et al., 2008; Roos, Roos, Ekdahl, et al., 1998; Xie et al., 2006). This indicates strong agreement among these items and consistent interpretation by Vietnamese patients. In contrast, the internal consistency of the Quality of Life subscale (0.70) was lower than other subscales but similar to the original KOOS (0.71) and versions adapted for Chinese (0.71), Singaporean (0.71) and Dutch (0.73) populations (Cheung et al., 2016; de Groot et al., 2008; Roos, Roos, Ekdahl, et al., 1998; Xie et al., 2006; L. Yang et al., 2023). This may be attributed to the influence of Cronbach's alpha on subscale length, as longer subscales tend to yield higher reliability values (Tavakol & Dennick, 2011). However, the QoL subscale in Finnish, Japanese and Saudi Arabian KOOS adaptations exhibited much higher internal consistency compared to the KOOS-V (Alfadhel et al., 2018; Goldhahn et al., 2017; Multanen et al., 2018). This discrepancy may be explained by differences in socioeconomic conditions, health perspectives, or varying expectations about quality of life between Vietnamese patients and those in other cultural contexts (Nguyen et al., 2017).

The KOOS-V demonstrated good to excellent test-retest reliability, with ICC values ranging from 0.77 to 0.90 across all subscales. These findings are comparable to the reliability reported for the original KOOS and other language adaptations, such as the Cantonese and French versions (Cheng et al., 2019; Ornetti et al., 2008; Roos, Roos, Ekdahl, et al., 1998). The Symptom, Pain, ADL and Sport/Recreation subscales exhibited particularly high ICC values, likely due to their more observable and less subjective nature. Furthermore, controlling the change in NPRS scores to no more than two points between assessments in the current study may have helped maintaining a consistent physical state during the test-retest period, thereby optimizing the ICC values for these subscales of the KOOS-V. In contrast, the Quality of Life subscale demonstrated a relatively lower ICC value of 0.77, reflecting the inherent variability in perceptions of quality of life that can be influenced by factors such as mood, stress and personal circumstances (Sloan et al., 2008).

The construct validity of the KOOS-V was consistent with previous research findings (Alfadhel et al., 2018; Almeida et al., 2022; Cheung et al., 2016; Gonçalves et al., 2009; Xie et al., 2006; L. Yang et al., 2023). The five subscales of the KOOS-V exhibited moderate to strong correlations with the Physical Function and Bodily Pain domains of the SF-36, as well as moderate correlations with the NPRS. This suggests the KOOS-V demonstrates convergent validity in relation to other established measures. However, the correlations between the KOOS-V Pain subscale and the SF-36 Bodily Pain domain were moderate, comparable to the Portuguese version but higher than the Chinese, Singapore-English and Singapore-Chinese versions (Gonçalves et al., 2009; Xie et al., 2006; L. Yang et al., 2023). The correlations between the KOOS-V Pain subscale and the NPRS were also moderate, similar to the Portuguese version ($\rho = 0.51$) (Gonçalves et al., 2009). These differences between the KOOS-V, SF-36 and NPRS instruments could be attributed to the fact that the Bodily Pain domain of the SF-36 and the NPRS assess pain in a general sense, whereas the Pain subscale of the KOOS is more specifically focused on pain experienced during knee-related functional activities.

The assessment of cross-cultural validity was conducted by comparing the mean scores of the KOOS-V with 15 other validated versions among patients diagnosed with KOA. Across all versions, the ADL, Symptoms and Quality of Life subscales consistently showed higher scores, indicating these activities were less challenging. In contrast, the Sport/Recreation subscale showed the lowest scores, indicating that high-impact activities are most affected by KOA. This trend was consistent across different cultures, suggesting that the difficulties caused by KOA are universally perceived. This could be because the KOOS was initially designed for younger and middle-aged individuals with ACL or meniscus injuries or posttraumatic osteoarthritis (Roos, Roos, Lohmander, et al., 1998). However, when applied to an elderly population with KOA, these activities are more challenging.



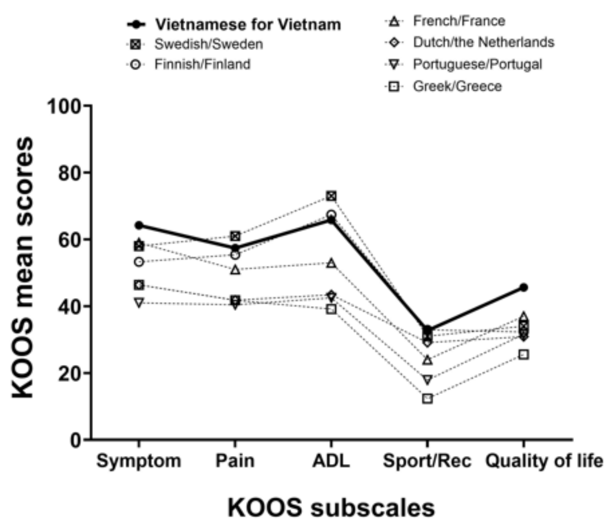


Figure 2.1 Average scores to the KOOS subscales for the Vietnamese version (solid thick line) and for other Asian countries (thin dashed lines, upper panel) and for other European countries (thin dashed lines, lower panel)

Comparing the Vietnamese version of the KOOS to other Asian countries, the mean scores were generally close to the average, though some discrepancies were observed. The Indonesian cohort had higher scores, likely due to their younger mean age (36.4 ± 16.7).The Japanese cohort also exhibited high scores despite an older mean age (68.9 ± 9.4), probably due to the effectiveness of their national health promotion program (Health Japan 21) (Hirashiki et al., 2022). The similarity in scores for the Pain, Symptoms, ADL and Quality of Life subscales among Vietnam, China and Singapore may be attributed to shared Confucian cultural values that shape health perceptions and reporting (Nawrot, 2020). In contrast, lower KOOS scores in Pakistan, India and Saudi Arabia compared to other Asian countries could be attributed to the limited access to quality healthcare, a common challenge in low- and middle-income nations (Kruk et al., 2018). Compared to European countries, the Vietnamese version's scores were among the highest, similar to the Swedish and Finnish versions. This may reflect cultural differences, where collectivistic principles influence more positive self-assessments (Chen & Swartzman, 2001).

A potential limitation of this study concerns the assessment of the construct validity of the KOOS-V. While the subscales of the KOOS-V represent a participant's limitations in activities that specifically involve the knee, the SF-36 and the NPRS capture a more general, unspecific, perception of one's health condition. The SF-36 was the only instrument validated in Vietnamese at the time of the study, yet this difference in constructs between instruments may limit the correlations observed in this study. Although any difference in constructs between instruments should have a limited impact on the scores to the KOOS subscales, as shown by a similar scores pattern between Vietnam and other Asian and European countries, a further investigation of the specific construct captured by the subscales of the KOOS-V would be useful in future studies.

Conclusion

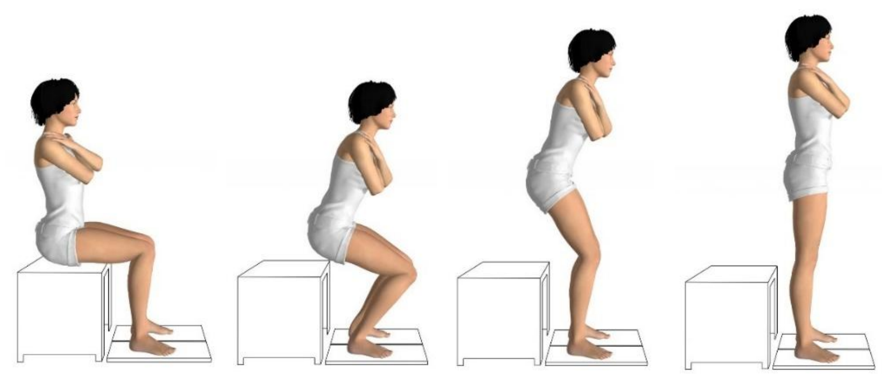
The KOOS-V demonstrates reliability and validity in assessing patients with KOA in Vietnam. The Vietnamese version of the KOOS developed in this study has demonstrated psychometric properties for patients with KOA that support its use in future clinical and research settings. Future research should also aim to validate the KOOS-V in other pathologies involving the knee.

Supplementary table. Content validity Index of the KOOS-V

	Final version	
	Relevance	**Clarity**
I-CVI	0.86 - 1.00	1.00
S-CVI		
S-CVI/ave	1.00	1.00
S-CVI/UA	0.99	1.00

CHAPTER 3

Postural control during Sit-to-Stand and Stand-to-Sit in Knee Osteoarthritis



"There are no solutions. There are only trade-offs."

— Thomas Sowell-

This chapter examines postural control during two fundamental bipodal transitions: standing up and sitting down. These movements are among the most frequently performed daily activities, yet they challenge balance regulation in ways that differ from steady-state tasks. Building on the validated KOOS-V introduced in the previous chapter, this chapter focuses on the kinetic characteristics of Sit-to-Stand and Stand-to-Sit to provide objective information about how forces and timing evolve throughout these transitions. By analysing these tasks across young adults, healthy older adults, and individuals with knee osteoarthritis, this chapter establishes a framework for understanding age- and disease-related differences in postural control. The insights gained here set the foundation for the unipodal transition explored in Chapter 4.

3.1. Sit-to-Stand and Stand-to-Sit kinetics in individuals with knee osteoarthritis, healthy older adults and healthy young adults

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Next Research (submitted)
Keywords: functional performance, pain, activities of daily living, One-Leg Standing test, Five-Time-Sit-to-Stand test, Knee injury and Osteoarthritis Outcome score

Introduction

Knee osteoarthritis (KOA) is one of the most prevalent musculoskeletal disorders worldwide, affecting about one-third of adults over 65 years of age and is a leading cause of pain, mobility limitations and loss of independence (Ouyang & Dai, 2025). Impaired ability to rise from a chair and return to sitting contributes to these restrictions and increases fall risk (Amano & Tamari, 2022). Sit-to-Stand and Stand-to-Sit are among the most frequent daily tasks, performed 60 times per day, and are included in performance tests such as the Five Times Sit-to-Stand Test and in patient-reported outcomes such as the Knee Injury and Osteoarthritis Outcome Score - Activities of Daily Living subscale (Dall & Kerr, 2010; Goldberg et al., 2012; Roos, 2024)

Both Sit-to-Stand and Stand-to-Sit start with an acceleration phase, where the body is either raised up or lowered down, followed by a deceleration or stabilization phase that slows down the movement to reach a stable stance or to avoid hard contact with the chair (Papa & Cappozzo, 2000; Roebroeck et al., 1994). The stabilization phase of SitTS has been reported to be longer in older compared with young adults (Akram & McIlroy, 2011; Moreira et al., 2025; Piano et al., 2020), and some studies also found a prolonged phase in KOA (Anan et al., 2015; Duffell et al., 2013), but its kinetic mechanisms remain unclear. For StandTS, studies in older adults showed that descent control relies on braking, with reduced knee extensor control leading to greater impact (Kondo et al., 2022) and fallers displaying reduced joint excursions and altered body centre of mass trajectories (Lin & Lee, 2022). In KOA, StandTS has been described as slower with altered joint moments and reduced balance control (Fu et al., 2021; Pan et al., 2023), yet the kinetic mechanisms underlying reduced control are still not defined. In addition, previous studies compared KOA only with age-matched adults, making it unclear how aging contributes to these changes.

Therefore, this study investigated SitTS and StandTS kinetics in KOA compared with both healthy older and young adults and explored their associations with functional performance and self-reported outcomes.

Materials and Methods

Experimental set-up

The aim of the study was to analyse the Sit-to-Stand (SitTS) and Stand-to-Sit (StandTS) tasks in individuals with knee osteoarthritis and in healthy participants. A backless and armless wooden chair was placed in front of two 1D-Twin force plates (40 × 30 cm; Arsalis SRL, Belgium) positioned on the floor, one under each foot. The chair height was adjusted so that, when seated, the participant's knees were flexed at 90°. The vertical component of the force under each foot was recorded at 1000 Hz and filtered with an 8th-order Bessel low-pass filter (cutoff 25 Hz) **(Figure 3.1)**. Data were processed using TwinPlates® software (Arsalis SRL, Belgium).

Subjects

A total of 60 individuals participated in this study: 21 individuals with knee osteoarthritis (KOA), 15 healthy older adults (HOA), and 24 healthy young adults (HYA). Characteristics of the participants are presented in **Table 3.1**. HYA and HOA had no history of knee pain. KOA met the diagnostic criteria of the National Institute for Health and Care Excellence, requiring to be aged 45 or older, experience joint pain during activity and have either no morning stiffness or stiffness lasting less than 30 minutes (King et al., 2024). Exclusion criteria for all three groups included a history of lumbar or lower-limb surgery or injury, and any neurological disorder known to affect balance.

Table 3.1. Characteristics of the participants

Parameter	KOA (N=21)	HOA (N=15)	HYA (N=24)
Age (years), mean±SD	64.6 ± 7.7	65.1 ± 9.0	22.1 ± 0.7
Sex (n Female/n Male)	19/3	12/3	12/12
Height (m), mean±SD	1.52 ± 0.06[b]	1.55 ± 0.08	1.63 ± 0.08
Body weight (kg), mean±SD	60.8 ± 11.1	54.8 ± 8.1	59.3 ± 12.8
BMI (kg m^{-2}), mean±SD	26.3± 4.3[b]	22.9 ± 3.0	22.2 ± 5.2
Physical performance tests (seconds), median (IQR)			
OLST	11.8 (23.0)[a]	43.0 (42.7)	N/A
FTSTS	15.1 (7.2)[a]	9.4 (4.7)	N/A

KOA: individuals with Knee Osteoarthritis; HOA: Healthy Older Adults; HYA: Healthy Young Adults; OLST: One Leg Standing Test; FTSTS: Five-time Sit-to-Stand test; SD: Standard deviation; N/A: Not applicable; [a] : Statistically significant difference from Healthy Older Adults group, [b] : Statistically significant difference from Healthy Young Adults group.

KOA were recruited in Ho Chi Minh city in one of the following hospitals: An Binh hospital, University Medical center, Traditional medicine hospital or Le Van Thinh hospital but also through community. Healthy participants were recruited via advertisements. HOA were age- and gender-matched with KOA. Data were collected between March and September 2024. Ethical approval for the study was obtained from the Ethical Committee of the University of Medicine and Pharmacy at Ho Chi Minh City, Vietnam (approval number 389/HDDD-DHYD, dated

29/02/2024). The research adhered to the principles outlined in the Declaration of Helsinki, and all participants provided written informed consent prior to participation.

Experimental procedure

All participants wore shorts and were barefoot upon entering the laboratory. KOA completed the validated Vietnamese version of the Knee Injury and Osteoarthritis Outcome Score (KOOS-V), includes five subscales: Pain, Symptoms, Activities of Daily Living (ADL), Sport and Recreation (Sport/Rec), and Quality of Life (QoL) scored from 0 to 100 for each subscale, with higher values indicating better status (Le et al., 2025; Roos, 2024) and rated their knee pain using the 11-point Numerical Pain Rating Scale (NPRS; 0 = no pain; 10 = worst possible pain (Jensen et al., 1999).

Next, the HOA and KOA performed the Five Time Sit to Stand (FTSTS) test and the One Leg Standing Test (OLST). For the FTSTS, participants stood up and sat down five times from a 43-45 cm chair as quickly as possible without hand support (Goldberg et al., 2012). For the OLST, they stood on one leg with eyes open until losing balance or touching the ground (Vellas et al., 1997). Both legs were tested.

All participants then performed combined SitTS and StandTS trials. They stood on the force plates with one foot per plate, adjusted to a comfortable stance (marked for consistency). The experiments proceeded as follows. First, participants sat still for 5 seconds with their arms crossed over shoulders. Then, they stood up as quickly as possible upon hearing an auditory cue ("Stand up!") and remained still for 10 seconds. A second cue ("Sit down!") was then given and the participants returned to the seated position as quickly as possible and remained seated quietly for five seconds. Each participant performed three trials, with one-minute rest between trials to prevent fatigue (Piano et al., 2020).

Outcome measures

The vertical component of the ground reaction forces recorded under each foot were summed to obtain the total vertical force (F_z, expressed in proportion of body weight) which was used to identify key time events in SitTS and StandTS **(Figure 3.1)** (Etnyre & Thomas, 2007; Jeon et al., 2024).

For SitTS, the onset of movement (t_1) was defined as the time when F_z started to increase after reaching its minimal value. Before t_1, a small decrease in F_z is typically observed, reflecting the preparatory trunk flexion and anterior shift of the body's COM prior to lift-off (Etnyre & Thomas, 2007; Papa & Cappozzo, 2000; Roebroeck et al., 1994). In previous studies, this initial decrease in F_z from the seated baseline was used to define movement onset. In the present study, t_1 was considered as the onset of movement because it marks the start of active force generation by the lower limbs, whereas the early unloading phase may not accurately identify the onset since no force plate was placed under the seat. t_{BW} was defined as the time when F_z is becoming greater than body weight (BW), and t_2 as the time of the peak F_z. The seat-off moment, when the buttocks lose contact with the seat, occurs sometime between t_{BW} and t_2. After t_2, F_z decreased in a rebound pattern below body weight before stabilizing. t_3 was defined as the time when F_z crossed BW after the peak, marking the transition between rising and braking. t_4 was defined as the time of the minimum F_z, corresponding to braking, and t_5 as the time when F_z first returned to body weight after t_4, indicating quiet standing.

The main temporal and kinetic parameters were then derived. The duration of SitTS (t_{SitTS}, s) was calculated as t_5-t_1, the duration of the push (t_{push}, s) as t_3-t_1, the duration of deceleration phase (t_{decel}, s) as t_5-t_3, the loading rate (LR, kN.s^{-1}) as $(F_{zBW} - F_{zt1}) / (t_{BW} - t_1)$, the maximal acceleration at t_2 (a_{t2}, g) as $(F_{zt2}) - 1$, the maximal deceleration at t_4 (a_{t4}, g) as $F_{zt4} - 1$, the maximal vertical velocity at t_3 (v_{t3}, m.s^{-1}) as $|(\text{mean } F_z \text{ during } t_3 \text{ to } t_5) - 1| \times 9.81 \times (t_5 - t_3)$.

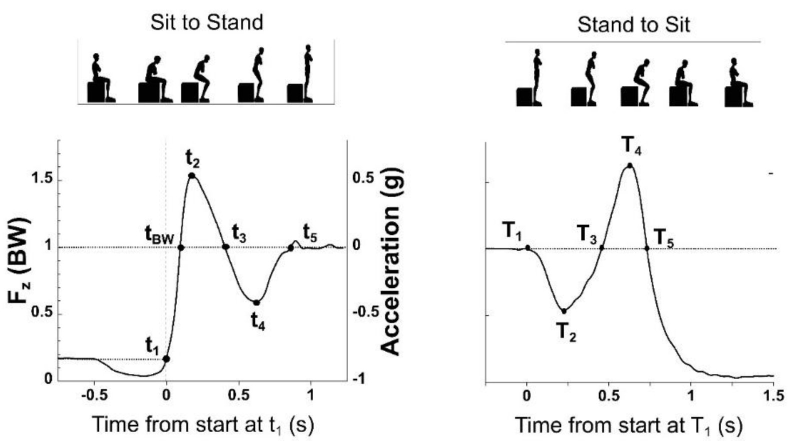


Figure 3.1. Schematic of key time events and vertical component of ground reaction forces during Sit-to-Stand and Stand-to-Sit tasks. Key events are illustrated for each task in a healthy young adult (Male, 22 years, 82.2 kg, 1.74 m) (see Methods)

For StandTS, T_1 was defined as the first time when F_z decreased by more than 1% of BW for at least 50 milliseconds, indicating the start of the descent. T_2 was defined as the time of the minimum F_z, corresponding to maximal downward acceleration of the body. T_3 was defined as the time when F_z returned to BW after the minimum, marking the transition between descent and braking. T_4 was defined as the time of the peak F_z, reflecting the braking before seat contact. T_5 was defined as the time when F_z first reached BW, indicating the completion of the movement. The seat-off moment, when the buttocks first contacted the seat, occurs between T_4 and T_5.

Similarly, for StandTS, the duration of the movement ($T_{StandTS}$, s) was calculated T_5-T_1, the duration of acceleration phase (T_{accel}, s) as T_3-T_1, the maximal acceleration at T_2 (a_{T2}, g) as $F_{zT2} - 1$, the maximal deceleration at T_4 (a_{T4}, g) as $F_{zT4} - 1$, the maximal velocity at T_3 (v_{T3}, m.s^{-1}) as $\bar{F_z} \times 9.81 \times (T_3 - T_1)$ where F_z is the average vertical force between t_3 and t_5.

The duration of the FTSTS and the OLST (average of left and right) tasks was measured in seconds. The KOOS score was collected for each subscale and classified as extreme (0–12.5), severe (12.6–37.5), moderate (37.6–62.5), mild (62.6–87.5) or no difficulty (≥87.6) (Roos, 2024). The highest NPRS score between two knees was used for analysis (Lee et al., 2025).

Data analysis

All variables were computed using a customized program in LabVIEW (National Instruments, USA). For each participant, the average of three SitTS and of StandTS trials was used for analysis. Normality was assessed with the Shapiro–Wilk test. Seven normally distributed variables (BMI, LR, a_{t2}, a_{t4}, v_{t3}, T_{accel} and v_{T3}) were analyzed with one-way ANOVA followed by Dunnett's post-hoc test using the KOA group as the reference (KOA versus HOA; KOA versus HYA). Seven non-normally distributed variables (height, t_{SitTS}, t_{push}, t_{decel}, $T_{StandTS}$, a_{T2} and a_{T4}) were analyzed with Kruskal–Wallis tests followed, when significant, by Mann–Whitney U tests (KOA versus HOA; KOA versus HYA) with within-variable multiplicity controlled by Bonferroni adjustment. Family-wise multiplicity was also controlled using Bonferroni correction. Significance levels were based on final adjusted p-values. In addition, comparisons between HOA and HYA were performed to examine age-related effects, using independent-sample t-tests or Mann–Whitney U tests as appropriate. Correlations between kinetic variables with significant group differences were examined using Spearman's rank correlation. All tests were two-tailed with a significance level of $p < 0.05$. Continuous data is presented as median and interquartile range. Analyses were performed in SPSS 29.0.1.0 (IBM Corp., Armonk, NY, USA).

