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Article

The Effects of Aging and Cognition on Gait Coordination Analyzed Through a Network Analysis Approach

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Abstract

Background/Objectives: Walking coordination is crucial for maintaining independence and quality of life, but it is significantly affected by aging and cognitive decline. This study investigates how age and cognitive status relate to lower limb coordination during gait, using a network-based analysis of joint kinematics. Methods: Fifty-six healthy participants (31–82 years old) underwent gait analysis with a stereophotogrammetric system and cognitive assessment through standardized neuropsychological tests. Kinematic data were processed to build "kinectomes", representing the inter-joint coordination across the gait cycle. Results: The results showed that the mean lower limb coordination on the sagittal plane negatively correlated with age and positively with cognitive performance. Detailed analysis revealed that age-related declines in coordination were primarily driven by reduced synchronization at the knees, while cognitive status was associated with overall coordination rather than joint-specific changes. Conclusion: These findings emphasize the knees' critical role in preserving gait coordination with aging and underline the involvement of cognitive aspects in global coordination mechanisms. In summary, our network-based approach provides a refined perspective on gait dynamics, highlighting the relationship between coordination and both age and cognition.

Keywords: gait coordination; aging; cognitive function; network theory

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1. Introduction

Walking is a fundamental mode of human locomotion, essential to preserve functional independence and perform activities of daily living [1]. Efficient walking requires adequate coordination, which stems from fine-tuning the degrees of freedom of the musculoskeletal segments involved in the gait cycle. However, several factors, including neurological disorders, musculoskeletal impairments, and physiological processes, such as aging, can alter gait execution [2–4]. The aging process is an inherent aspect of human biology that induces progressive motor and cognitive changes that significantly affect walking. In fact, these changes may lead to impaired coordination, which in turn may affect balance and overall gait stability [5]. These alterations not only compromise mobility and independence but also increase the risk of falls, significantly affecting the ability to perform daily life activities, and constituting a major global health problem [6]. Research has also shown that aging plays a crucial role in altering executive functions, attention, and motor planning, and such cognitive changes can further impact coordination, exacerbating gait instability [7]. Based on current knowledge, we believe that assessing gait kinematic coordination in relation to age and cognitive status may be relevant for identifying potential areas of intervention at both the motor and cognitive levels. Nevertheless, the literature still lacks a thorough investigation of these aspects. On the one hand, most studies derive coordination indices from spatiotemporal gait features, such as variability and asymmetry, without considering the complex interactions between different body segments [8,9]. On the other hand, the cognitive dimension of physiological aging in relation to gait coordination remains poorly explored. These studies generally report a decline in inter-limb coordination [10,11], which, in some cases, is also associated with walking speed, a parameter known to decrease with advancing age [12]. Swanson & Fling further characterized this knowledge by demonstrating a relationship between coordination and motor cortex inhibition in older adults [13]. Specifically, the authors reported that, unlike in young adults, greater inhibition of the motor cortex appeared to benefit gait coordination in older adults. Concerning the metrics used to define coordination, the phase coordination index (PCI) appears to be one of the most commonly used [9,13,14]. This index is based on the temporal aspects of steps and strides and measures the accuracy and consistency of the phase relationship between the lower limbs during walking. However, despite its usefulness (particularly as a highly synthetic index–ability to compress multiple aspects of limb coordination into a single metric), the PCI does not consider the spatio–temporal interactions among joints, which are a key factor for determining coordination [15]. In addition, since PCI is derived from average values calculated over multiple gait cycles, its application requires extended walking trials, which may be challenging or uncomfortable for some individuals [16]. Indeed, to cite Turvey, "*coordination necessarily involves bringing into proper relation multiple and different component parts*" [17]. More in-depth analyses have instead been conducted by estimating coordination through the continuous relative phase between joints' kinematics. However, in this case, the number of studies is limited, as is the number of joints involved in the analysis, which are almost exclusively intra-limb [18,19]. To address this limitation, we chose to apply network analysis to joint kinematics during gait. This approach, previously employed to analyze coordination between different parts of the body, is based on the use of a correlation matrix [20,21]. This matrix, named kinectome, represents kinematic interactions between pairs of joints (inter- and intra-limb). It consists of nodes, which correspond to joints, and links, which indicate correlation values and describe the degree of coordination between different joint pairs. The methodological innovation of the kinectome lies in its systemic representation of joint coordination. Instead of reducing complex motor patterns to simplified metrics, kinectome preserves the entire network of functional inter-articular relationships, offering a rich and interpretable picture that reflects the complexity of human movement. This detailed mathematical description showed significant specificity for both subjects and movements and was able to describe movement patterns of coordination in both physiological and pathological conditions [21–23].