Results

The KOA and HOA were comparable in age, height, weight and BMI **(Table 3.1)**. KOA had a shorter height and a greater BMI compared to HYA. In physical performance tests, KOA showed longer FTSTS duration and shorter OLST duration compared to HOA. Among KOA, three of them (14%) had unilateral involvement (i.e. pain was present in only one knee), two declared a mild, ten a moderate and nine a severe knee pain intensity (NPRS). KOOS subscale scores showed moderate impairment in Symptoms (61.4 ± 11.5, mean ± SD), Pain (57.2 ± 14.9) and ADL (65.0 ± 16.7), severe impairment in Sport/Recreation (25.2 ± 22.1), and substantial impairment in Quality of Life (39.8 ± 17.4).

To illustrate the general pattern of F_z over time, typical traces from one participant per group are shown in **Figure 3.2**.

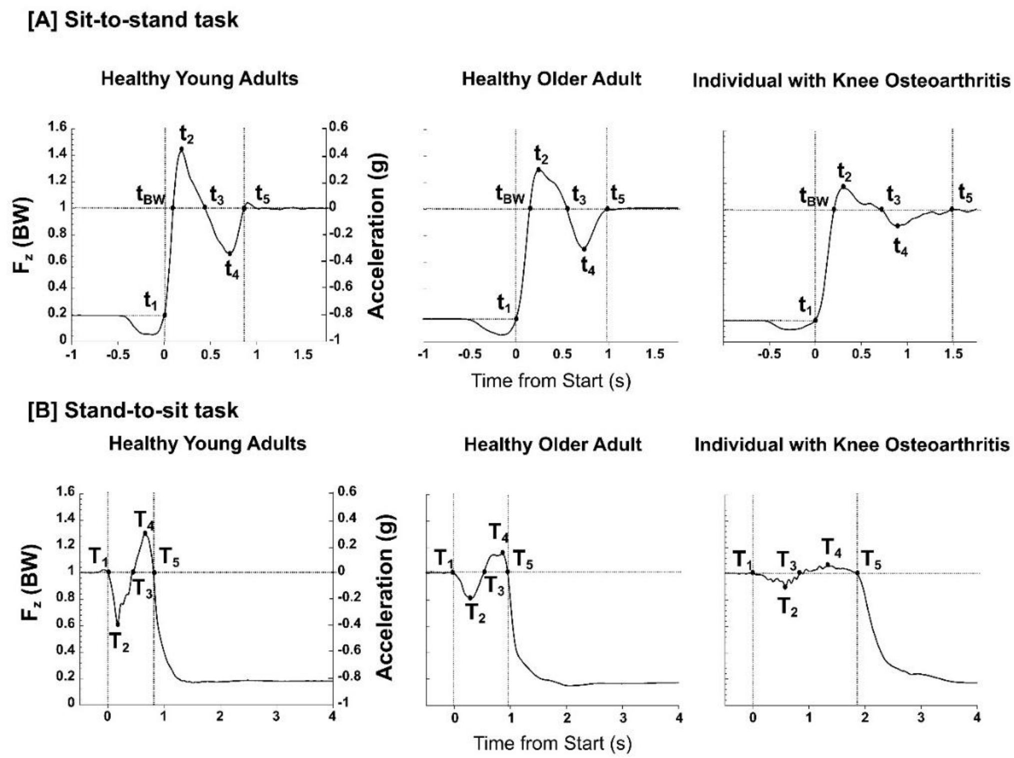


Figure 3.2. Vertical component of the ground reaction force (Fz, BW) vs time (s) typical traces during the Sit-to-Stand and Stand-to-Sit tasks [A] Sit-to-Stand and [B] Stand-to-Sit. From left to right: Healthy Young Adult (22 years old, 63.2 kg, 1.69 m, female), Healthy Older Adult (61 years old, 52.6 kg, 1.53 m, female) and KOA patient (61 years old, 68.4 kg, 1.53 m, female).

For the SitTS, F_z was steady at baseline during quiet sitting, then decreased slightly before t_1, corresponding to a forward weight shift and pre-loading preceding lift-off. Then F_z increased steeply and reached a peak at t_2, corresponding to maximal upward acceleration. The KOA participant showed a peak force at t_2 of about 1.17 BW **(Figure 3.2A, right)**, the HOA had a similar pattern but with a slightly higher peak (1.29 BW), while the HYA reached a sharp, high peak (1.43 BW). After t_2, Fz decreased progressively, reaching a minimum value at t_4, corresponding to maximal downward deceleration. At this point, the KOA participant reached

0.88 BW, the HOA 0.70 BW and the HYA 0.66 BW. The movement ended at t_5, when F_z returned to BW. The total duration of SitTS was 1.48 s for the KOA, 1.12 s for the HOA, and 0.86 s for the HYA.

For the StandTS, F_z gradually decreased after T_1. The KOA participant showed a slow and limited decrease, reaching 0.90 BW at T_2 **(Figure 3.2B, right)**, the HOA 0.81 BW, and the HYA 0.62 BW. After T_2, F_z increased again. In the KOA participant, this rise was gradual with a low, flat peak at T_4 (1.06 BW), while the HOA showed a small secondary rise (1.15 BW), and the HYA a higher and sharper peak (1.29 BW). The total duration of StandTS was 1.86 s for the KOA, 0.96 s for the HOA, and 0.81 s for the HYA.

Group comparisons of kinetic parameters are presented in **Figure 3.3** and **3.4**. In SitTS, KOA showed longer total and push phase durations than HYA **(Figures 3.3A-C)**. The deceleration phase duration was longer, and maximal deceleration smaller in KOA compared to both HOA and HYA **(Figures 3.3C, E)**. The maximal acceleration, maximal velocity, and loading rate in KOA were similar to HOA but smaller than in HYA **(Figures 3.3D, F, G)**. When comparing the two healthy groups, HOA differed from HYA only in maximal acceleration (a_{t2}) and maximal velocity (v_{t3}), with lower values observed in HOA **(Figures 3.3D, F)**.

In StandTS, KOA showed a longer acceleration phase than HYA **(Figure 3.4B)**. The total duration was longer while maximal acceleration, deceleration, and maximal velocity were smaller in KOA compared to both HOA and HYA **(Figures 3A, C-E)**. SitTS total duration was shorter than StandTS in KOA (1.22 (0.91) s versus 1.46 (0.90) s), $p = 0.005$) but not in HOA (0.81 (0.33) s versus 0.92 (0.34) s, $p = 0.21$). In contrast, SitTS total duration was longer than StandTS in HYA (0.82 (0.17) s versus 0.77 (0.15) s, $p = 0.049$) **(Table 3.2)**. HOA showed a longer StandTS duration and lower maximal acceleration and maximal velocity than HYA **(Figures 3.4A, C, E)**.

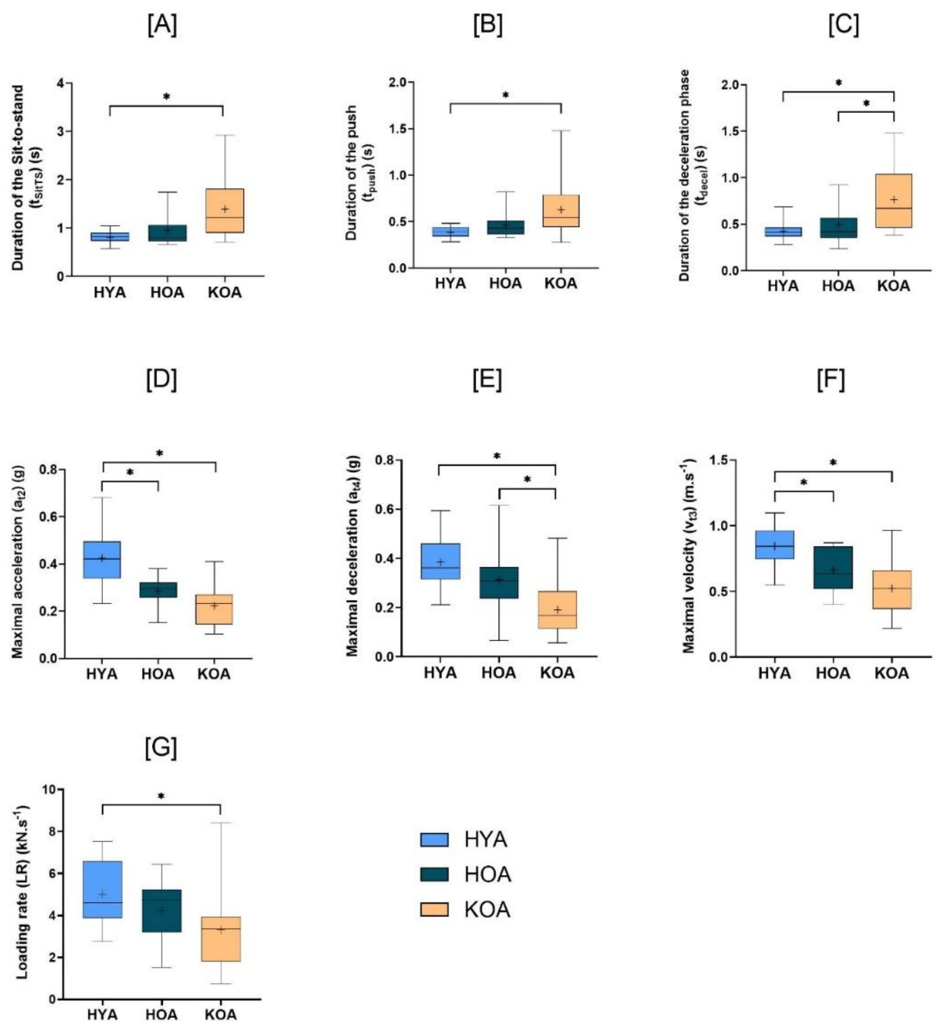


Figure 3.3 Comparison of kinetic parameters during Sit-to-Stand task across groups. The box represents the interquartile range (25th–75th percentiles), the horizontal line inside the box indicates the median, and the cross indicates the mean, the whiskers represent the minimum and maximum values; healthy young adults (HYA, left), healthy older adults (HOA, middle), and individuals with knee osteoarthritis (KOA, right); [A]: duration of the Sit-to-Stand task (t_{SitTS}); [B]: duration of the push (t_{push}), [C]: duration of the deceleration phase (t_{decel}), [D]: maximal acceleration (a_{t2}); [E]: maximal deceleration (a_{t4}); [F]: maximal velocity (v_{t3}); [G]: loading rate (LR). *: significance level (p) ≤ 0.05.

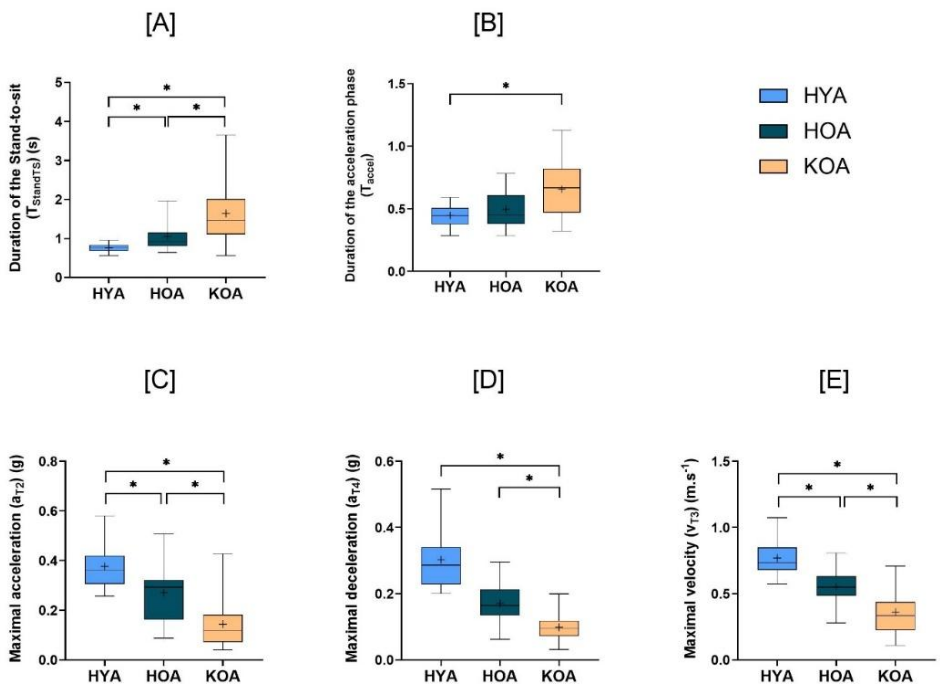


Figure 3.4. Comparison of kinetic parameters during Stand-to-Sit tasks across groups. The box represents the interquartile range (25th–75th percentiles), the horizontal line inside the box indicates the median, and the cross indicates the mean, the whiskers represent the minimum and maximum values; healthy young adults (HYA, left), healthy older adults (HOA, middle), and individuals with knee osteoarthritis (KOA, right); [A]: duration of Stand-to-Sit task ($T_{StandTS}$); [B]: duration of the acceleration phase (T_{accel}); [C]: maximal acceleration (a_{T2}); [D]: maximal deceleration (a_{T4}) and [E]: maximal velocity (v_{T3}). *: significance level (p) ≤ 0.05.

Table 3.2. Kinetic variables of Sit-to-Stand and Stand-to-Sit tasks across groups

Variable, *Median (IQR)*	**KOA** (N=21)	**HOA** (N=15)	**HYA** (N=24)
Sit-to-Stand			
t_{SitTS} (s)	1.22 (0.91)^{b}	0.81 (0.33)	0.82 (0.17)
t_{push} (s)	0.54 (0.35)^{b}	0.43 (0.15)	0.39 (0.10)
t_{decel} (s)	0.67 (0.58)^{a,b}	0.42 (0.22)	0.41 (0.10)
LR (kN.s^{-1})	3.34 (2.14)^{b}	4.75 (2.05)	4.60 (2.71)
a_{t2} (g)	0.23 (0.13)^{b}	0.30 (0.07)	0.42 (0.16)
a_{t4} (g)	-0.17 (0.15)^{a,b}	-0.31 (0.13)	-0.36 (0.15)
v_{t3} (m.s^{-1})	0.52 (0.30)^{b}	0.63 (0.32)	0.84 (0.22)
Stand-to-Sit			
$T_{StandTS}$ (s)	1.46 (0.90)^{a,b}	0.92 (0.34)	0.77 (0.15)
T_{accel} (s)	0.67 (0.35)^{b}	0.45 (0.23)	0.45 (0.13)
a_{T2} (g)	-0.12 (0.11)^{a,b}	-0.29 (0.16)	-0.36 (0.11)
a_{T4} (g)	0.10 (0.05)^{a,b}	0.17 (0.08)	0.29 (0.11)
v_{T3} (m.s^{-1})	0.34 (0.22)^{a,b}	0.55 (0.15)	0.73 (0.17)

KOA: individuals with Knee Osteoarthritis; HOA: Healthy Older Adults; HYA: Healthy Young Adults; t_{SitTS}: the duration of Sit-to-Stand task from t_1 to t_5, t_{push}: the duration of the push from t_1 to t_3, t_{decel}: the duration of deceleration phase from t_3-t_5, LR: loading rate, at_2: the maximal acceleration at t_2, a_{t4}: the maximal deceleration at t_4, v_{t3}: the maximal velocity at t_3, $T_{StandTS}$: the duration of Stand-to-Sit task from T_1 to T_5, T_{accel}: the duration of acceleration phase from T_1 to T_5, a_{T2}: the maximal acceleration at T_2, a_{T4}: the maximal deceleration at T_4, v_{T3}: the maximal velocity at T_3, ^{a}: statistically significant difference from Healthy Older Adults ^{b}: statistically significant difference from Healthy Young Adults.

Table 3.3. Spearman's correlation coefficients among kinetic, functional performance (OLST, FTSTS) and KOOS variables (ADL and Pain)

	OLST	**FTSTS**	**KOOS-Pain**	**KOOS-ADL**
Individuals with Knee Osteoarthritis				
Sit-to-Stand				
t_{SitTS}	-0.455*	0.557**	NS	-0.598**
t_{decel}	-0.516*	0.544*	-0.470*	-0.609**
a_{t2}	0.617**	-0.702**	0.474*	0.802**
a_{t4}	0.627**	-0.655**	0.576*	0.841**
v_{t3}	0.560**	-0.588**	0.446*	0.804**
Stand-to-Sit				
$T_{StandTS}$	-0.434*	NS	NS	-0.570**
a_{T2}	0.603**	NS	NS	0.580**
a_{T4}	0.544*	NS	NS	0.455*
v_{T3}	0.686**	-0.524*	NS	0.594**
KOOS subscale				
KOOS-Pain	0.491*	-0.458*		
KOOS-ADL	0.705**	-0.598**		
Healthy Older Adults				
Sit-to-Stand				
t_{SitTS}	NS	0.543*		
t_{decel}	NS	NS		
a_{t2}	0.546*	NS		
a_{t4}	NS	NS		
v_{t3}	NS	NS		
Stand-to-Sit				
$T_{StandTS}$	-0.711**	0.700**		
a_{T2}	0.636*	-0.536*		
a_{T4}	0.707**	-0.654**		
v_{T3}	NS	-0.568*		

OLST: One leg standing test; FTSTS: Five-Time Sit to Stand test; KOOS-Pain: subscale of the Knee Injury and Osteoarthritis Outcome Score-Pain subscale (9 items, see Appendix II); KOOS-ADL: subscale of the KOOS (17 items); t_{SitTS}: duration of the Sit-to-Stand task; a_{t2}: maximal acceleration; a_{t4}: maximal deceleration; v_{t3}: maximal velocity; $T_{StandTS}$: duration of the Stand-to-Sit task; a_{T2}: maximal acceleration; a_{T4}: maximal deceleration; v_{T3}: maximal velocity; NS: Non-significant; * $p \leq 0.05$; ** $p \leq 0.01$

Significant correlations were observed between kinetic and functional performance variables **(Table 3.3)**. In the KOA group, shorter SitTS duration (t_{SitTS}), greater maximal acceleration (a_{t2}) and deceleration (a_{t4}), and higher maximal velocity (v_{t3}) correlated with good performance (shorter FTSTS and longer OLST duration). For StandTS, shorter movement duration ($t_{StandTS}$), greater maximal acceleration (a_{T2}) and deceleration (a_{T4}) correlated with longer OLST duration but not with FTSTS, while higher maximal velocity (v_{T3}) correlated with good performance for both FTSTS and OLST. Higher KOOS-Pain score correlated with shorter deceleration phase duration, greater maximal acceleration, maximal deceleration and higher peak velocity of SitTS. KOOS-ADL scores correlated with shorter SitTS and StandTS durations, greater maximal acceleration and deceleration, and higher peak velocities during both tasks. In comparison, for the HOA group, shorter SitTS duration correlated with only shorter FTSTS duration and greater maximal acceleration correlated to longer OLST. For StandTS, shorter movement duration, greater maximal acceleration, maximal deceleration correlated with good performance in both tests while higher maximal velocity only correlated with shorter FTSTS duration. Overall, in KOA SitTS kinetic variables showed strong correlations with functional measures, and the same was true for the HOA but only for StandTS variables.

Discussion

This study investigated the kinetics of the Sit-to stand and Stand-to-Sit tasks in individuals with knee osteoarthritis and compared it to that observed in age-matched older and in young participants. The main findings were that KOA performed the two tasks slower and with reduced maximal acceleration, deceleration and velocity compared with healthy young adults, while healthy older adults generally showed intermediate values. Greater acceleration and velocity and shorter durations were associated with good performance in functional tests (i.e. FTSTS, OLST) and with self-reported function (i.e. KOOS-Pain and KOOS-ADL).

In SitTS, KOA showed longer total and push durations, smaller maximal acceleration, lower peak velocity and loading rate compared with young adults but did not differ from older adults, suggesting that several modifications observed in KOA may overlap with age-related changes rather than purely disease-specific effects. A recent meta-analysis showed that KOA adopt a compensatory SitTS strategy (Sonoo et al., 2019), similar to the so-called "momentum-transfer strategy" described in older adults (Kerr et al., 1997; Papa & Cappozzo, 2000; Sadeh et al., 2023), where increased trunk flexion brings the centre of mass of the body into the base of support before vertical rising to compensate for reduced lower-limb force production. What we observed here was first a smaller maximal acceleration, indicating reduced capacity to initiate vertical rise. This reduction was also observed in older adults, indicating an age-related effect; second, a lower peak velocity, with a significant difference between HOA and HYA, further supporting an effect of aging, in line with evidence showing decreased speed in older adults in Sit-to-Stand task (Kerr et al., 1997; Papa & Cappozzo, 2000; Sadeh et al., 2023). This reduction may be related to pain, as computer simulations of unilateral knee pain have shown slower rising speed (Van Der Kruk & Geijtenbeek, 2024). Third, a lower loading rate, consistent with age-related declines in rapid force generation reported in older adults (Ahn et al., 2024; Akram & McIlroy, 2011). Quadriceps rate-of-force-development is known to be reduced in severe KOA (Suzuki et al., 2022), but the absence of difference in loading rate from older adults in our cohort suggests possible compensation from hip and ankle movements (Caruthers et al., 2016). Four, there were longer durations of the whole task and phase of the push, similar to previous studies showing no differences between KOA and age-matched controls (Bouchouras et al., 2015; Verlaan et al., 2018). However, no differences were found between HOA and HYA in loading rate or durations, suggesting that these variables may be affected by the combined influence of ageing and knee osteoarthritis rather than by either factor alone.

In addition, KOA exhibited a longer deceleration duration and smaller maximal deceleration compared to both control groups, indicating that braking required for standing stabilization was altered and not explained by aging alone. Previous studies reported prolonged terminal phases of SitTS in KOA (Anan et al., 2015; Duffell et al., 2013; Verlaan et al., 2018). SitTS typically ends with backward trunk lean and lower-limb extension to stabilize (Kerr et al., 1997; Roebroeck et al., 1994). In older adults, this phase is often challenging (Akram & McIlroy, 2011; Piano et al., 2020; Sadeh et al., 2023), and altered stabilization has been linked to falls and functional disability (Lin & Lee, 2022; Moreira et al., 2025). KOA studies have either left this phase unexplained or linked it to increased trunk flexion. Our results extend this by showing that KOA not only took longer to stabilize but also showed modified braking.

In StandTS, KOA showed longer duration, smaller maximal acceleration, velocity and deceleration compared with both HOA and HYA, indicating that the differences cannot be explained by aging alone. Similar changes have been described in KOA, including slower descent, altered kinematics and reduced balance control (Fu et al., 2021; Pan et al., 2023). StandTS is not simply the reverse of SitTS, since forward trunk flexion and lower-limb flexion must occur simultaneously to control both vertical and anteroposterior directions, placing high demands on braking and inter-joint coordination (Kerr et al., 1997; Kondo et al., 2022). In our cohort, KOA exhibited three specific kinetic alterations. First, smaller acceleration at initiation suggests a cautious strategy to limit rapid descent, possibly by stiffening the knee and increasing trunk flexion (Fu et al., 2021; Pan et al., 2023). Second, reduced maximal velocity reflected slower movement. Third, smaller maximal deceleration indicated modified braking before seat contact, consistent with previous work in older adults (Kondo et al., 2022).

In KOA, StandTS was longer than SitTS, reinforcing that braking during descent is particularly altered. In HOA, no difference was observed, consistent with reports showing inconsistent results (Kerr et al., 1997; Lin & Lee, 2022), suggesting that aging does not consistently alter one task more than the other.

Interestingly, shorter SitTS durations and greater acceleration and deceleration were associated with good FTSTS and OLST scores, good level of daily activity on KOOS-ADL, indicating that both the force generation and the descent are critical for mobility and daily activities. On the other hand, StandTS variables correlated with KOOS-ADL and OLST only, suggesting that the modified control of KOA observed during the descent is also linked to daily activity limitations but in that case rather to the static balance than the dynamic one.

The SitTS parameters are also correlated with less pain (KOOS-Pain). This finding confirms earlier results showing that SitTS duration is related to pain levels in KOA (Turcot et al., 2012). In HOA, SitTS parameters showed limited associations with functional outcomes and the StandTS parameters correlated with performance tests, highlighting the role of descent control in age-related mobility decline.

Several limitations should be acknowledged here. Most KOA participants had bilateral involvement, preventing analysis of inter-limb asymmetry (Christiansen et al., 2015; Turcot et al., 2012). Functional tests were not administered in HYA, as this group was included as a biomechanical reference rather than for clinical functional comparison, limiting our ability to determine whether correlations between kinetics and function are specific to pathology. Finally, the cross-sectional design precludes causal inference. To provide more on the strategy used by the KOA, kinematics and electromyographic muscular activities should be explored, they may add to the understanding of the KOA compensatory strategy.

Despite these limitations, our findings bring clinical implications. Rehabilitation for KOA should address both rising-up and the going-down tasks, exploring together the concentric and eccentric capacities of the participants. Strengthening alone may improve propulsion during SitTS but will not cover the braking deficits. Training focuses on eccentric quadriceps control when sitting down and braking control after rising may help improve safety and efficiency. In this context, Stand-to-Sit should be prioritised clinically when the aim is to assess postural control, as it specifically challenges controlled eccentric braking.

Conclusion

In summary, individuals with knee osteoarthritis performed Sit-to-Stand and Stand-to-Sit with longer durations and lower acceleration, velocity and deceleration than young adults, while older adults showed intermediate values. In Sit-to-Stand, reduced deceleration distinguished knee osteoarthritis from aging. In Stand-to-Sit, all kinetic variables differed from both control groups, indicating altered descent control likely due to knee osteoarthritis. Correlations with clinical tests and KOOS showed that Sit-to-Stand parameters were related to pain and mobility, whereas Stand-to-Sit parameters were more related to daily activity limitations and balance. Task duration, maximal acceleration and maximal deceleration may therefore serve as functional indicators when evaluating rising and sitting down in knee osteoarthritis.

Following the between-group analyses presented in Section 3.1, the following section further explores inter-limb asymmetry during Sit-to-Stand and Stand-to-Sit.

3.2. Inter-limb asymmetry during Sit-to-Stand and Stand-to-Sit

Introduction

Inter-limb asymmetry has been associated with reduced functional performance and a higher risk of falls (Christiansen et al., 2011; Mertz et al., 2019; Smajla et al., 2020). Previous studies have shown that people with unilateral knee pain tend to shift load to the less symptomatic leg, leading to altered weight-bearing and reduced performance during functional tasks such as rising from and sitting down on a chair (Christiansen et al., 2011; Schofield et al., 2013). These asymmetries may persist even after surgical or rehabilitative interventions, suggesting that they are not only mechanical consequences but also reflect long-term adaptations in motor control (Almonroeder et al., 2023). In addition, delayed or asynchronous force production has been linked to compensatory strategies and instability during Sit-to-Stand and gait initiation transitions (Hiraoka et al., 2014). However, previous studies have mainly focused on force-related parameters during the Sit-to-Stand task, whereas timing asymmetry has never been investigated, and both force and timing asymmetries remain to be explored in the Stand-to-Sit task.

Therefore, the present analysis aimed to compare both force and timing asymmetries during Sit-to-Stand and Stand-to-Sit tasks in individuals with knee osteoarthritis (KOA), age matched older (HOA) adults and healthy young (HYA), and to explore their relationships with functional performance and self-reported outcomes.

Materials and Methods

Experimental set-up and subjects

The same participants and recordings as in Section 2.1 were used. In a nutshell, participants were asked to perform combined rise from a chair (Sit-to-Stand, SitTS) and sit down on a chair (Stand-to-Sit, StandTS). The vertical component of ground reaction forces was recorded separately under both feet using two 1D twin force plates (Arsalis, Belgium) measuring the vertical component of the ground reaction force. In addition, KOA were asked to complete the KOOS-V, and both KOA and HOA performed the Five Times Sit to Stand (FTSTS) test and the One Leg Standing Test (OLST).

Outcome measures

The vertical ground reaction forces recorded under the left ($F_{z\text{-}L}$, in body weight) and right ($F_{z\text{-}R}$, in body weight) feet were used to analyze inter-limb asymmetry. The sum of those two (F_z, in body weight) was used to identify key time events. For the SitTS task, the onset of movement (t_1) was defined as the moment when total F_z returned to the baseline value after reaching its first minimum, then F_z increased to a first peak (t_2), corresponding to the maximal upward acceleration, decreased to a minimum (t_4) corresponding to maximal deceleration (braking), and rose again until the end of the task (t_5). The event t_{after} was defined as one second after t_5. In addition, t_{L2} and t_{L4} were defined as the timings of maximal acceleration and maximal deceleration for the left leg, respectively, and t_{R2} and t_{R4} were defined similarly for the right leg **(Figure 3.5)**. For the StandTS task, T_{before} was defined as one second before movement onset (T_1), then F_z decreased from the quiet-standing baseline to a minimum (T_2), corresponding to the maximal downward acceleration, then increased to a peak (T_4), corresponding to maximal deceleration before seat contact, and finally declined until the end of the movement (T_5). In addition, T_{L2} and T_{L4} were defined as the timings of maximal acceleration and deceleration of the left leg, respectively, and T_{R2} and T_{R4} were defined similarly for the right leg.

The Force Absolute Symmetry Index (FASI, %) was calculated as:

$$2 \times |(F_{Z\text{-}L} - F_{Z\text{-}R}) / (F_{Z\text{-}L} + F_{Z\text{-}R})| \times 100\%,$$

where 0% indicates perfect symmetry and higher values represent greater asymmetry (Christiansen et al., 2011). For example, a FASI value of 20% indicates that one leg bears about 10% more body weight than the other. FASI was computed during the entire task ($FASI_{SitTS}$ or $FASI_{StandTS}$), at specific time points (t_2, t_4, T_2, T_4), between t_5 and t_{after}, and between T_{before} and T_1. For Timing Absolute Symmetry Index, the events were identified separately from the left leg (F_{z_L}) and from the right (F_{z_R}) leg using the same definitions as above. Timing Absolute Symmetry Index (TASI, in ms) was calculated as $|\text{Time event}_{\_Left} - \text{Timing}_{\_Right}|$. TASI was computed at t_2, t_4, T_2 and T_4. For example, TASI at t2 was calculated as $|t_{L2} - t_{R2}|$.

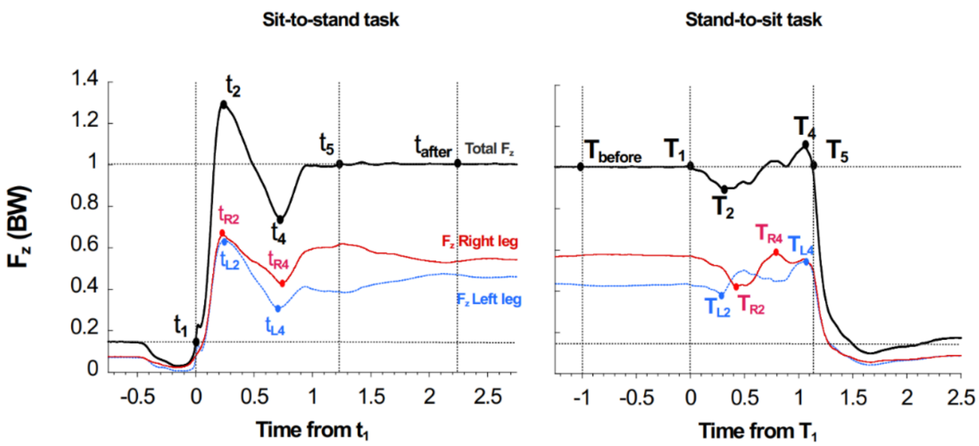


Figure 3.5. Schematic of key time events and vertical component of ground reaction forces during Sit-to-Stand (left) and Stand-to-Sit (right) tasks. Key events are illustrated for each task in an individual with knee osteoarthritis (Female, 61 years, 56.2 kg, 1.49 m, NPRS Left- Right = 5-7) (see Methods)

Data analysis

For each participant, the average of three trials was used for analysis. Normality was assessed with the Shapiro–Wilk test. Two normally distributed variables ($FASI_{t4}$, $FASI_{StandTS}$) were analyzed with one-way ANOVA followed by Dunnett's post-hoc test using the KOA group as the reference (KOA versus HOA; KOA versus HYA). Ten non-normally distributed variables ($FASI_{SitTS}$, $FASI_{t2}$, $TASI_{t2}$, $TASI_{t4}$, $FASI_{after}$, $FASI_{before}$, $FASI_{T2}$, $FASI_{T4}$, $TASI_{T2,}$ $TASI_{T4}$) were analyzed with Kruskal–Wallis tests followed, when significant, by Mann–Whitney U tests (KOA versus HOA; KOA versus HYA) with within-variable multiplicity controlled by Bonferroni adjustment. In addition, comparisons between HOA and HYA were performed using independent-sample t-tests or Mann–Whitney U tests, as appropriate, to explore age-related effects. Within-group comparisons between phases were performed using Wilcoxon signed-rank tests to examine differences between movement events (t_2 vs t_4 for Sit-to-Stand, T_2 vs T_4 for Stand-to-Sit). Family-wise multiplicity was also controlled using Bonferroni correction. Significance levels were based on final adjusted p-values. Correlations between symmetric variables and physical performance test (eg. OLTS, FTSTS) and KOOS subscores (eg. KOOS-Pain, KOOS-ADL) were examined using Spearman's rank correlation. All tests were two-tailed with a significance level of $p < 0.05$. Continuous data is presented as median and interquartile range. Analysis were performed in SPSS 29.0.1.0 (IBM Corp., Armonk, NY, USA).

Results

In SitTS, FASI was higher at t_4 (26–34%) than at t_2 (9–11%) in all groups ($p < 0.001$), indicating greater inter-limb difference during braking than during force generation. In StandTS, FASI values at T_2 (17–28%) and T_4 (10–18%) were comparable in the KOA ($p= 0.614$) and HOA groups ($p= 0.650$), whereas HYA showed higher values at T_2 than at T_4 ($p= 0.006$), indicating greater inter-limb difference during the acceleration than deceleration phase only in the HYA group **(Table 3.4, Figure 3.6).**

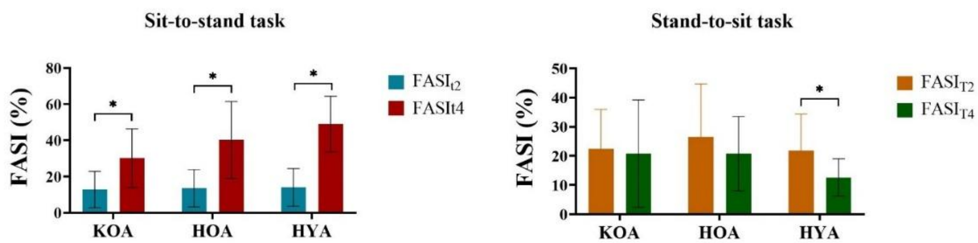


Figure 3.6. Within-group comparison of force asymmetry at key events during Sit-to-Stand and Stand-to-Sit tasks. Sit-to-Stand task (left): $FASI_{t2}$ (blue): Force Absolute Symmetry Index (FASI, in %) at the time of maximal acceleration (t_2), $FASI_{t4}$ (red): FASI at the time of maximal deceleration (t_4). Stand-to-Sit task (right): $FASI_{T2}$ (orange): FASI at the time of maximal acceleration (T_2), $FASI_{T4}$ (green): FASI at the time of maximal deceleration (T_4). Bars represent mean values, and error bars indicate standard deviation of each group. HYA: Healthy Young Adults (n=24); HOA: Healthy Older Adults (n=15); KOA: individuals with knee osteoarthritis (n=21). *: $p \leq 0.05$.

Concerning between groups comparison, FASI values were comparable across groups for both Sit-to-Stand and Stand-to-Sit tasks **(Table 3.4, Figure 3.7)**. During the standing phases (one second after t_5 for SitTS, and one second before T_1 for StandTS), differences in inter-limb force distribution ranged between 9% and 18% across groups **(Table 3.4)**. KOA showed greater timing asymmetry for the maximal upward acceleration during Sit-to-Stand ($TASIt_2$) compared to HYA, and greater timing asymmetry for the maximal deceleration during Sit-to-Stand ($TASIt_4$), the maximal downward acceleration ($TASI_{T_2}$) and deceleration ($TASI_{T_4}$) during Stand-to-Sit compared to both HOA and HYA **(Table 3.4, Figure 3.8)**. In addition, HOA showed higher FASI values during one second after t_5, during Stand-to-Sit at T_4 and higher TASI values at T_2 and T_4 than HYA.

Table 3.4. Asymmetry variables of Sit-to-Stand and Stand-to-Sit tasks across groups

Variable, Median (IQR)	**KOA** (N=21)	**HOA** (N=15)	**HYA** (N=24)
Sit-to-Stand			
$FASI_{SitTS}$ (%)	20.05 (10.64)	20.37 (18.34)	20.33 (10.51)
$FASI_{after}$ (%)	16.71 (9.74)	18.01 (11.45)	11.33 (6.51)
$FASI_{t2}$ (%)	9.69 (12.07)	11.16 (13.70)	9.14 (8.20)
$FASI_{t4}$ (%)	25.90 (25.70)	33.80 (30.97)	27.65 (18.60)
$TASI_{t2}$ (ms)	38.67 (78.33)[b]	28.33 (49.00)	17.33 (14.17)
$TASI_{t4}$ (ms)	151.67 (322.17)[a,b]	57.00 (60.67)	36.33 (46.67)
Stand-to-Sit			
$FASI_{StandTS}$ (%)	16.47 (12.54)	19.55 (11.90)	16.19 (10.44)
$FASI_{before}$ (%)	8.87 (20.20)	11.77 (11.39)	10.26 (13.35)
$FASI_{T2}$ (%)	16.67 (20.72)	27.87 (21.72)	20.83 (18.97)
$FASI_{T4}$ (%)	16.45 (20.52)	17.50 (15.44)	10.40 (11.40)
$TASI_{T2}$ (ms)	200.33 (243.67)[a,b]	94.67 (97.33)	44.83 (45.83)
$TASI_{T4}$ (ms)	377.67 (238.17)[a,b]	92.67 (128.33)	34.50 (58.50)

KOA: individuals with Knee Osteoarthritis; HOA: Healthy Older Adults; HYA: Healthy Young Adults; $FASI_{SitTS}$: average Force inter-limb Absolute Symmetry Index (FASI) during Sit-to-Stand task , $FASI_{t2}$: FASI at t_2, $FASI_{t4}$: FASI at t_4, $TASI_{t2}$: timing difference between t_2 of the left and the right leg, $TASI_{t4}$: timing difference between t_4 of the left and the right leg, $FASI_{after}$: FASI during one second after t_5, $FASI_{StandTS}$: average Force inter-limb Absolute Symmetry Index (FASI) during Stand-to-Sit task , $FASI_{T2}$: FASI at T_2, $FASI_{T4}$: FASI at T_4, $TASI_{T2}$: timing difference between T_2 of the left and the right leg, $TASI_{T4}$: timing difference between T_4 of the left and the right leg, $FASI_{before}$: FASI during one second before T_1; [a]: statistically significant difference from HOA, [b]: statistically significant difference from HYA.

Significant correlations were observed between timing asymmetry and functional outcomes in both KOA and HOA groups **(Table 3.5)**. In the KOA group, greater timing asymmetry at t_2 during Sit-to-Stand was associated with shorter OLST, longer FTSTS duration, and lower level of activities of daily living (KOOS-ADL), while greater asymmetry at t_4 was associated with higher pain (KOOS-Pain) and lower KOOS-ADL scores. During Stand-to-Sit, greater timing asymmetry at T_2 was associated with shorter OLST duration and lower KOOS-ADL scores. In the HOA group, greater timing asymmetry at t_2 during Sit-to-Stand and at T_2 during Stand-to-Sit was also associated with shorter OLST duration.

Among the KOA participants (n=21), three reported unilateral knee pain; no pain on one side (Numeric Pain Rating Scale – NPRS = 0) and at least a NPRS of 3 on the other side (Uni_KOA 1 NPRS left–right: 3-0, Uni_KOA 2: NPRS 4-0, Uni_KOA 3: NPRS 5-0). Their physical performance showed marked variability, with FTSTS times ranging from 10.7 s to 27.6 s. The OLST duration varied between the affected and non-affected sides, with no consistent pattern across participants **(Table 3.6)**. An additional exploratory analysis was performed with these three KOA participants, and their asymmetry indices are compared with those of bilateral KOA participants (n= 18), HOA (n= 15), and HYA (n= 24) in **Figure 3.7** and **Figure 3.8**. Uni_KOA 1 and Uni_KOA 2 showed FASI and TASI values comparable to those of the bilateral KOA and control groups, remaining within the group mean ± SD range. Uni_KOA 3 presented higher values, exceeding the mean ± SD of bilateral KOA and control participants at several parameters, including FASI at t_2, t_4, Stand-to-Sit, and T_4, as well as TASI at t_2, t_4, and T_2. The different patterns of the three unilateral KOA during Sit-to-Stand and Stand-to-Sit tasks are illustrated in **Figure 3.9**.

Table 3.5. Spearman's correlation coefficients among inter-limb asymmetry, functional performance (OLST, FTSTS) and KOOS (ADL and Pain) variables.

	OLST	FTSTS	KOOS-Pain	KOOS-ADL
Individuals with Knee Osteoarthritis				
Sit-to-Stand				
$TASI_{t2}$ (ms)	-0.444*	0.537*	NS	-0.560**
$TASI_{t4}$ (ms)	NS	NS	-0.480*	-0.668**
Stand-to-Sit				
$TASI_{T2}$ (ms)	-0.521*	NS	NS	-0.603**
$TASI_{T4}$ (ms)	NS	NS	NS	NS
Healthy Older Adults				
Sit-to-Stand				
$TASI_{t2}$ (ms)	-0.561*	NS		
$TASI_{t4}$ (ms)	NS	NS		
Stand-to-Sit				
$TASI_{T2}$ (ms)	-0.675**	NS		
$TASI_{T4}$ (ms)	NS	NS		

OLST: One Leg Standing Test; FTSTS: Five-Time Sit to Stand test; KOOS-Pain: subscale of the Knee Injury and Osteoarthritis Outcome Score-Pain subscale (9 items, see Appendix II); KOOS-ADL: subscale of the KOOS (17 items, see Appendix II); $TASI_{t2}$: timing difference between t_2 of the left and the right leg, $TASI_{t4}$: timing difference between t_4 of the left and the right leg, $TASI_{T2}$: timing difference between T_2 of the left and the right leg, $TASI_{T4}$: timing difference between T_4 of the left and the right leg; NS: Non-significant; * $p \leq 0.05$; ** $p \leq 0.01$

Table 3.6. Characteristics of individuals with unilateral knee osteoarthritis

Parameter	Uni-KOA 1	Uni-KOA 2	Uni-KOA 3
Age (years)	70	65	70
Sex	Male	Female	Female
Height (m)	1.67	1.53	1.52
Body weight (kg)	79.7	45.5	54.1
BMI (kg m^{-2})	28.6	19.4	23.4
NPRS			
Left/Right (affected/non-affected)	3/0	4/0	5-0
Physical performance tests (seconds)			
OLST left (affected)	25.3	60.0	4.7
OLST right (non-affected)	63.6	52.0	3.3
FTSTS	10.7	13.1	27.6

OLST: One Leg Standing Test; FTSTS: Five-time Sit to Stand test; NPRS: Numeric Pain Rating Scale, Uni_KOA: individual with unilateral knee osteoarthritis

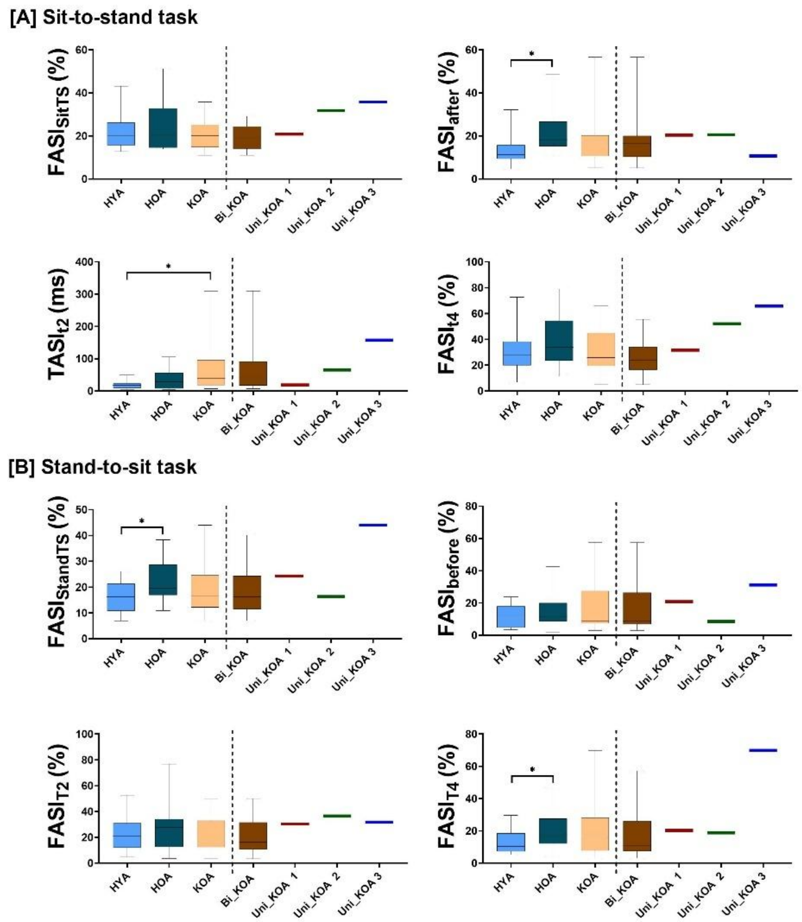


Figure 3.7. Inter-limb asymmetry indices (FASI, in %) during the Sit-to-Stand in all groups (HYA, HOA, KOA), in the three participants with unilateral KOA and in the remaining subgroup of KOA. [A] Sit-to-Stand task: FASI$_{SitTS}$: average Force inter-limb Absolute Symmetry Index (FASI, in %) during the entire task; FASI$_{after}$: FASI during one second after t_5; FASI$_{t2}$: FASI at t_2; FASI$_{t4}$: FASI at t_4. [B] : Stand-to-Sit task: FASI$_{StandTS}$: FASI during the entire task; FASI$_{before}$: FASI during one second before T_1; FASI$_{T2}$: FASI at T_2; FASI$_{T4}$: FASI at T_4. Bars represent mean values, and error bars indicate standard deviation of each group. HYA: Healthy Young Adults (n=24); HOA: Healthy Older Adults (n=15); KOA: individuals with knee osteoarthritis (n=21), Bi_KOA: bilateral knee osteoarthritis (n=18). The three participants with unilateral KOA (Uni_KOA 1–3) are plotted individually according to their pain profiles (NPRS left–right: Uni_KOA 1: 3–0, Uni_KOA 2: 4–0, and Uni_KOA 3: 5–0, respectively).

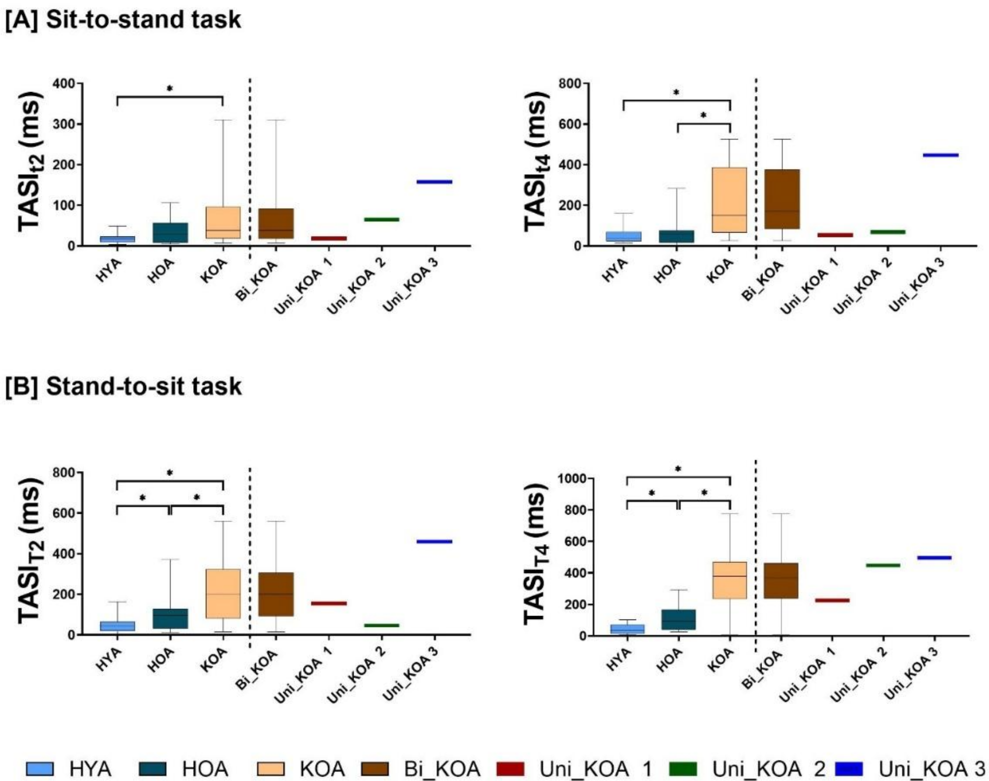


Figure 3.8. Timing inter-limb asymmetry indices during the Sit-to-Stand and Stand-to-Sit tasks in all groups (HYA, HOA, KOA), in three participants with unilateral KOA and in the remaining subgroup of KOA. [A]: Sit-to-Stand task: TASI$_{t2:}$ Timing Absolute Symmetry Index (TASI, in msec) at t_2; TASI$_{t4}$: TASI at t_4. [B]: Stand-to-Sit task. TASI$_{T2}$: TASI at T_2; TASI$_{T4:}$ TASI at T_4. Other indications are as in Figure 3.7.

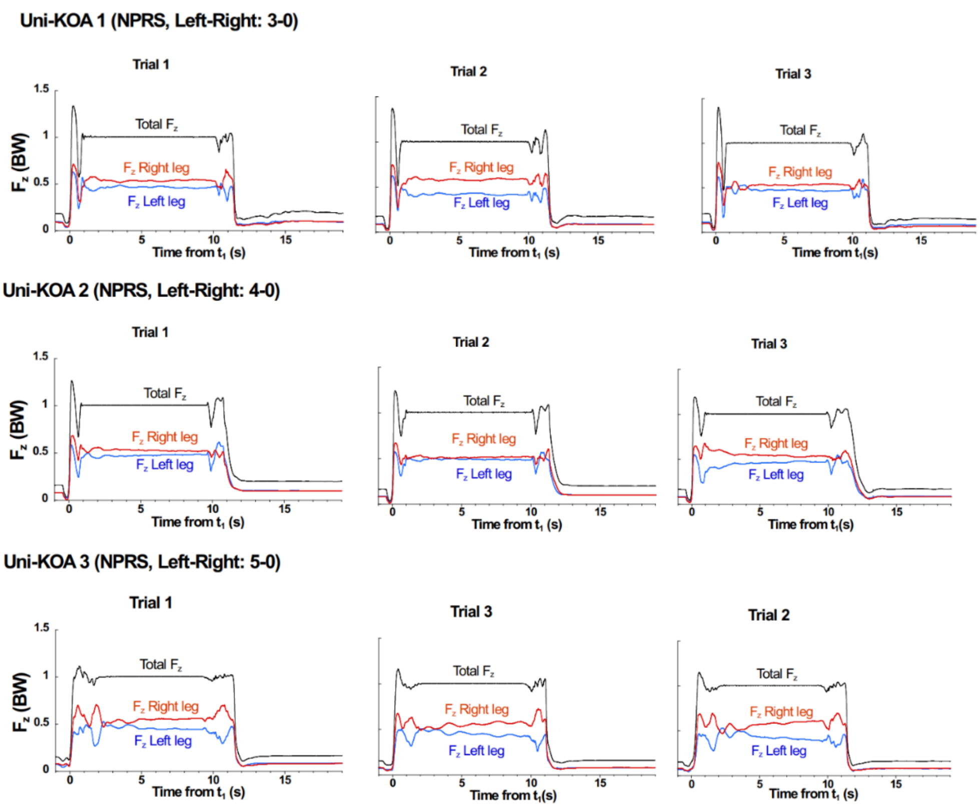


Figure 3.9. Typical traces of Sit-to Stand and Stand-to-Sit tasks in three participants with unilateral knee osteoarthritis. Vertical component of ground reaction force (F_z, in body weight) traces during three Sit-to-Stand and Stand-to-Sit trials in 3 participants with unilateral knee osteoarthritis. Each row presents one individual. Top: Uni_KOA 1 caracterised by NPRS left-right 3–0; Middle: Uni_KOA 2 by NPRS 4–0; Bottom: Uni_KOA 3 by NPRS 5–0. For each trial, blue dotted line: $F_{z\text{-}L}$, red solid: $F_{z\text{-}R}$, black thin line: Fz total ($=F_{z\text{-}L}+F_{z\text{-}R}$). Time is presented relative to movement onset (t_1).

Discussion

This study examined inter-limb asymmetry in both force magnitude and timing during Sit-to-Stand and Stand-to-Sit tasks in individuals with knee osteoarthritis (KOA), age matched older adults and healthy young adults. Force asymmetry did not differ significantly between groups, whereas timing asymmetry was clearly greater in KOA (t_2, t_4, T_2, and T_4). This shows that KOA can keep the load distribution between legs relatively balanced, but that the loading timing of each leg is different.

In Sit-to-Stand, t_2 marks the instant of maximal upward acceleration when both legs generate force to lift the body, whereas t_4 corresponds to the instant of maximal deceleration when the upward motion slows before achieving upright stance, requiring coordinated adjustment of lower-limb forces (Etnyre & Thomas, 2007; Papa & Cappozzo, 2000; Roebroeck et al., 1994). In Stand-to-Sit, T_2 marks the instant of maximal downward acceleration when the body starts moving rapidly toward the seat and the total vertical ground reaction force reaches its minimum, whereas T_4 corresponds to the instant of maximal deceleration just before seat contact, when the hip and knee extensors act eccentrically to control the descent (Ashford & De Souza, 2000; Jeon et al., 2024).

During Sit-to-Stand, all groups showed higher force asymmetry at t_4 than at t_2, suggesting that differences between legs increase when the body slows down and stabilizes at the end of rising. In contrast, during Stand-to-Sit, this pattern was seen only in healthy young adults, who showed higher values at T_2 than at T_4, while KOA and older adults had similar values for both events. These findings show that load modulation at key movement events differed between young adults and the two older groups, suggesting age-related changes in inter-limb load adjustment during descent, consistent with previous studies reporting slower, less controlled of Stand-to-Sit movement and greater impact forces at seat contact in these groups (Jeon et al., 2024; Kondo et al., 2022)

The overall level of force asymmetry was comparable between groups, but some differences between HOA and HYA were observed ($FASI_{after}$, $FASI_{StandTS}$, $FASI_{T4}$). These differences were not amplified in KOA, indicating that force asymmetry is primarily influenced by ageing rather than by knee osteoarthritis. Earlier studies showed that people with KOA often unload the painful leg and rely more on the contralateral leg during weight-bearing tasks (Christiansen et al., 2015; Schofield et al., 2013). In the present study, this was not observed, likely because most participants had bilateral symptoms. When both knees are affected, pain and effort are shared more evenly, resulting in similar average loading. These results indicate that KOA can maintain a balanced distribution of force even when movement control is altered. However, symmetrical loading does not necessarily mean that both legs act in a synchronized way. Timing asymmetry provides deeper insight into how inter-limb coordination changes with age and osteoarthritis. In the present study, TASI values showed a gradual increase from young to older to KOA participants, indicating that age-related delays in coordination are amplified by joint pathology. During Sit-to-Stand, timing asymmetry was greater in KOA than in HYA but comparable to HOA at the time of maximal acceleration, whereas it was markedly higher in KOA than in both control groups at maximal deceleration. This suggests that temporal control becomes particularly impaired in KOA when stabilization is required at the end of rising. During Stand-to-Sit, KOA showed greater timing asymmetry than both control groups at all key events, revealing disrupted synchronization in both the acceleration and braking phases of descent. The two legs did not act together, indicating that the timing of force generation and reduction was misaligned. This temporal mismatch may help smooth load transfer and limit discomfort in the short term (Astephen et al., 2008; Zeni & Higginson, 2009). Yet similar patterns have been associated with poorer balance control and uneven loading between legs (Hortobágyi et al., 2009; MacKinnon & Winter, 1993; Sadeghi et al., 2000).

Previous research has shown that inter-limb differences in performance are not solely determined by strength, and that asymmetry often persists even after muscle strength recovers following knee arthroplasty. Such findings suggest that altered timing, rather than reduced force capacity, may represent a persistent adaptation in motor coordination. The current results extend this idea to bilateral KOA, showing that even when both legs share the mechanical limitation, the precise synchronization between them remains altered. Timing asymmetry may therefore serve as a sensitive marker of impaired coordination and a potential target for rehabilitation (Almonroeder et al., 2023; Christiansen et al., 2015).

The correlation patterns highlight that timing asymmetry represents different aspects of motor control depending on the task phase. During Sit-to-Stand, greater asymmetry at t_2 was related to poorer performance in both the OLST and FTSTS tests, as well as to lower KOOS-ADL scores. Since t_2 corresponds to the time of maximal upward acceleration, it represents a critical moment when both legs need to act in a coordinated manner to generate vertical force. Therefore, temporal desynchronization at this stage may reflect altered inter-limb coordination and was associated with poorer static balance (OLST) and slower performance in dynamic balance tasks (FTSTS). At t_4, timing asymmetry showed a stronger association with KOOS ADL and KOOS Pain but not with the performance tests. This event corresponds to maximal deceleration, when the body stops moving upward and stabilizes in standing. A lack of synchronization at this stage can reduce movement smoothness and postural control, making the transition to upright stance more effortful. The strong link with KOOS-ADL suggests that temporal mismatch at the time of maximal deceleration is functionally relevant for daily activities. Most ADL tasks, such as rising from a chair, standing, descending stairs, or getting in and out of a car, depend on this ability to coordinate the end of movement precisely. Timing asymmetry at t_4 may therefore represent a subtle but functionally meaningful indicator of altered coordination that is associated with pain and limitations of daily activity in knee osteoarthritis (Etnyre & Thomas, 2007; Hiraoka et al., 2014; Papa & Cappozzo, 2000; Roebroeck et al., 1994).

During Stand-to-Sit, greater timing asymmetry at T_2 was associated with poorer OLST and lower KOOS-ADL scores. T_2 marks the point of maximal downward acceleration, when the body starts to move rapidly toward the seat and the total vertical ground reaction force reaches its minimum. At this moment, both legs must coordinate to control the transition from upright stance to descent while maintaining equilibrium. A lack of temporal synchronization between legs may reflect altered inter-limb coordination during the initial phase of sitting down. This instability can challenge static balance once seated, explaining the link with poorer OLST. The association with KOOS-ADL suggests that this early descent control is also functionally meaningful. Many daily activities, such as lowering into a chair, sitting onto a toilet, or descending stairs, require precise timing between legs to manage gravitational acceleration safely. Impaired temporal coordination at T_2 may increase perceived difficulty or insecurity during these movements even when overall task duration is normal. The absence of correlation with FTSTS is consistent with the nature of this test, which primarily captures the rising phase and includes only a brief and less demanding sitting component (Ashford & De Souza, 2000; Jeon et al., 2024; Papa & Cappozzo, 2000). No significant correlations were found at T_4 in any group. At this late phase, both legs act eccentrically to decelerate the body until seat contact, and the mechanical constraints of the chair reduce the demand for precise bilateral coordination. Timing differences here may therefore have little effect on functional performance or perceived difficulty.

The exploration analysis of the three unilateral KOA participants provides additional information about how uneven pain affects the way the two legs work together. All three had pain mainly on one side, but their results were different. Two participants had force and timing asymmetric values within the same range as those of bilateral KOA and healthy groups, while one participant showed higher asymmetry in several events. This difference suggests that when pain between sides becomes more unequal, coordination between the legs is more affected.

In unilateral cases, the difference in pain and tolerance between legs can disturb how the legs coordinate, leading to greater differences in both force and timing. Previous studies have also shown that people with pain on one side tend to reduce or delay loading on the painful leg during Sit-to-Stand (Christiansen et al., 2015; Hiraoka et al., 2014). These findings suggest that the difference in pain between sides may play an important role in how people with knee osteoarthritis adapt their movement.

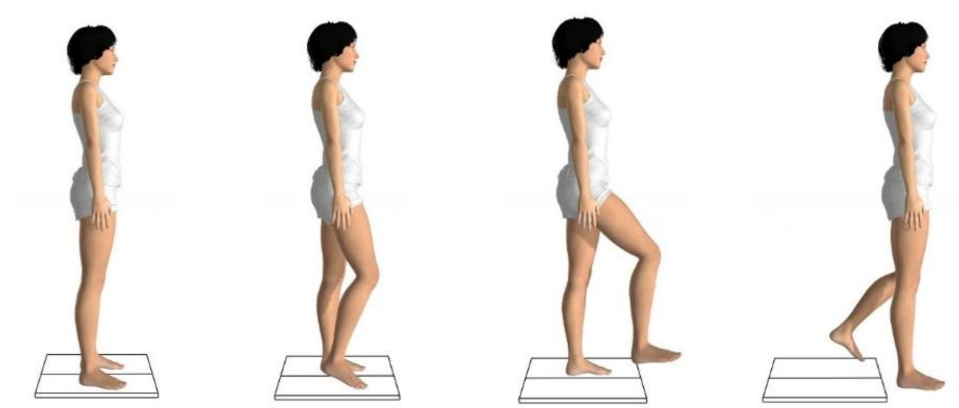
This study has some limitations. The cross-sectional design prevents causal interpretation, and the small number of unilateral cases limits generalization. Future studies should confirm these findings in larger samples and combine force and electromyographic data to characterize muscle activation timing. Establishing the minimal clinically important difference for TASI would also support its use as an outcome measure in rehabilitation.

Conclusion

Individuals with knee osteoarthritis appear to balance the load between their legs but not the timing of their actions. Because greater timing asymmetry was associated with reduced functional performance and higher pain, timing-based measures may provide valuable insight into coordination strategies and serve as sensitive indicators of functional impairment in clinical rehabilitation.

CHAPTER 4

Postural control during Gait initiation in Knee Osteoarthritis



"By failing to prepare, you are preparing to fail."

— Benjamin Franklin

This chapter focuses on gait initiation, a unipodal transition that places greater demands on balance control than the bipodal tasks examined in Chapter 3. Initiating gait requires coordinated anticipatory adjustments, redistribution of load between legs, and the generation of forward progression from a narrow base of support. These features make gait initiation particularly sensitive to age- and disease-related changes in postural regulation. In this chapter, kinetic analyses are used to describe how forces and timing evolve during this transition in young adults, healthy older adults, and individuals with knee osteoarthritis. By examining both preferred- and non-preferred-leg conditions, this chapter provides complementary insight into postural control strategies that cannot be captured through observational or performance-based assessments alone, and it completes the multi-task exploration of functional transitions in this thesis.

4.1. Gait initiation with preferred and non-preferred leg kinetics in individuals with knee osteoarthritis, healthy older adults and healthy young adults

Manuscript in preparation

Keywords: functional performance, unipodal transition, centre of pressure, anticipatory postural adjustments, weight transfer

Introduction

Gait initiation is the transition from quiet standing to steady walking. It is a mechanically demanding task because the body must generate forward progression while controlling stability as support shifts from double- to single-leg stance (Breniere & Do, 1986; Yiou et al., 2017). This transition is crucial for functional mobility, such as walking forward after standing up, starting to walk after stopping. Difficulties during gait initiation are associated with slower mobility and an increased risk of falls, particularly in older adults and individuals with impaired postural control (Callisaya et al., 2016; Uemura et al., 2011).

To analyse the mechanisms underlying this transition, biomechanical studies commonly divide gait initiation into two phases. First, the anticipatory postural adjustment phase is a feedforward neuromuscular adjustment that generates centre of pressure and body's centre of mass shifts and create the mechanical conditions to prepare the body for forward progression (Brenière & Do, 1991; Yiou et al., 2017). Then, the locomotion phase converts these preparatory adjustments into forward movement through coordinated modulation of ground-reaction forces and lower-limb joint moments (Brenière & Do, 1991; Yiou et al., 2017). These phases are sensitive to ageing and pathology, making gait initiation of interest for studying postural and locomotion control.

Ageing typically reduces the amplitude and velocity of centre of pressure displacements and slows the transition to forward progression, reflecting cautious control of weight transfer and propulsion (Kimijanová et al., 2021; Kwag et al., 2024; Polcyn et al., 1998). Knee osteoarthritis is also expected to influence gait initiation, as pain, reduced proprioception, altered muscle activation, and joint stiffness can constrain load transfer and modify centre-of-pressure trajectories (Hinman et al., 2002; Hunter & Bierma-Zeinstra, 2019; Rice & McNair, 2010; Sharma et al., 1997). Existing studies in knee osteoarthritis have reported smaller centre of pressure displacements, reduced forward movement, and longer movement duration compared with healthy older adults, suggesting a more constrained weight-transfer strategy (da Silva Soares et al., 2020; Esfandiari et al., 2020; Katoh, 2019; Viton et al., 2000). However, several aspects remain to be explored. First, few studies have analysed mediolateral control in detail, despite its central role in stabilising body weight transfer. Second, knee osteoarthritis has mostly been compared with age-matched controls, making it difficult to distinguish osteoarthritis-specific changes from age-related effects. Third, how individuals with knee osteoarthritis initiate gait with their preferred or with their non-preferred leg as leading leg is not known. This study aimed to describe the kinetic characteristics of gait initiation in individuals with knee osteoarthritis compared to healthy older and young adults, to examine the effect of initiating gait with the preferred versus non-preferred leg, and to explore how these parameters relate to functional measures within the osteoarthritis group. These findings may provide additional information on body weight-transfer control during gait initiation to support rehabilitation assessment in individuals with knee osteoarthritis.

Materials and Methods

This study investigated the gait initiation task in individuals with knee osteoarthritis (KOA), healthy older adults (HOA), and healthy young adults (HYA).

Participants

Fifty-five participants took part in the study, including 25 with KOA, 15 HOA, and 15 HYA. Characteristics of the participants are presented in **Table 4.1**. The inclusion and exclusion criteria and recruitment procedures were the same as described in Chapter 3. Ethical approval for the study was obtained from the Ethical Committee of the University of Medicine and Pharmacy at Ho Chi Minh City, Vietnam (approval number 24890-ĐHYD, dated 04/11/2024). The research adhered to the principles outlined in the Declaration of Helsinki. All participants provided written informed consent before the experiment.

Experimental set-up and procedure

The experimental configuration, data acquisition system, and signal processing were the same as in Chapter 3. Before performing the gait initiation task, all participants completed two physical performance tests (eg. Five-time-Sit-to-Stand and One leg standing test), and KOA additionally completed the Knee Injury and Osteoarthritis Outcome Score (KOOS) and rated their level of knee pain on Numeric pain rating scale (NPRS) for each leg.

For the gait initiation task participants stood barefoot with one foot on each of the two 1D-Twin force plates (40 × 30 cm, Arsalis SRL, Belgium, see Chapter 3) in a comfortable position. An investigator stood beside the participants to prevent falls. First, participants stood quietly for 5 seconds, then initiated gait at the auditory cue (“Go”) and walked straight ahead for about one meter at their usual pace. The leg they naturally used for the first step was called the preferred leg. Each participant completed three valid trials. Second, participants started the movement with the opposite leg (non-preferred leg) following the same procedure. Short breaks were provided between trials if needed. Trials were considered non-valid if the participant moved before the cue, started with one leg and then switched to the other, lost balance before stepping off the plates, or needed assistance from the investigator to step off the plates.

Outcome measures

The vertical component of the ground reaction forces recorded under leading (F_{zlead}) and trailing (F_{ztrail}) foot was summed to obtain the total vertical force (F_z, in body weight). The centre of pressure (COP) coordinates were computed using the equations: $COP_{AP} = M_y/F$ and $COP_{ML} = M_x/F$, where COP_{AP} and COP_{ML} are COP coordinates along the anteroposterior (AP) and mediolateral (ML) axes, respectively; M_x and M_y are the moments around the ML and AP axes;

F is the vertical component of the ground reaction force at that time point. COP_{AP} and COP_{ML} were calculated for both feet combined (COP_{net}) and separately for the leading and for the trailing foot. The COP_{APnet} was used to determine the main time events and phases of gait initiation and the COP_{MLnet} to analyse the lateral body weight-shift control **(Figure 4.1)**.

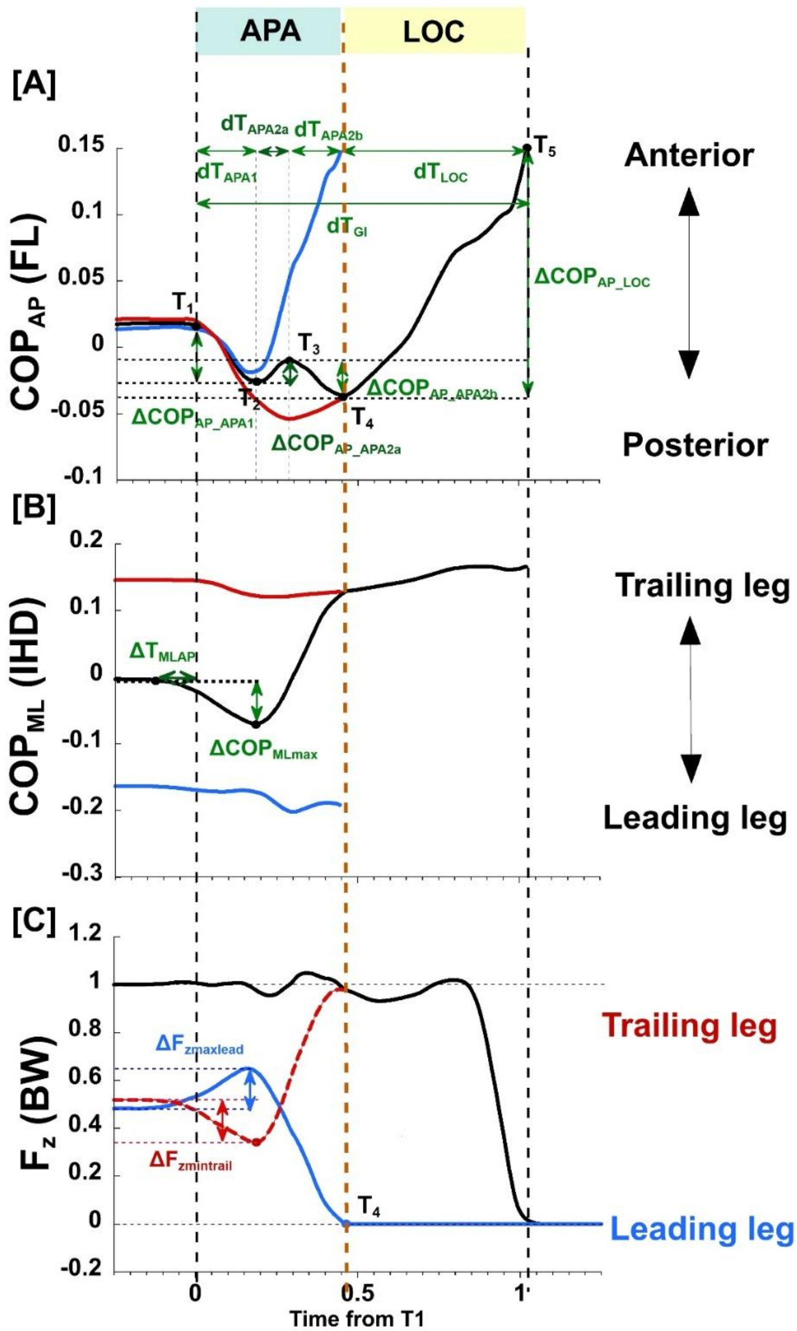
For the gait initiation phases, the onset (T_1) was defined as the first time when COP_{APnet} decreased by more than three standard deviations from the mean of the one-second quiet-standing baseline and remained for at least 100 ms. T_2 was the time of the minimum of COP_{APnet}, T_3 the time of maximum COP_{APnet} between T_2 and T_4, T_4 the last moment before step-off of the leading leg, T_5 the last moment before step-off of the trailing leg **(Figure 4.1)**. These time events defined three Anticipatory Postural Adjustment (APA) subphases and the Locomotion (LOC) phase (Cau et al., 2014). APA1 phase is from T_1–T_2 corresponds to the initial backward and lateral shift unloading the leading leg, APA2a phase from T_2–T_3 corresponds to the forward transfer of weight to the trailing leg, APA2b phase from T_3–T_4 corresponds to the backward shift under the trailing foot preparing propulsion, LOC phase from T_4–T_5 corresponds to the forward movement from toe-off of the leading leg to toe-off of the trailing leg **(Figure 4.1)**. The onset of lateral movement ($COP_{MLstart}$) was defined as the first time when COP_{MLnet} decreased by more than three standard deviations from the mean of the one-second quiet-standing baseline and remained for at least 100 ms **(Figure 4.1B)**.

Temporal and kinetic variables were derived from the identified timing events. The total duration of gait initiation (dT_{GI}, s) was calculated as T_5-T_1, the duration of the first APA subphase (dT_{APA1}, s) as T_2-T_1, the duration of the second APA subphase (dT_{APA2a}, s) as T_3-T_2, and the third APA subphase (T_{APA2b}, s) as T_4-T_3. The net anteroposterior COP displacement was calculated for each subphase (ΔCOP_{AP_APA1}, ΔCOP_{AP_APA2a}, ΔCOP_{AP_APA2b}) as the absolute difference in COP_{AP} coordinates between the start and end of the subphase and normalised to foot length (FL). The maximal mediolateral COP displacement (ΔCOP_{MLmax}) calculated as the difference in COP_{ML} coordinates between $T_{MLstart}$ and the point of maximum displacement toward the leading leg, normalized to the distance between the midpoints of both heels during quite standing (inter heel distance, IHD, see also **Figure 1.5**). The difference in timing between the onset of COP_{ML} and COP_{AP} (dT_{MLAP}, s) was calculated as $|T_1 - T_{MLstart}|$, and the percentage of trials in which the COP_{ML} began before the COP_{AP} displacement was calculated for each group. The maximum F_z under the leading leg ($\Delta F_{zmaxlead}$) and the minimum under the trailing leg ($\Delta F_{zmintrail}$) were calculated as the difference between the maximum or minimum Fz value and each leg's baseline force recorded during T_1 to T_4, normalised to body weight (BW) **(Figure 4.1C)**. For LOC phase, the duration (T_{LOC}, s) was calculated as T_5–T_4, and the anteroposterior COP displacement (ΔCOP_{AP_LOC}, FL) as the difference in COP_{AP} coordinates during T_4-T_5.

The duration of the Five-Times Sit-to-Stand Test (FTSTS), of the One leg standing test of the leading leg ($OLST_{lead}$) and of trailing leg ($OLST_{trail}$) was measured in seconds. The KOOS score was collected for each subscale and classified as extreme (0–12.5), severe (12.6–37.5), moderate (37.6–62.5), mild (62.6–87.5) or no difficulty (≥87.6) (Roos, 2024). The highest NPRS score between two knees was used for analysis (Lee et al., 2025).

Data analysis

All variables were computed using a customized program in LabVIEW (National Instruments, USA). For each participant, the average of three valid trials was used for analysis in both conditions: gait initiation with the preferred leg (GI-P) and with the non-preferred leg (GI-NP). Normality was assessed with the Shapiro–Wilk test. For the GI-P condition, seven variables were normally distributed (dT_{GI}, dT_{APA1}, ΔCOP_{AP_APA1}, ΔCOP_{AP_APA2a}, ΔCOP_{AP_LOC}, $\Delta F_{zmintrail}$, $\Delta F_{zmaxlead}$) and analyzed with one-way ANOVA followed by Dunnett's post-hoc test using the KOA group as the reference (KOA versus HOA; KOA versus HYA). Six variables were non-normally distributed (dT_{APA2a}, dT_{APA2b}, T_{LOC}, ΔT_{MLAP}, ΔCOP_{MLmax}, ΔCOP_{AP_APA2b}) and were analyzed with Kruskal–Wallis tests followed, when significant, by Mann–Whitney U tests (KOA versus HOA; KOA versus HYA) with within-variable multiplicity controlled by Bonferroni adjustment. In addition, comparisons between HOA and HYA were performed to examine potential age-related differences. For the GI-NP condition, the same approach was applied for the seven normally distributed variables (dT_{APA1}, ΔCOP_{MLmax}, ΔCOP_{AP_APA1}, ΔCOP_{AP_APA2a}, ΔCOP_{AP_LOC}, $\Delta F_{zmintrail}$, $\Delta F_{zmaxlead}$) and the nine non-normally distributed variables (dT_{GI}, dT_{APA2a}, dT_{APA2b}, T_{LOC}, ΔT_{MLAP}, ΔCOP_{AP_APA2b}). Within-group comparisons between GI-P and GI-NP for each group were also explored using paired t-tests for the normally distributed variables and Wilcoxon signed-rank tests for the non-normally distributed variables. Within KOA group, correlations between kinetic variables that showed significant group differences and the functional measures (FTSTS, $OLST_{lead}$, $OLST_{trail}$, KOOS-Pain, KOOS-ADL) were tested using Spearman's rank correlation. Family-wise multiplicity was controlled using Bonferroni correction, and significance levels were based on final adjusted p-values. All tests were two-tailed with a significance level of $p < 0.05$. Continuous data are presented as median and interquartile range (IQR). Analysis was performed in SPSS 29.0.1.0 (IBM Corp., Armonk, NY, USA).


APA
LOC
[A]
dTAPA2a
dTAPA2b
dTAPA1
dTLOC
dTGI
T1
T2
T3
T4
T5
ΔCOPAP_LOC
ΔCOPAP_APA2b
ΔCOPAP_APA1
ΔCOPAP_APA2a
COPAP (FL)
Anterior
Posterior
[B]
ΔTMLAPI
ΔCOPMLmax
COPML (IHD)
Trailing leg
Leading leg
[C]
ΔFzmaxlead
ΔFzmintrail
T4
Fz (BW)
Trailing leg
Leading leg
Time from T1

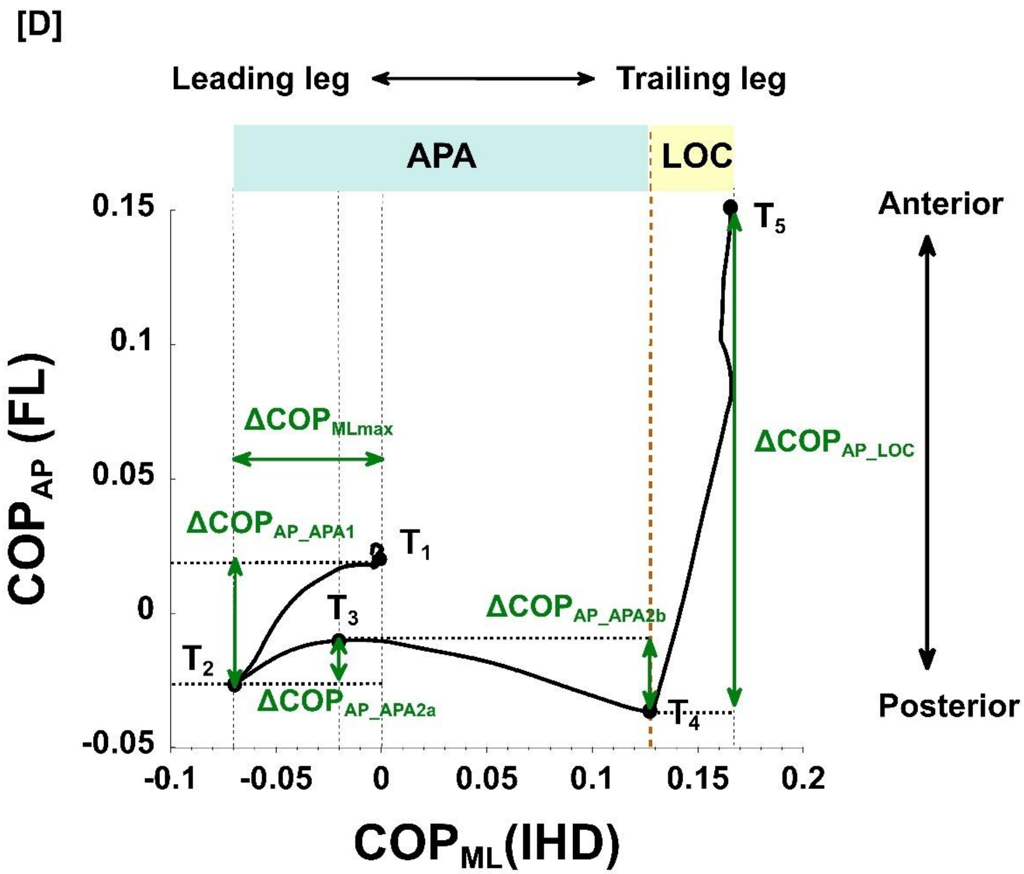


Figure 4.1. Schematic of key time events, centre of pressure (COP) and vertical component of ground reaction forces during gait initiation. Key events are illustrated for each task in a healthy young adult (Female, 21 years, 60.8 kg, 1.66 m) (see Methods). APA: Anticipatory Postural Adjustment phase; LOC: Locomotion phase. Panel [A]: COP displacement in anteroposterior direction (COP_{AP}) vs time (s); combined COP_{AP} of both feet (COP_{APnet}, black line); COP_{AP} of the leading leg (blue line); COP_{AP} of the trailing leg (red line). Panel [B]: COP displacement in mediolateral direction (COP_{ML}) vs time (s); combined COP_{ML} of both feet (COP_{MLnet} , black line); COP_{ML} of the leading leg (blue line); COP_{ML} of the trailing leg (red line). Panel [C]: vertical component of ground reaction force (F_Z) vs time (s); total F_z generated by both feet (black line); F_z generated by the leading leg (F_{zlead}, blue line); F_z generated by the trailing leg (F_{ztrail}, red line). Panel [D]: COP trajectory in anteroposterior (Y axis) and mediolateral (X axis) direction. T_1: onset of COP_{APnet}; T_2: time of the minimum of COP_{APnet}, T_3: time of the maximum of COP_{APnet} between T_2 and T_4; T_4: step-off of the leading leg; T_5: step-off of the trailing

leg; dT_{GI}: duration of gait initiation; dT_{APA1}: duration of the first APA subphase (T_2–T_1); dT_{APA2a}: duration of the early second APA subphase (T_3–T_2); dT_{APA2b}: duration of the late second APA subphase (T_4–T_3); dT_{LOC}: duration of the locomotion phase (T_5–T_4); ΔCOP_{AP_APA1}: posterior COP displacement toward the leading leg during APA1; ΔCOP_{AP_APA2a}: anterior COP displacement toward the trailing leg during APA2a; ΔCOP_{AP_APA2b}: posterior COP displacement toward the leading leg during APA2b; ΔCOP_{AP_LOC}: anterior COP displacement under the trailing leg during locomotion phase; FL: foot length, defined as the anteroposterior distance between the heel and the tip of the toe, used to normalize anteroposterior COP displacements. ΔCOP_{MLmax}: maximal mediolateral COP displacement toward the leading leg; dT_{MLAP}: time difference between the onset of mediolateral and of anteroposterior COP displacements; IHD: inter heel distance defined as the mediolateral distance between the centres of the two heels, used to normalize mediolateral COP displacements. $\Delta F_{zmintrail}$: maximum decrease in vertical component of ground reaction forces (F_z) under the trailing leg relative to its baseline during T_1–T_4; $\Delta F_{zmaxlead}$: maximum increase in Fz under the leading leg relative to its baseline during T_1–T_4.

Table 4.1. Characteristics of the participants

Parameter	KOA (N=25)	HOA (N=15)	HYA (N=15)
Age (years), mean±SD	65.8 ± 7.6	65.1 ± 9.0	21.0 ± 1.0
Sex (n Female/n Male)	23/2	12/3	12/3
Height (m), mean±SD	1.51 ± 0.05[b]	1.55 ± 0.08	1.62 ± 0.07
Body weight (kg), mean±SD	61.4 ± 10.9	54.8 ± 8.08	60.5 ± 14.1
Foot length (cm), mean±SD	22.7 ± 0.99	22.7 ± 1.3	22.3 ± 1.2
IHD (cm), mean±SD	26.4 ± 2.4[b]	26.0 ± 3.4	29.0 ± 2.8
Physical performance tests (seconds), mean±SD			
OLST (average of both legs)	16.3 ± 17.9[a]	42.3 ± 24.1	
$OLST_{lead}$ (GI-P)	14.8 ± 18.8[a]	46.8 ± 25.5	N/A
$OLST_{trail}$ (GI-P)	17.8 ± 19.4[a]	37.9 ± 27.8	N/A
FTSTS	17.7 ± 8.9[a]	14.4 ±19.7	N/A

KOA: individuals with Knee Osteoarthritis; HOA: Healthy Older Adults; HYA: Healthy Young Adults; IHD: Inter-heel distance; OLST: One Leg Standing Test; $OLST_{lead}$: OLTS duration when standing on the leading leg; $OLST_{trail}$: OLST duration when standing of the trailing leg; GI-P: Gait initiation with preferred leg; FTSTS: Five-Times Sit-to-Stand Test; SD: Standard deviation; N/A: Not applicable; [a] : Statistically significant difference from Healthy Older Adults group, [b] : Statistically significant difference from Healthy Young Adults group.

Results

Participant characteristics are summarized in **Table 4.1**. The KOA and HOA were comparable in age, height, weight and BMI. KOA had a shorter height compared to HYA. Foot length did not differ between groups. Inter-heel distance was comparable between KOA and HOA, and both older groups exhibited a significantly narrower stance than HYA. In physical performance tests, KOA showed longer FTSTS duration and shorter OLST duration compared to HOA. In KOA, KOOS subscale scores showed mild impairment in ADL (65.6 ± 16.8); moderate impairment in Symptoms (61.4 ± 11.3, mean ± SD), Pain (59.7 ± 15.0) and Quality of Life (40.8 ± 17.1), and severe impairment in Sport/Recreation (21.0 ± 14.1).

Overall, the total duration of gait initiation was similar across groups and tasks, ranging from 1.147 to 1.298 s (**Tables 4.2 and 4.3**). For both preferred and non-preferred leg tasks, the locomotion phase consistently accounted for the larger proportion of gait initiation, representing approximately 55–59% of the total duration across groups. For the gait initiation with the preferred leg task (GI-P), KOA showed during APA phase similar subphase durations compared to both healthy control groups **(Figure 4.2, Table 4.2)**. However, KOA showed a smaller posterior displacement toward the leading leg during the first APA subphase (ΔCOP_{AP_APA1}) compared to both HOA and HYA, smaller mediolateral displacement toward the leading leg (ΔCOP_{MLmax}) compared to HOA, smaller decrease in trailing leg force ($\Delta F_{zmintrail}$) and smaller increase in leading leg force ($\Delta F_{zmaxlead}$) compared to HOA **(Figure 4.2, Table 4.2).** During LOC phase, KOA showed a longer phase duration (dT_{LOC}) compared with both healthy groups (HOA and HYA) and smaller anterior displacement under the trailing leg (ΔCOP_{AP_LOC}) compared to HOA **(Figure 4.2 bottom line, Table 4.2)**. For the gait initiation with the non-preferred leg task (GI-NP), KOA showed during APA phase a longer duration of APA2a (dT_{APA2a}) compared to HOA **(Figure .4.3, Annex 4.2)**. During LOC phase, KOA showed smaller anterior displacement under the trailing leg (ΔCOP_{AP_LOC}) compared to HYA **(Figure 4.3 bottom line, Table 4.2)**. No significant differences were observed between HOA and HYA for any gait initiation variables **(Figures 4.2 and 4.3)**.

When comparing GI-P and GI-NP, no significant differences were observed for any variables for KOA and HYA, while HOA showed smaller anterior COP displacement toward the trailing during APA2a with the non-preferred leg (Median (IQR), 0.139 (0.133) vs 0.124 (0.115), p=0.041) **(Tables 4.1 and 4.2)**. In both GI-P and GI-NP, the majority of trials showed a mediolateral COP displacement prior to the anteroposterior onset, whatever the group. For GI-P, this sequencing occurred in 68% of trials in KOA, 67% in HYA and 78% in HOA. For GI-NP, the proportion of ML-first trials remained similar in KOA (66%) and HYA (67%) and but slightly decreased in HOA (69%).

Significant correlations were observed between kinetic parameters and functional performance within the KOA group **(Figure 4.4)**. During GI-P, longer locomotion phase duration (dT_{LOC}) correlated with less pain (higher KOOS-Pain scores) ($\rho = 0.443$, $p = 0.027$), greater anterior COP displacement under trailing leg during the locomotion phase (COP_{AP_LOC}) with longer trailing leg OLST duration ($\rho = 0.408$, $p = 0.043$). During GI-NP, greater COP_{AP_LOC} correlated with longer trailing leg OLST duration ($\rho = 0.448$, $p < 0.05$).

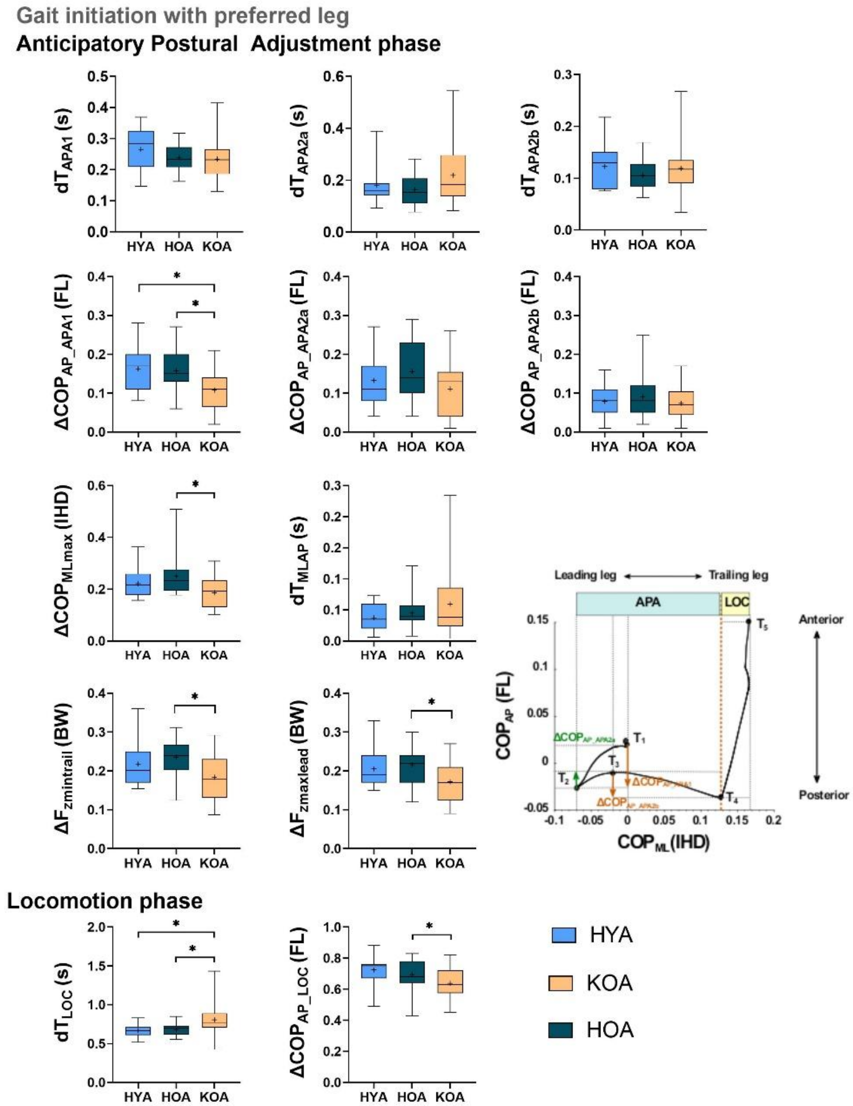


Figure 4.2. Comparison of kinetic parameters during gait initiation with preferred leg across groups. The box represents the interquartile range (25th–75th percentiles), the horizontal line inside the box indicates the median, and the cross indicates the mean, the whiskers represent the minimum and maximum values. KOA: individuals with Knee Osteoarthritis; HOA: Healthy Older Adults; HYA: Healthy Young Adults; other legends: see Figure 4.1; * significance level (p) ≤ 0.05.

Table 4.2 Kinetic variables of gait initiation with preferred leg tasks across groups

Variable, *Median (IQR)*	**KOA** (N=25)	**HOA** (N=15)	**HYA** (N=15)
dT_{GI} (s)	1.298 (0.385)	1.197 (0.139)	1.211 (0.280)
Anticipatory Postural Adjustment phase			
dT_{APA1} (s)	0.232 (0.080)	0.233 (0.064)	0.285 (0.116)
dT_{APA2a} (s)	0.183 (0.160)	0.152 (0.096)	0.159 (0.045)
dT_{APA2b} (s)	0.117 (0.044)	0.104 (0.043)	0.130 (0.072)
ΔCOP_{AP_APA1} (FL)	0.111 (0.077)^{a,b}	0.145 (0.077)	0.172 (0.087)
ΔCOP_{AP_APA2a} (FL)	0.132 (0.119)	0.139 (0.133)	0.114 (0.087)
ΔCOP_{AP_APA2b} (FL)	0.068 (0.059)	0.078 (0.070)	0.082 (0.062)
ΔCOP_{MLmax} (IHD)	0.192 (0.103)^{a}	0.234 (0.080)	0.205 (0.052)
ΔT_{MLAP} (s)	0.038 (0.061)	0.039 (0.024)	0.035 (0.040)
$\Delta F_{zmintrail}$ (BW)	0.165 (0.089)^{a}	0.219 (0.075)	0.192 (0.075)
$\Delta F_{zmaxlead}$ (BW)	0.179 (0.099)^{a}	0.240 (0.064)	0.201 (0.080)
Locomotion phase			
dT_{LOC} (s)	0.763 (0.181)^{a,b}	0.698 (0.113)	0.669 (0.102)
ΔCOP_{AP_LOC} (FL)	0.625 (0.147)^{b}	0.681 (0.137)	0.753 (0.093)

KOA: individuals with Knee Osteoarthritis; HOA: Healthy Older Adults; HYA: Healthy Young Adults; BW: body weight; other legends: see Figure 4.1; ^{a}: statistically significant difference from Healthy Older Adults ^{b}: statistically significant difference from Healthy Young Adults.

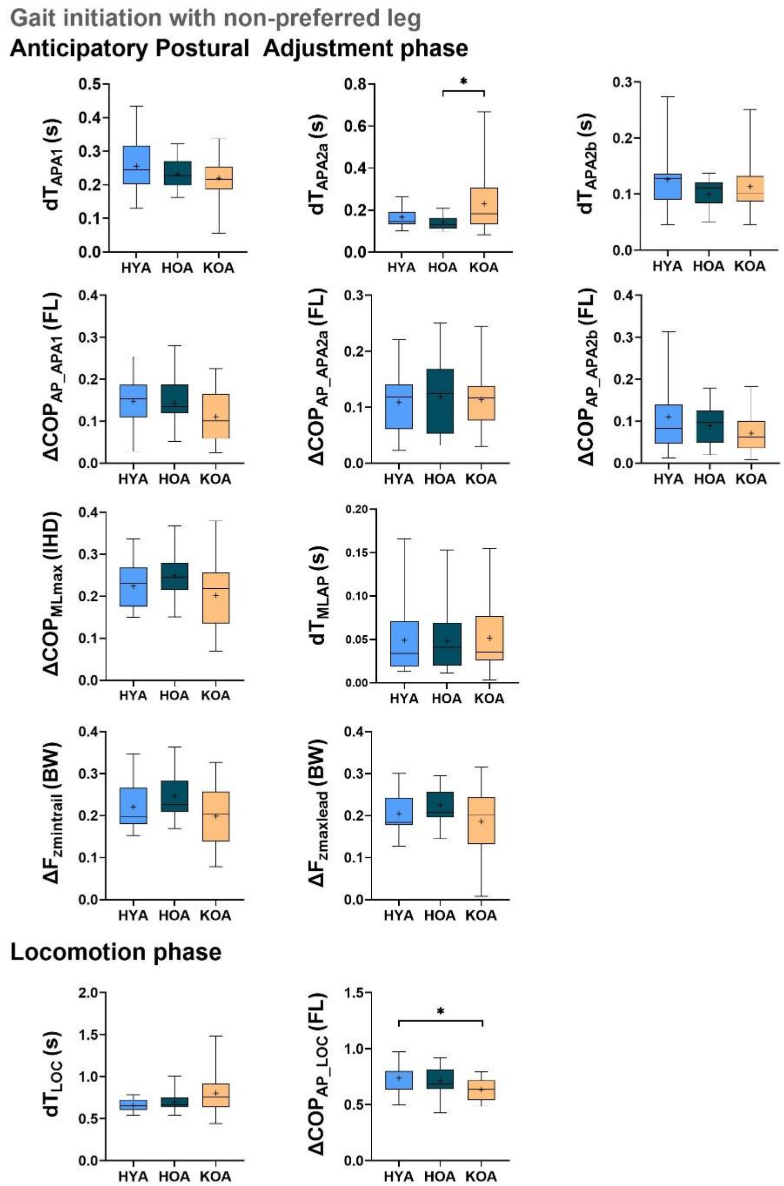


Figure 4.3. Comparison of kinetic parameters during gait initiation with non-preferred leg across groups. Legends as in Figure 4.1 and 4.2.

Table 4.3 Kinetic variables of gait initiation with non-preferred leg tasks across groups

Variable, *Median (IQR)*	**KOA** (N=25)	**HOA** (N=15)	**HYA** (N=15)
T_{GI} (s)	1.293 (0.376)	1.147 (0.215)	1.217 (0.235)
Anticipatory Postural Adjustment phase			
dT_{APA1} (s)	0.217 (0.067)	0.227 (0.072)	0.245 (0.114)
dT_{APA2a} (s)	0.183 (0.174)[a]	0.130 (0.051)	0.145 (0.057)
dT_{APA2b} (s)	0.102 (0.045)	0.111 (0.037)	0.128 (0.046)
ΔCOP_{AP_APA1} (FL)	0.101 (0.107)	0.135 (0.068)	0.154 (0.077)
ΔCOP_{AP_APA2a} (FL)	0.117 (0.061)	0.124 (0.115)	0.118 (0.079)
ΔCOP_{AP_APA2b} (FL)	0.062 (0.065)	0.098 (0.077)	0.083 (0.093)
ΔCOP_{MLmax} (IHD)	0.218 (0.122)	0.245 (0.065)	0.230 (0.093)
ΔT_{MLAP} (s)	0.035 (0.051)	0.041 (0.048)	0.034 (0.052)
$\Delta F_{zmintrail}$ (BW)	0.201 (0.113)	0.208 (0.060)	0.184 (0.064)
$\Delta F_{zmaxlead}$ (BW)	0.204 (0.119)	0.226 (0.073)	0.197 (0.086)
Locomotion phase			
dT_{LOC} (s)	0.756 (0.282)	0.666 (0.108)	0.651 (0.118)
ΔCOP_{AP_LOC} (FL)	0.635 (0.175)[b]	0.682 (0.175)	0.759 (0.166)

Legends as in Table 4.2.

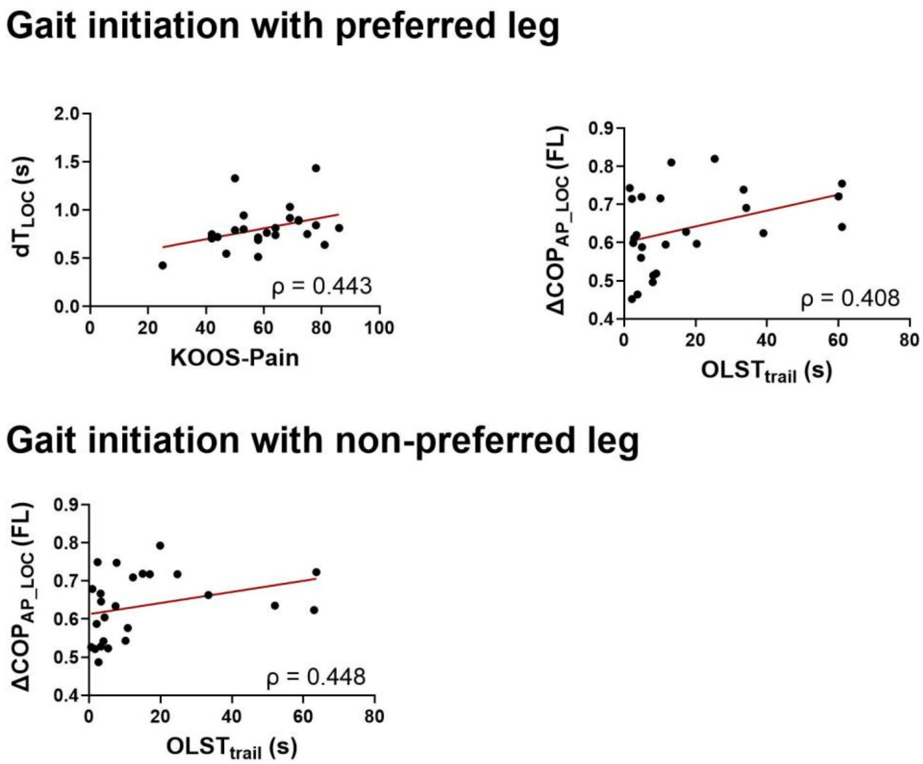


Figure 4.4. Spearman's correlation coefficients among kinetic, functional performance (OLST, FTSTS) and KOOS variables among KOA. OLST$_{trail}$: One leg standing test (OLST) duration when standing on the trailing leg; KOOS-Pain: subscale of the Knee Injury and Osteoarthritis Outcome Score-Pain subscale (9 items, see Appendix II); dT$_{LOC}$: duration of the locomotion phase (T$_5$–T$_4$); ΔCOP$_{AP_LOC}$: anterior COP displacement under the trailing leg during locomotion phase; FL: foot length, defined as the anteroposterior distance between the heel and the tip of the toe, used to normalize anteroposterior COP displacements.

Discussion

This study examined gait initiation performed with both the preferred and non-preferred legs in individuals with knee osteoarthritis (KOA), healthy older (HOA) and young (HYA) adults. The main findings were that KOA showed smaller posterior and mediolateral centre of pressure displacements and reduced weight transfer between legs during the anticipatory postural adjustments phase while subphase durations were similar across groups. For the locomotion phase, KOA showed longer duration and smaller anterior COP displacement compared with healthy participants. Across groups, the mediolateral COP shift was prior to the anteroposterior onset for the majority of trials.

The total duration of gait initiation did not differ between groups, unlike previous studies reporting longer duration in KOA (da Silva Soares et al., 2020; Esfandiari et al., 2020; Viton et al., 2000). When gait was initiated with the preferred leg, KOA showed smaller backward COP displacement during APA1 compared with both healthy groups and smaller mediolateral displacement compared with healthy older adults. All APA subphase durations were similar across groups, indicating that the temporal structure of this preparatory phase remained unchanged in KOA, whereas the displacement of the COP was modified.

The backward COP shift in APA1 creates the initial imbalance required for forward movement (Brenière & Do, 1991; Yiou et al., 2017). In the present study, KOA produced a smaller backward shift without altering timing, suggesting an amplitude adjustment rather than a temporal modification. This finding is consistent with previous work reporting in KOA a reduced backward COP excursions early during gait initiation (da Silva Soares et al., 2020; Esfandiari et al., 2020; Katoh, 2019). When the COP shifts laterally toward the leading leg, the centre of mass of the body moves in the opposite direction toward the trailing leg, positioning body weight over the trailing leg before the leading leg is unloaded for forward movement (Yiou et al., 2017). In the present study, mediolateral COP displacement tended to be larger in HOA than in HYA, consistent with age-related adjustments in balance control (Kimijanová et al., 2021; Polcyn et al., 1998). Here, KOA and HOA were similar in age and IHD (stance width) , yet their ML COP pattern differed, it could reflect disease-specific adjustments in anticipatory postural control. In addition, KOA showed displacement values similar to HYA, suggesting that they may limit the lateral adjustment that normally contributes to transferring body weight onto the trailing leg.

COP reflects how the moment directs the shift, whereas vertical force reflects how much weight is transferred. These components do not vary in a fixed relation because COP displacement is driven by moment regulation rather than by changes in vertical loading (Winter, 1995). Here, the results showed a reduced magnitude of weight transfer in KOA illustrated by a smaller loading of the trailing leg together with a smaller unloading of the leading leg compared with healthy older adults. This limitation of the magnitude of weight transfer does not appear to be an effect of aging but rather a characteristic specific to the health condition; it may be implemented to avoid discomfort or a feeling of instability at the start (or onset? Choose the one you prefer) of the movement.

During locomotion phase, KOA showed a longer duration compared to both healthy groups and a smaller forward COP displacement compared to older adults. The locomotion phase corresponds to converting the preparatory shifts into forward progression, supported mainly by the ankle plantar flexors and hip extensors (Brenière & Do, 1991; Yiou et al., 2017). A longer duration combined with a smaller forward excursion reflects slower forward progression. Previous studies have reported similar findings in KOA, with reduced forward movement and prolonged locomotion phase (da Silva Soares et al., 2020; Esfandiari et al., 2020; Katoh, 2019; Viton et al., 2000). Future work integrating knee kinetics and muscle activation may clarify how knee involvement interacts with ankle–hip contributions during this transition . This will also provide a better understanding of the contribution of the knee in the stability of the trailing leg during early single-leg support, but this remains to be explored (Zhao et al., 2021).

The correlations within the KOA group provide additional insight. A longer locomotion duration was associated with lower KOOS-Pain scores, suggesting that individuals with less pain can tolerate a more sustained forward progression. In contrast, those with more pain may limit both displacement and duration to reduce time spent on single-leg support. Greater forward COP movement under the trailing leg was also associated with longer OLST duration of that leg in both preferred- and non-preferred-leg conditions. This supports the idea that the ability to move the COP during the locomotion phase is linked to single-leg postural control.

The non-preferred-leg condition explored the effect of changing the leading leg. Classifying legs by dominance or "more affected" status is inconsistent in gait initiation, as dominance differs between mobilisation and stabilisation tasks (van Melick et al., 2017), and in KOA, radiographic findings and symptoms often mismatch (Sonobe et al., 2024). Using the preferred leading leg provides a functional and consistent criterion. When gait was initiated with the non-preferred leg, only one APA difference remained: KOA showed a longer APA2a duration than HOA; APA2a corresponds to shifting the COP forward and inward toward the midline, and such longer duration may indicate that KOA needed more time to do the transition when initiating from non-preferred side.

Comparison between preferred and non-preferred leg conditions showed that KOA and HYA showed similar patterns across both initiations, which is consistent with previous reports that mild to moderate KOA typically presents limited inter-limb asymmetry (Viton et al., 2000). Larger differences between legs are more common in severe unilateral KOA and were not expected in our sample. In contrast, HOA showed a reduction in forward COP displacement during APA2a when initiating gait with the non-preferred leg. However, this difference was limited to a single variable and should therefore be interpreted with caution.

The COP sequencing pattern was also examined. Across groups and conditions, most trials showed a ML-first sequence. This pattern reflects the role of the ML shift in unloading the leading leg and positioning the COM toward the trailing leg before forward (Naili et al., 2018). Similar proportions of ML-first across groups indicate that this temporal organisation was not related to knee osteoarthritis. Switching to the non-preferred leg did not modify this pattern in KOA or young adults. The small decrease in ML-first sequencing observed in healthy older adults may reflect reduced adaptability with normal ageing.

Several limitations should be acknowledged. The analysis relied on the vertical component of the ground reaction forces, which limited the characterization of anticipatory postural adjustments, particularly in the mediolateral direction. Electromyography would clarify the muscle activation strategies underlying these adjustments. An additional force plate capturing the leading-leg foot contact would provide information on the landing pattern.

Conclusion

Gait initiation phase durations were similar across groups, but individuals with knee osteoarthritis showed smaller backward and lateral COP shifts and smaller loading of the leading leg and unloading of the trailing leg during Anticipatory Postural Adjustment phase. During the locomotion phase, forward movement was slower, with smaller COP displacement and longer duration, and these features were related to pain and single-leg balance performance. These findings suggests to focus rehabilitation on improving backward and lateral weight-shift control during APA and forward weight transfer during the locomotion phase.

In section 4.1, KOA showed smaller backward and lateral weight shifts when gait was initiated with the preferred leg, but these differences were no longer present when the gait was initiated with the non-preferred leg. This raised the question of whether the choice of leading leg reflects between-leg differences such as pain or balance asymmetry. Exploring this question may help clarify how individuals with knee osteoarthritis organise weight transfer at movement onset and why modifications were more evidenced in the preferred-leg condition.

4.2. Gait initiation and leg selection in individuals with knee osteoarthritis

Introduction

In healthy adults, small between-leg differences in balance control or force capacity have been reported (Sadeghi et al., 2000). Healthy adults also show a consistent preference for using the same leg to initiate a compensatory step, with one leg used for up to 90% of steps during symmetric stance conditions (Lakhani et al., 2011). This finding suggests that between-leg differences in balance control or force-generating capacity may influence which leg is selected for stepping. During gait initiation, the trailing leg supports most of the body weight in the later anticipatory adjustments and contributes to the initial forward movement (Yiou et al., 2017).

In knee osteoarthritis, between-leg differences are frequent. Pain intensity often differs between knees, and single-leg balance performance may also vary, affecting the capacity of each leg to support body weight. Whether such differences relate to the leg chosen to initiate gait has not been examined. This section explored whether preferred leading-leg selection was associated with between-leg differences in pain or single-leg balance within the knee osteoarthritis group.

Materials and Methods

The same participants, experimental set-up and gait-initiation recordings as described in Section 4.1 were used. In the preferred-leg condition, gait initiation was performed at the auditory cue, and the leg naturally used for the first step was recorded as the preferred leading leg. Physical performance tests (Five-Times Sit-to-Stand Test and One-Leg Standing Test, OLST) and knee pain ratings on the Numerical Pain Rating Scale (NPRS) were identical to Section 3.1.

For this section, additional classifications based on pain distribution and single-leg balance performance were applied within the knee osteoarthritis group to examine whether between-leg differences were related to preferred leading-leg selection. Pain distribution was determined from NPRS scores and participants were classified as unilateral when pain was present in only one knee and bilateral when pain was present in both. Among those with bilateral pain, pain was considered symmetrical when NPRS scores were identical between legs (difference = 0) and asymmetrical when the between-leg difference was ≥1 point. Single-leg balance was assessed using the One-Leg Standing Test (OLST) and was recorded separately for each leg. The leg with the longer OLST duration was considered the better-performing leg ($OLST_{better}$), and the leg with the shorter duration was considered the poorer leg ($OLST_{poorer}$). Participants were then classified according to whether their preferred leading leg was the better or the poorer OLST leg. This classification was applied to the preferred-leg condition.

All definitions of gait-initiation events, outcome variables and data-processing steps were identical to section 4.1.

Results

Regarding pain scored by NPRS, three participants (12%) had unilateral involvement (pain present in only one knee, Uni_KOA), while the remaining 22 (88%) had bilateral KOA. Among them, 17 (68%) reported an asymmetrical level of pain between legs (Bi_KOA.asym.pain) and five (20%) reported symmetrical pain (Bi_KOA.sym.pain). All uni_KOA and 53% Bi_KOA asym.pain selected their less painful leg as the preferred leading leg during gait initiation **(Figure 4.5)**. Pain distribution did not show a consistent relation with preferred leading-leg selection **(Figure 4.5A)**: participants with unilateral or bilateral pain were equally likely to initiate gait with the more or less painful leg. Pain distribution was therefore not used for further classification.

When considering the results of OLST for each leg, 33% uni_KOA, 29% Bi_KOA.asym.pain and 20% Bi_KOA.sym.pain selected their better OLST leg as the preferred leading leg during gait initiation. In other words, the majority in all subgroups preferred their better OLST legs as trailing leg for the gait initiation **(Figure 4.5B)**.

When comparing participants whose preferred leading leg was $OLST_{better}$ versus $OLST_{poorer,}$ maximal mediolateral COP displacement (ΔCOP_{MLmax}) was the only variable that differed between groups ($p < 0.05$). KOA OLST better and OLST poorer were comparable in age, height, weight, and in all KOOS subscale scores, except for KOOS Sport/Rec where the $OLST_{better}$ reported higher scores (30.7 ± 17.2 vs 17.2 ± 11.0, p = 0.028). The OLST duration of the leading leg also differed between groups (26.7 ± 25.5 vs 10.2 ± 13.7 s, p = 0.034, **Table 4.4**).

Table 4.4. Characteristics of the participants

Parameter	$OLST_{better}$ (N=7)	$OLST_{poorer}$ (N=18)
Age (years), mean±SD	62.6 ± 6.1	66.1 ± 8.7
Sex (n Female/n Male)	6/1	16/2
Height (m), mean±SD	1.53 ± 0.07	1.52 ± 0.06
Body weight (kg), mean±SD	59.2 ± 11.5	62.1 ± 10.8
Physical performance tests (seconds), mean±SD		
$OLST_{lead}$	26.8 ± 25.5*	10.2 ± 13.7*
$OLST_{trail}$	16.1 ± 21.5	18.48 ± 19.14
FTSTS	13.5 ± 4.0	19.4 ± 9.8
KOOS subscales		
Symptoms	58.7 ± 13.5	62.5 ± 10.6
Pain	61.5 ± 14.4	59.0 ± 15.6
ADL	71.6 ± 15.3	63.3 ± 17.2
Sport/Rec	30.7 ± 17.2*	17.2 ± 11.0*
Quality of life	41.1 ± 21.9	40.6 ± 15.6

$OLST_{better}$: participants whose leading leg corresponded to the longer One leg standing test (OLTS) duration; $OLST_{poorer}$: participants whose preferred leg corresponded to the shorter OLTS duration; $OLST_{lead}$: OLST duration of the leading leg; $OLST_{trail}$: OLST duration of the trailing leg; KOOS: The Knee injury and Osteoarthritis Outcome Score; ADL: Activity of Daily Living subscale; Sport/Rec: Sport and Recreation Function subscale; *: $p \leq 0.05$.

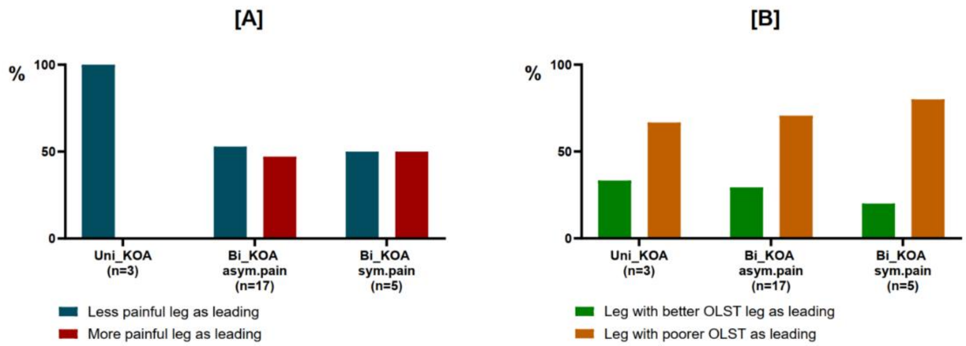


Figure 4.5. Distribution of preferred leading leg selection among participants with knee osteoarthritis according to pain pattern [A] and single-leg balance performance (OLST) [B]. Uni_KOA: individuals with knee osteoarthritis affecting one knee (n=3); Bi_KOA.asym.pain: individuals with bilateral knee osteoarthritis reporting asymmetrical pain (NPRS difference ≥ 1 between knees, n=17); Bi_KOA.sym.pain: individuals with bilateral knee osteoarthritis reporting symmetrical pain (NPRS difference = 0, n=5).

Discussion

This exploratory analysis examined whether between-leg differences were related to preferred leading-leg selection during gait initiation in individuals with knee osteoarthritis. Pain distribution showed no consistent relation with the chosen leading leg. In contrast, single-leg balance showed a clearer pattern because most participants used the leg with poorer OLST performance as the leading leg and kept the better OLST leg as the trailing leg. Maximal mediolateral COP displacement was the only gait-initiation variable that differed between OLST-based groups, with larger excursions when the better OLST leg served as the leading leg.

This pattern is consistent with the mechanical role of the trailing leg during the anticipatory postural adjustments. Before the first step, body weight must be transferred toward the trailing side while the centre of mass moves laterally and forward (Brenière & Do, 1991; Yiou et al., 2017). This phase places high demands on mediolateral stability and the trailing leg must support most of the body weight. Using the better OLST leg as the trailing leg may therefore represent a stabilising choice. The longer OLST duration of the leading leg in the better-OLST group indicates that when participants did initiate gait with their better leg, that leg still had sufficient single-leg standing capacity.

Only mediolateral COP displacement differed between groups. Participants who used their better OLST leg as the leading leg produced larger COP excursions toward that side, whereas participants who used their poorer OLST leg constrained this shift. This suggests that the extent of mediolateral weight transfer toward the leading leg is limited by the balance capacity of that leg. The absence of differences in anteroposterior COP variables and vertical forces indicates that OLST asymmetry influenced only the mediolateral component of the anticipatory adjustments. This direction-specific sensitivity aligns with observations that mediolateral control requires greater postural regulation than anteroposterior control (Bauby & Kuo, 2000; Winter et al., 1996). No differences were observed during the locomotion phase. Once the leading leg was lifted and forward progression began, both groups produced similar patterns. Previous work shows that anticipatory adjustments reorganise posture to favour forward movement, while the locomotion phase mainly converts this prepared configuration into motion (Brenière & Do, 1991; Yiou et al., 2017). The present findings follow this distinction as between-leg differences were reflected in mediolateral preparation rather than in the forward progression.

Pain asymmetry did not explain leg selection. This differs from findings in conditions where one leg is clearly more affected. Studies have reported side-dependent support patterns when the affected or less affected leg supports body weight (Viton et al., 2000). In the present sample, only three participants had unilateral pain, and the large majority had bilateral involvement.

These findings highlight the usefulness of simple balance measures when examining leg-selection strategies in knee osteoarthritis. OLST may help identify which leg individuals rely on as the trailing leg and how confidently they transfer weight toward the leading leg. Rehabilitation strategies that focus on improving single-leg stability of the trailing leg or training focusing on mediolateral transfer toward the leading leg may be clinically relevant.

Several limitations should be considered. Subgroup sizes were small and OLST captures only one aspect of between-leg function. Other factors such as strength, proprioception or fear of falling may also influence leg selection. An analysis focused on kinetic variables and electromyographic recordings would provide further insight into neuromuscular strategies. Gait initiation was examined under control laboratory conditions and behaviour may differ in daily environments.

Conclusion

Leading-leg selection in knee osteoarthritis appeared to relate more ~~strongly~~ to single-leg balance than to pain distribution. Between-leg differences influenced mediolateral weight transfer but not forward progression. These findings suggest that mediolateral control is sensitive to functional asymmetry and may be a relevant focus for rehabilitation.

General discussion

This thesis examined postural control in individuals with knee osteoarthritis by combining a culturally adapted patient-reported outcome measure with kinetic analyses of key functional tasks. The overall aim was to describe how people with knee osteoarthritis regulate weight transfer and balance during everyday transitions, and how these movement characteristics relate to perceived pain and activity limitations.

Chapter 2 developed and validated the Vietnamese version of the Knee Injury and Osteoarthritis Outcome Score (KOOS-V). The findings showed that KOOS-V has good reliability and validity in Vietnamese-speaking adults with knee osteoarthritis and can be used to quantify knee-related pain, symptoms and difficulties in daily activities in this context.

Chapters 3 and 4 focused on kinetic assessment of three postural tasks: Sit-to-Stand, Stand-to-Sit and gait initiation. Transitions between sitting and standing were analysed to characterise how individuals with knee osteoarthritis perform movements against and with gravity, while gait initiation was used to examine the transition from bipedal to single-leg support. Across these tasks, individuals with knee osteoarthritis were able to complete the movements but showed modified temporal and kinetic profiles compared with healthy young and older participants. These changes were associated with functional test performance and KOOS scores.

Together, the three chapters provide a framework that links self-reported outcomes, simple functional tests and quantitative kinetic measures. This framework contributes to a more complete description of postural control in knee osteoarthritis and offers a basis for developing more targeted assessment and rehabilitation strategies.

Interpretation of KOOS-V findings in the Vietnamese knee osteoarthritis population

Beyond the translation, cultural adaptation and psychometric validation of the KOOS-V, Chapter 2 also provides the first descriptive data on the perceived functional profile of Vietnamese adults with knee osteoarthritis. These patterns offer relevant background for interpreting the biomechanical analyses in the following chapters. The KOOS-V results revealed a distribution of subscale scores that is consistent with international findings: Activities of Daily Living (ADL) and Symptoms showed the highest mean values, Pain an intermediate position, and Sport/Recreation and Quality of Life consistently received the lowest scores **(see Figure 2.1)**. This graded profile reflects the increasing demands of daily versus higher-impact activities and highlights that perceived limitations vary across functional domains rather than affecting all dimensions equally.

A particularly relevant observation is that the two experimental samples used in Chapters 3 and 4 exhibited a similar KOOS pattern to the broader validation cohort. As illustrated in **Figure D1**, all three groups, despite differences in recruitment context and sample size, showed the same pattern of subscale means, with ADL and Symptoms at the top and Sport/Recreation and Quality of Life at the bottom. This consistency suggests that the participants included in the kinetic analyses are reasonably representative of the broader Vietnamese KOA population in terms of perceived functional challenges, supporting the validity of integrating self-reported and performance-based findings.

The KOOS-V results also show that perceived and observed function capture different aspects of knee osteoarthritis. ADL scores were moderate, indicating that routine daily activities were manageable but still involved some perceived difficulty. In contrast, the low Sport/Recreation and Quality of Life scores suggest greater difficulty in more demanding or confidence-dependent situations. These perceptions help frame the movement strategies seen in Sit-to-Stand, Stand-to-Sit and gait initiation, while noting that KOOS scores reflect perceived difficulty and therefore offer a complementary perspective alongside the performance-based findings from the laboratory tasks.

Postural control strategies across Sit-to-Stand, Stand-to-Sit and gait initiation

The two chapters on kinetic analyses examined three functional tasks that capture different aspects of postural control. Each task – Sit-to-Stand, Stand-to-Sit, and gait initiation – demands a distinct balance of force generation and postural regulation. In the following sections, the characteristics of each task will be discussed and the key findings in the context of knee osteoarthritis (KOA) will be synthesized.

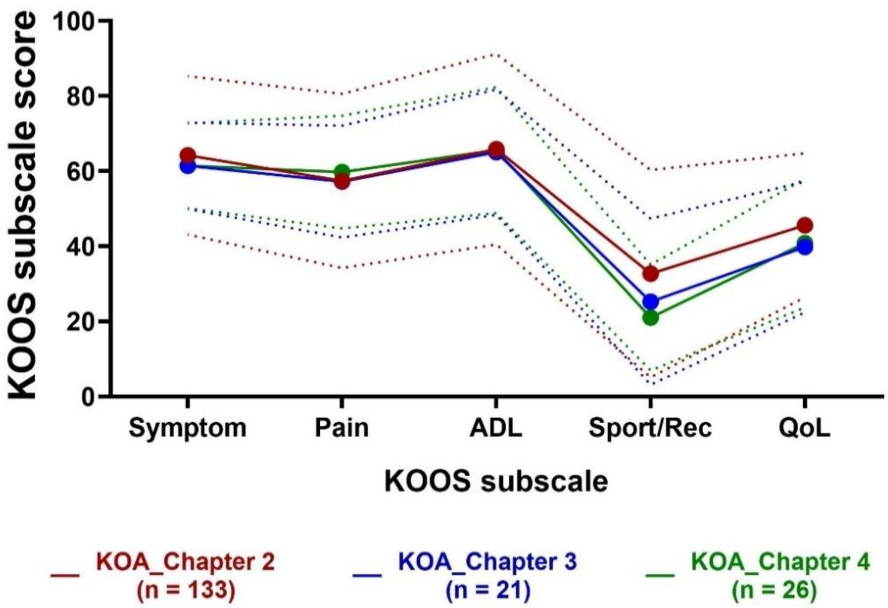


Figure D1. KOOS-V subscale profiles across three knee osteoarthritis samples. Solid lines represent mean scores and dotted lines indicate ±1 standard deviation. Colours correspond to the three study samples (Chapter 2 in red, Chapter 3 in blue, Chapter 4 in green).

Sit-to-Stand: Force Generation and Stabilization

The Sit-to-Stand (SitTS) transfer is one of the most mechanically demanding daily tasks, requiring substantial concentric force to lift the body against gravity followed by stabilization in upright stance (Faria et al., 2010; Sloot et al., 2020). As outlined in the general introduction, SitTS comprises two main phases: an acceleration phase during which the body's centre of mass is propelled upward, and a deceleration phase as the body transitions toward stable standing. Functional limitations during the acceleration phase in individuals with knee osteoarthritis are often attributed to quadriceps weakness and pain (Bennell et al., 2013; Rice & McNair, 2010). However, evidence regarding peak vertical force generation in KOA is mixed. Current evidence shows that peak vertical force in KOA is comparable to that of healthy older adults (HOA) (Anan et al., 2015; Sonoo et al., 2019; Verlaan et al., 2018). This suggests that upward force generation is maintained in KOA, even in the presence of neuromuscular activation deficits (Rice & McNair, 2010). This aligns with findings from the present study, where the KOA group exhibited maximal upward acceleration, loading rates, and peak trunk velocity similar to HOA, though both groups differed from healthy young adults (HYA), consistent with age-related performance declines at this stage.

In contrast, KOA showed modifications primarily during the deceleration phase, characterized by lower peak downward acceleration and longer stabilization duration than HOA. This suggests that while force generation during ascent was maintained, movement during braking was altered. This interpretation is supported by our exploratory symmetry analysis. HYA showed more symmetrical bilateral loading at peak acceleration but transitioned to less symmetrical loading during deceleration, likely reflecting a flexible strategy for balance regulation (**Figure 2.6**). This modulation was less pronounced in HOA and further diminished in KOA. Notably, despite maintaining relatively symmetrical loading throughout, KOA participants exhibited reduced inter-limb timing synchronization during deceleration. In other words, even though force symmetry was preserved, temporal coordination was compromised.

Together, these findings suggest that individuals with KOA tend to go for force generation rather than dynamic control in SitTS. This strategy may help achieve mechanical success during the ascent but leads to modifications during braking. Several explanations could be considered. First, during tasks requiring force, such as Sit-to-Stand, KOA tend to prioritize force generation to accomplish the movement, potentially at the expense of dynamic control during braking. Second, reduced muscle strength or neuromuscular efficiency may increase the attentional and mechanical demands of force production, leaving fewer resources available for fine-grained postural regulation. Third, deficits in motor control may limit the capacity to modulate timing and coordination between legs, such that reduced dynamic control reflects a functional constraint rather than an intentional strategy. In this context, the observed pattern may represent an adaptive response to neuromuscular limitations aimed at ensuring task completion and stability rather than an optimized control strategy.

Stand-to-Sit: Controlled Descent and Braking Eccentrically

Stand-to-Sit (StandTS) requires eccentric control of lower extremity muscles to manage the body's descent (Chang et al., 2014), making it a task that relies more on postural control than force production. In the present study, KOA showed clear differences from HOA across most kinetic variables, reinforcing the interpretation that control, rather than peak force capacity, is the primary challenge during this task.

Despite these challenges, the KOA group maintained symmetrical bilateral loading throughout StandTS, with force asymmetry indices (FASI) comparable to both healthy groups. However, they relied on a stiff bilateral strategy without the flexibility observed in HYA. Specifically, HYA modulated their inter-limb loading by showing less symmetry at maximal downward acceleration and greater symmetry at maximal deceleration, reflecting a capacity to adjust control based on the distinct demands of each instant (**Figure 2.6**). By contrast, KOA preserved similar loading symmetry at both events — a strategy that may prioritize mechanical stability but suggests limited adaptive control. This interpretation aligns with prior studies reporting increased co-contraction and reduced flexibility in movement strategies in KOA (Childs et al., 2004; Hubley-Kozey et al., 2006; Taniguchi et al., 2024; Zeni et al., 2010).

Temporal coordination showed an even clearer distinction. Although load symmetry was maintained, KOA exhibited increased inter-limb timing mismatch, indicating that symmetry was achieved through delayed or desynchronized force application between legs. This pattern suggests that force-based control remains a priority, but temporal coordination is modified. Such alterations may reflect a conservative or protective strategy, consistent with stiffening behaviours described in previous biomechanical studies of KOA movements (Hortobágyi et al., 2009; Hubley-Kozey et al., 2006; Taniguchi et al., 2024).

Gait Initiation: Anticipatory Adjustments and Forward Propulsion

Gait initiation (GI) is a task that requires anticipatory and reactive postural adjustments to shift and propel the body forward while maintaining balance (Yiou et al., 2017). It is therefore well-suited to assess another dimension of postural control in KOA. GI consists of two main phases: the anticipatory postural adjustment (APA) phase, during which the body's centre of mass (COM) is shifted to enable leading leg clearance, and the locomotor (LOC) phase, in which forward movement begins.

Here, KOA performed APA with durations and anteroposterior centre of pressure displacements (COP AP) comparable to those of both HOA and HYA, except for a reduced posterior displacement at the very beginning of APA. However, mediolateral COP displacement (COP ML) during APA was significantly lower in the KOA group compared to HOA. This suggests a limited lateral and posterior weight shift toward the leading leg during preparation. While phase durations remained largely preserved across groups, this initial limitation appears to have been compensated during the LOC phase, which was prolonged in KOA and marked by shorter forward COP progression. Such reduced forward propulsive impulse during gait initiation may compromise dynamic balance and possibly contribute to fall risk, as falls are often reported during gait initiation, particularly in the transition from APA to forward stepping (Callisaya et al., 2016; Mbourou et al., 2003; Yoshida et al., 2022).

Across tasks

The results across the three functional tasks reveal a consistent strategy adopted by KOA. When faced with force-demanding tasks such as SitTS, KOA show a tendency toward emphasizing force generation and maintaining bilateral load symmetry; however, this is achieved at the expense of precise control, as evidenced by prolonged deceleration times and reduced inter-limb timing synchronization. On the other hand, tasks that are less force-intensive but require finely coordinated balance and multi-directional control—such as Stand-to-Sit and gait initiation—also challenge KOA who show modified weight-shifting patterns consistent with a more conservative control strategy. Importantly, asymmetric timing/altered coordination patterns should not be interpreted solely as negative features. In some individuals, they may represent functional or protective strategies aimed at preserving stability or limiting joint stress in demanding tasks.

Integration of KOOS-V and kinetic findings

Correlations between Sit-to-Stand performance, KOOS-V and functional performance tests

Correlation patterns from Chapter 3 indicate that Sit-to-Stand (SitTS) performance reflects an integrated combination of force production, dynamic balance capacity and pain-related modulation. Participants who executed SitTS more rapidly and with greater acceleration tended to perform better on both clinical balance and mobility tests, suggesting that SitTS captures broader functional attributes rather than isolated strength or control components **(Figure D2).**

SitTS performance also aligned with self-reported functional difficulty. Participants who reported less pain and fewer limitations in daily activities tended to exhibit more effective SitTS strategies **(Figure D3)**. This convergence between performance-based and self-reported measures highlights SitTS as a task that is sensitive to both biomechanical capacity and perceived functional aspect.

Together, these associations suggest that SitTS shows a unique position among the three tasks examined: it is influenced by pain, relates to everyday activity limitations, and reflects both dynamic control and movement speed. As such, SitTS provides a useful performance-based counterpart to KOOS-Pain and KOOS-ADL in characterizing functional status in knee osteoarthritis.

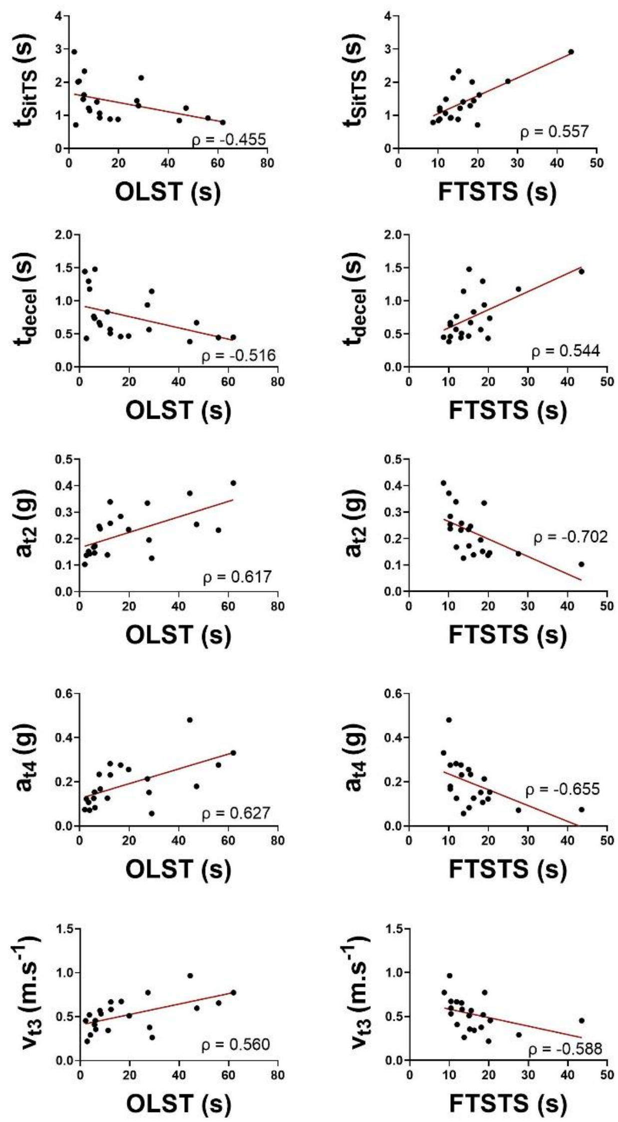


Figure D2. Correlations between Sit-to-Stand kinetics and physical performance tests. t_{SitTS}: the duration of Sit-to-Stand task from t_1 to t_5, t_{push}: the duration of the push from t_1 to t_3, t_{decel}: the duration of deceleration phase from t_3-t_5, LR: loading rate, at_2: the maximal acceleration at t_2, a_{t4}: the maximal deceleration at t_4, v_{t3}: the maximal velocity at t_3.

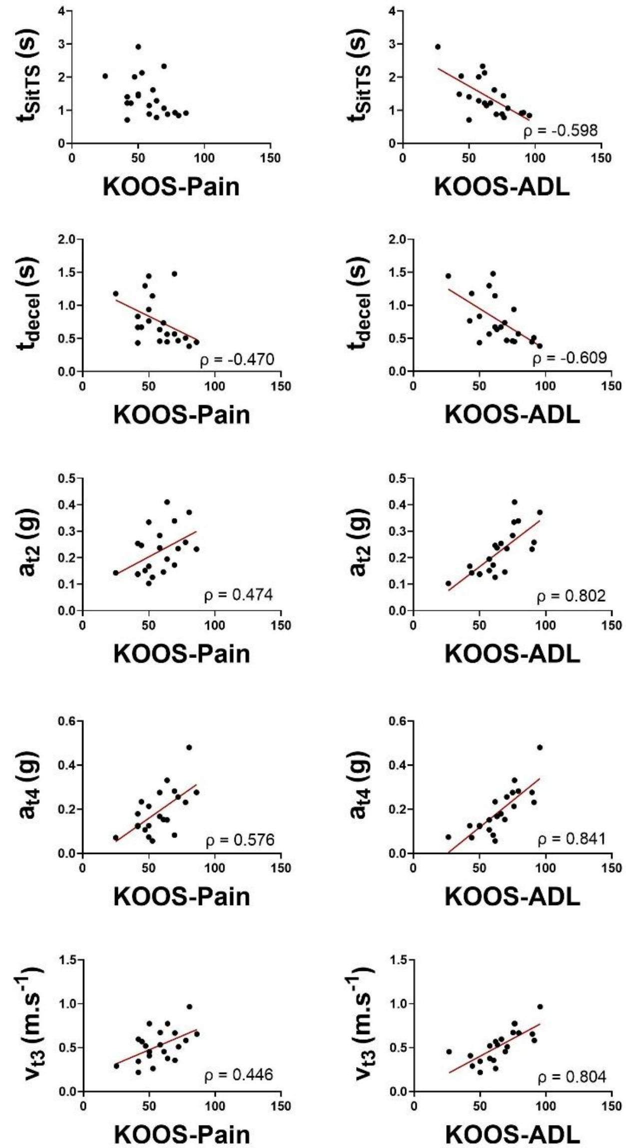


Figure D3. Correlations between Sit-to-Stand kinetics and KOOS subscale. KOOS-Pain: subscale of the Knee Injury and Osteoarthritis Outcome Score-Pain subscale (9 items); KOOS-ADL: subscale of the KOOS (17 items)

Correlations between Stand-to-Sit performance, KOOS-V and functional performance tests

Correlation analyses provided further insights. StandTS kinetics variables correlated with static balance performance, as shown by the One-Leg Standing Test (OLST), but not with the Five Times Sit-to-Stand Test (FTSTS), despite StandTS being a component of the latter **(Figure D4)**. This pattern suggests that StandTS captures balance-related control demands that are not fully reflected by repeated Sit-to-Stand performance. Moreover, kinetic variables were significantly associated with KOOS-ADL but not with KOOS-Pain **(Figure D5)**, contrasting with the SitTS task where pain-related measures played a more prominent role. These findings reinforce the notion that StandTS is especially sensitive to postural control capacity, rather than overall strength, speed or pain.

Correlations between Gait initiation performance, KOOS-V and functional performance tests

A notable observation from the exploratory analysis of gait initiation (GI) was the influence of limb-specific balance capacity. KOA showed greater lateral weight shift toward leading leg during Anticipatory Postural Adjustment (APA) when that leg had better performance on the One-Leg Standing Test (OLST). Since APA involves rapid, low-amplitude weight transfer, this finding suggests that biomechanical deficits alone do not fully account for reduced weight-shift; psychological factors such as confidence in leg support likely play a role (Heuts et al., 2004; Maly et al., 2007; Taniguchi et al., 2024). This interpretation is supported by correlation analyses: kinetic variables during GI were most strongly correlated with OLST **(Figure 4.4)**, rather than with the Five Times Sit-to-Stand Test (FTSTS), indicating that static single-leg balance capacity may be more relevant to this task. In addition, variables measured during the LOC phase correlated with KOOS-Pain scores **(Figure 4.4)**, suggesting that moving forward after weight transfer onto the trailing leg which requires knee extensor activation and increases joint loading, is the phase most influenced by pain. Notably, no GI kinetic variables were correlated with KOOS-ADL, likely reflecting the limited ability of this subscale (even if 17 items) to capture dynamic transitions challenge of gait initiation.

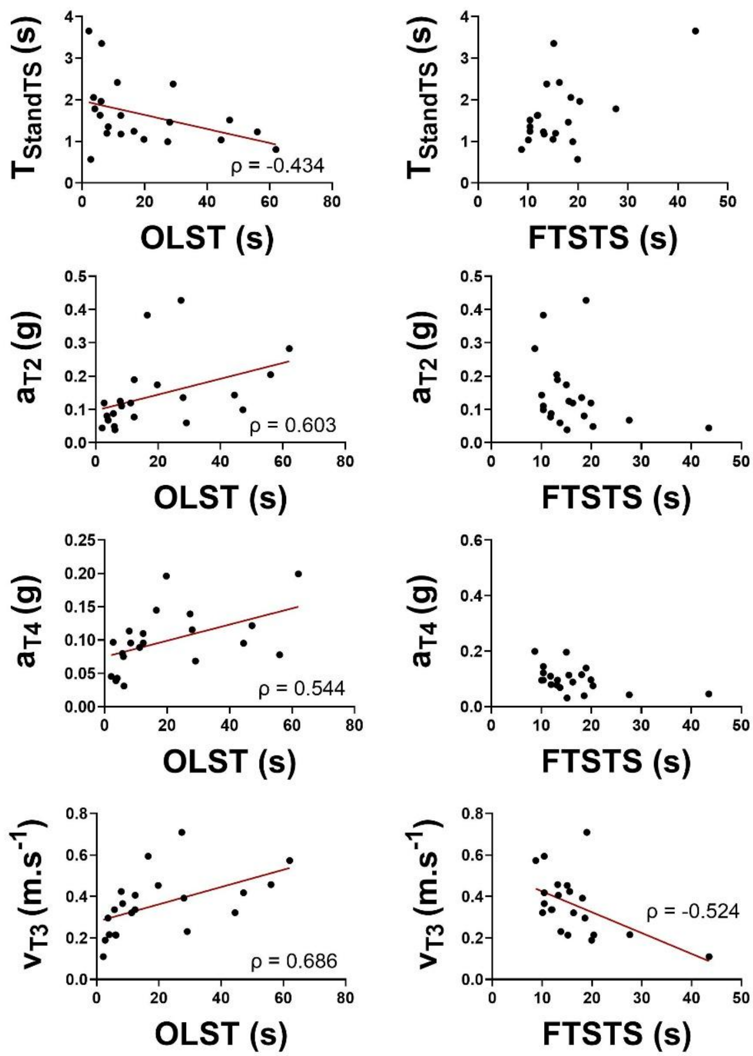


Figure D4. Correlations between Stand-to-Sit kinetics and physical performance tests. $T_{StandTS}$: duration of the Stand-to-Sit task; a_{T2}: maximal acceleration; a_{T4}: maximal deceleration; v_{T3}: maximal velocity. Remark: for the FTSTS, an outlier could be observed. When excluding this participant, the correlations between OLST Sit-to-Stand and Stand-to-Sit durations were no longer significant, indicating that these specific relations should be interpreted with caution.

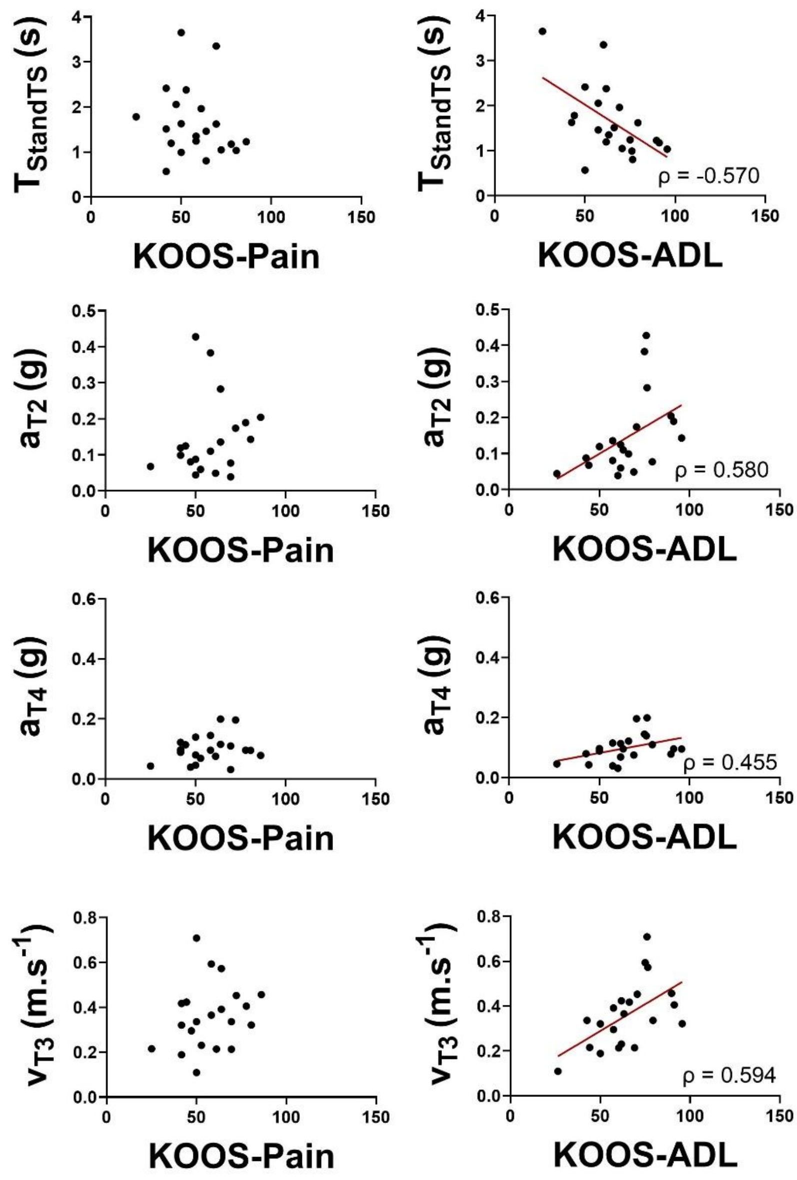


Figure D5. Correlations between Stand-to-Sit kinetics and KOOS subscale.

Clinical Implications

The consistent pattern of force prioritization over control across SitTS, StandTS, and gait initiation tasks suggests that rehabilitation for KOA should extend beyond traditional strengthening strategies. Findings from this thesis indicate that KOA were generally able to generate sufficient force to accomplish the mechanical aspects of movement but faced challenges when dynamic control was required, particularly during phases that demand precise braking and coordinated weight transfer.

This interpretation aligns with evidence showing that strengthening programmes reduced pain and increased muscle capacity without altering movement patterns during daily activities such as walking or stair climbing (Foroughi et al., 2011; Rafiq et al., 2021). In addition, the relationship between strength gains and self-reported function is often weak or absent (Hall et al., 2017), and compensatory postural strategies may persist even after improvements in strength and symptoms (Signorelli et al., 2025). Together, these findings suggest that strengthening alone is unlikely to modify the control-related characteristics identified across the three tasks. Recent reviews and clinical trials recommend multicomponent exercise programmes that incorporate balance training, coordination exercises, and task-specific movement practice (Abdel-Fattah et al., 2023; Wang et al., 2025; Zampogna et al., 2020). From a clinical perspective, these results support the inclusion of Stand-to-Sit as a priority task when the aim is to assess postural control in KOA. It can reveal balance control alterations that are less apparent during force-dominant tasks such as Sit-to-Stand.

The task-specific results in this thesis further highlight the relevance of control-focused components in evaluating functional performance. Dynamic tasks such as Stand-to-Sit and gait initiation revealed altered temporal coordination and weight-shifting strategies despite maintained bilateral load symmetry, suggesting that control-related outcomes (e.g., inter-limb timing, stabilization phases) may provide complementary insights to those offered by strength- or speed-based performance metrics alone.

Methodological and Contextual Contributions

This thesis makes several methodological and contextual contributions beyond its scientific findings. Methodologically, this thesis demonstrates a feasible approach for the quantitative assessment of postural control in a resource-limited context. Kinetic data were collected using a twin portable one-dimensional force plates in a simple setup, showing that clinically relevant information on movement control can be obtained without sophisticated laboratory equipment. This represents a foundational step in building movement analysis capacity in Vietnam, where kinetic assessment in rehabilitation research has been rare and limited in scope. Through this work, standardized procedures for data acquisition, processing, and interpretation were developed and implemented in a university-based laboratory, ensuring that the knowledge gained is embedded within the local academic infrastructure and can be replicated by other teams **(Figure D6)**.

The implementation of this system has provided direct support for research training. Since 2022, three master's dissertations and six bachelor theses have been completed using the protocols established in this thesis. This reflects a research-enabled education model, where students and early-career researchers gain hands-on experience by contributing to ongoing biomechanics data collection and analysis.

The thesis also contributes to outcome measurement in Vietnam through the cross-cultural adaptation and validation of the Vietnamese version of the Knee Injury and Osteoarthritis Outcome Score (KOOS-V). As the only validated knee-specific patient-reported outcome measure available in Vietnamese, it has already supported clinical studies and student research. To further enhance its usability, a freely accessible online scoring calculator was developed **(Figure D7)**. The tool is hosted on a lightweight JavaScript-based platform via GitHub pages and was created with formal permission from the Mapi Research Trust. It enables clinicians and researchers to obtain KOOS-V subscale scores rapidly and accurately, reducing the time and potential errors associated with manual scoring. Because KOOS scoring is relatively complex, particularly when processing missing items, the availability of an automated calculator provides practical value for both clinical and research settings. The tool is intended to remain open-access and will be integrated into the official website of the University of Medicine and Pharmacy at Ho Chi Minh City to support wider implementation of KOOS-V in Vietnam.

Finally, this thesis supports national efforts to strengthen rehabilitation science and services in Vietnam. It was conducted within the ARES-funded project "Advancing Physiotherapy Education and Services in Vietnam" (2020–2025), a collaboration between UCLouvain, Université libre de Bruxelles, and the University of Medicine and Pharmacy at Ho Chi Minh City. The work helps prepare for the next ARES initiative, "Improving rehabilitation care in Vietnam: Creation of a research centre for the functional assessment of people with disabilities" (2025–2030), by establishing the laboratory and analytical foundations needed to support a national movement

Figure D6. Initial laboratory setup supporting the development of kinetic assessment capacity. analysis centre dedicated to evidence-based rehabilitation.

Future Directions

The broader experimental dataset collected during this doctoral research also includes Sit-to-Stand and Stand-to-Sit in different seat heights, stair-climbing initiation and reaching, and provides multiple avenues for further investigation. These future analyses can deepen the understanding of postural control adaptations in KOA and extend the clinical relevance of movement analysis in rehabilitation.

The primary future direction concerns the investigation of stair negotiation, including stair ascent and descent, represents a more complex transitional movement requiring coordinated anticipatory control, higher forward propulsion, and increased trailing leg loading (Reeves et al., 2008). Assessing these tasks will extend the present findings on gait initiation and inter-limb coordination to a more demanding and clinically relevant task. This direction is particularly relevant given that stair-related activities are frequently reported as challenging and risky by KOA, and they place high demands on both force generation and dynamic control.

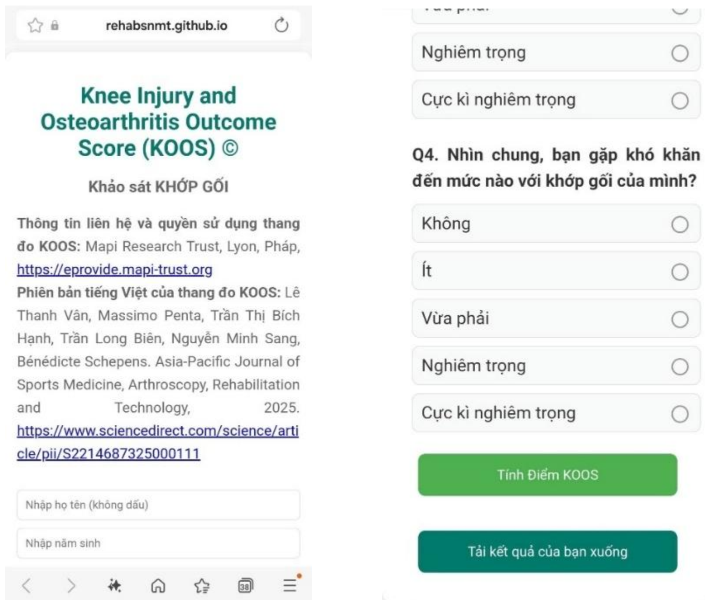


Figure D7. Mobile interface of the KOOS-V online calculator

A second priority is the comparison of Sit-to-Stand at the seat heights. This analysis will help clarify how modified joint loading alters movement strategy and control demands in KOA, informing clinical decisions regarding chair height in rehabilitation or daily activities.

Additional exploratory directions include the analysis of reaching tasks performed in standing which introduce distinct balance demands by emphasizing medio-lateral control and trunk–lower limb coordination—mechanisms relevant to daily activities beyond locomotion and increasingly considered in multidimensional fall-risk assessment frameworks. Integrating these data could contribute to the development of composite postural profiles in KOA.

Finally, integrating electromyography with force data would allow examination of timing and activation patterns that may contribute to conservative loading strategies during functional transitions. Such work would support interventions that target neuromuscular control in addition to movement mechanics.

Strengths and Limitations

This thesis demonstrates several strengths in its methodological design and analytical approach. The use of three functional tasks—Sit-to-Stand, Stand-to-Sit, and gait initiation—enabled the examination of postural control under varied mechanical and control demands, providing a multidimensional perspective on movement strategies in knee osteoarthritis. The kinetic approach used in this work allowed detailed temporal and force-related analysis, revealing subtle control deficits that may not be captured by performance-based measures alone. The integration of kinetic data with self-reported outcomes also facilitated a clinically relevant interpretation of functional limitations.

However, several limitations should be acknowledged. Surface electromyography was not reported, limiting insight into neuromuscular coordination underlying the observed kinetic adaptations. The use of one-dimensional force plates confined the analysis to vertical ground reaction forces, preventing an evaluation of medio-lateral or anterior-posterior control mechanisms. Healthy young adults were recruited from a university student population, which may represent a relatively high-functioning subgroup and limit generalisability to the broader young adult population. Participant recruitment differed across study components. For the KOOS validation, KOA were recruited from three regions representing northern, central, and southern Vietnam. While this sample does not represent all KOA nationwide, it reflects a range of educational and living contexts relevant for cross-cultural validation. In contrast, KOA and HOA included in the kinetic analyses were recruited from Ho Chi Minh City. This common recruitment context reduced geographical and environmental variability between groups and strengthened internal group comparisons. However, the generalisability of the kinetic findings to other regions remains limited. Finally, the absence of complementary psychological or balance-related self-report measures limits the interpretation of how factors such as fear of falling or confidence may have influenced movement behaviour.

Conclusion

This thesis examined postural control strategies in individuals with knee osteoarthritis across three functional tasks—Sit-to-Stand, Stand-to-Sit, and gait initiation—using kinetic analysis combined with self-reported outcomes. It provided the first Vietnamese translation, cultural adaptation and validation of the KOOS-V, offering initial descriptive data on symptom and functional profiles in the Vietnamese knee osteoarthritis population. These findings established a patient-reported foundation that complements the biomechanical analyses and supports the integration of perceived and observed function in clinical assessment.

The kinetic findings indicate that while individuals with knee osteoarthritis are able to generate sufficient vertical force to perform these tasks, they exhibit consistent adaptations, including prolonged stabilization, reduced inter-limb coordination, and restricted weight-shifting strategies. These results highlight that movement control, rather than force production, is a primary challenge during functional transitions in knee osteoarthritis. The differing patterns observed across tasks emphasise the need for multidimensional assessment. Kinetic measures, physical performance-tests and self-reported outcomes provide related but non-overlapping information about function and control, making their integration essential for rehabilitation evaluation and intervention.

Beyond scientific insights, this thesis establishes a methodological framework for movement analysis in Vietnam and introduces the KOOS-V and its online scoring tool, contributing to improved assessment and research capacity in local rehabilitation settings. Together, these findings support a shift toward control-oriented rehabilitation approaches that address the complex interplay between mechanical capacity and postural regulation in everyday movements among individuals with knee osteoarthritis.

“À force de croire en ses rêves, l’homme en fait une réalité”

— Hergé—

Appendix

Content overview
of the The Knee Injury and Osteoarthritis Outcome Score (KOOS)

The Knee Injury and Osteoarthritis Outcome Score (KOOS) consists of 42 items grouped into five subscales. The content of each item is summarised below without reproducing the original wording.

1. Symptoms (7 items)

- Knee swelling
- Mechanical symptoms during knee movement (e.g. grinding, clicking)
- Sensation of catching or locking
- Ability to fully extend the knee
- Ability to fully flex the knee

(Note: symptoms are rated with reference to the previous week.)

2. Stiffness (2 items)

- Severity of knee stiffness after waking in the morning
- Severity of knee stiffness later in the day following rest

3. Pain (9 items)

- Frequency of knee pain
- Pain during twisting or pivoting movements
- Pain during knee extension
- Pain during knee flexion
- Pain during walking on flat surfaces
- Pain during stair ascent or descent
- Pain at night while in bed
- Pain during sitting or lying
- Pain during standing upright

4. Function in Daily Living (17 items)

- Difficulty descending stairs
- Difficulty ascending stairs
- Difficulty rising from sitting
- Difficulty standing
- Difficulty bending to the floor or picking up an object
- Difficulty walking on flat surfaces
- Difficulty getting in and out of a car

- Difficulty with shopping
- Difficulty putting on socks or stockings
- Difficulty rising from bed
- Difficulty removing socks or stockings
- Difficulty turning over or maintaining knee position in bed
- Difficulty getting in or out of a bath
- Difficulty sitting
- Difficulty using the toilet
- Difficulty performing heavy domestic activities
- Difficulty performing light domestic activities

5. Function in Sport and Recreation (5 items)

- Difficulty squatting
- Difficulty running
- Difficulty jumping
- Difficulty twisting or pivoting on the affected knee
- Difficulty kneeling

6. Quality of Life (4 items)

- Frequency of awareness of knee problems
- Degree of lifestyle modification due to knee problems
- Level of confidence in the knee
- Overall difficulty related to knee problems

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