By means of kinectomes, our aim is to investigate whether a relationship between gait coordination and both age and cognitive status exists, to then determine which specific joints are involved. To ensure that our findings reflect the baseline relationships between age, cognition, and coordination in healthy adults, we deliberately excluded individuals with known cognitive or motor impairments. This choice was made to avoid potential confounding effects of pre-existing conditions and to provide a reference point for future investigations in clinical populations. We hypothesize the following: (1) the capacity to coordinate lower limbs becomes worse with advanced age; (2) the cognitive condition may be related to the coordination ability; (3) different joints are differently influenced by age and cognition. To test these hypotheses, we used a stereophotogrammetric system to record gait from fifty-six healthy individuals. Network-based features of lower limb joints were then extracted, and correlation tests with age and cognitive scores were carried out.

2. Materials and Methods

Fifty-six healthy subjects were recruited, consisting of 36 males and 20 females. Main analyses were carried out on the whole sample according to the aim of the study. However, we also conducted a post hoc analysis, splitting the sample into two subgroups based on their age. The subgroups included 30 participants under the age of 60 and 26 participants aged 60 and above. The distribution of the ages in subgroups is shown in Figure S1 in the Supplementary Material. Demographic and cognitive data were collected as exclusion criteria and to perform further analysis. For testing cognitive conditions, participants performed neurological and psychological tests such as the Mini-Mental State Examination (MMSE) [24], Frontal Assessment Battery (FAB) [25], and Beck Depression Inventory (BDI) [26] (Table 1). The MMSE is a copyrighted instrument originally developed by Folstein et al. [24], with distribution rights currently held by Psychological Assessment Resources, Inc. (PAR). In this study, the MMSE was administered exclusively for non-commercial, academic purposes, in compliance with fair use provisions. Exclusion criteria were as follows: FAB < 12; MMSE < 24; BDI > 13; age < 18 years old; intake of psychoactive drugs; physical or neurological condition leading to motor impairment.

Table 1. Participants' information. Demographic and clinical characteristics of the full sample and age subgroups (mid adults—under 60 years old—and older adults—over 60 years old). Values are presented as mean ± standard deviation (minimum–maximum). MMSE: Mini-Mental State Examination; FAB: Frontal Assessment Battery; BDI: Beck Depression Inventory.

	Full Sample (n = 56) (mean ± standard deviation (minimum–maximum)	
Age (years)	58.88 ± 13 (31–82)	
Education (years)	13.92 ± 4.08 (5–18)	
Sex	36 M/20 W	
MMSE (maximum score = 30)	27.57 ± 1.36 (24.85–30)	
FAB (maximum score = 18)	16 ± 1.48 (12–18)	
BDI (maximum score = 30)	5.87 ± 3.44 (0–13)	
	Un 60	**Ov 60**
Age (years)	49.03 ± 8.11	70.23 ± 6.70
Education (years)	14.83 ± 3.18	12.88 ± 4.78

Table 1. *Cont.*

	Un 60	Ov 60
Sex	20 M/10 W	16 M/10 W
MMSE	27.46 ± 1.16	27.70 ± 1.58
FAB	15.84 ± 1.27	16.19 ± 1.70
BDI	5.03 ± 2.86	6.85 ± 3.84

2.1. Participants and Data Collection

The FAB and the BDI tests were administered only for inclusion/exclusion criteria and were not analyzed as outcome variables. Cognitive function was assessed using the MMSE, which evaluates cognitive domains including orientation, memory, attention and calculation, language, and visuospatial skills. MMSE results were used as the primary measure of cognitive status in this study.

The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Psychological Research of the Department of Humanities of the University of Naples Federico II (protocol code 26/2020 approved on 10 September 2020).

Informed consent was obtained from all subjects involved in the study.

2.2. Recording System and Processing Pipeline

The acquisitions were conducted at the Motion Analysis Laboratory of the University of Naples Parthenope, located within the Hermitage Capodimonte Maugeri Clinic in Naples. Data collection took place over a period of approximately two years, with weekly acquisition sessions. The gait data was collected using a stereophotogrammetric system comprising eight high-quality infrared cameras (Pro Reflex Unit—Qualisys Inc., Gothenburg, Sweden). The cameras tracked the light reflected by 55 passive markers placed on the participant's skin on specific bone landmarks, following a modified version of the Davis protocol [27] (Figure 1). Participants were instructed to walk in a straight line at their usual comfortable pace. We recorded four trials for each participant, each containing one complete gait cycle for both the right and left foot. Due to data quality control, some trials were discarded. To ensure consistency and comparability across participants, we retained two acquisitions per participant, resulting in a total of four gait cycles per participant [28]. Gait data were collected by the Qualisys Track Manager software (QTM), which accurately determined the three-dimensional position of each bone marker. Then, Visual 3D software was used to preprocess the data and extract the joints' excursion angles on three anatomical planes (i.e., sagittal, frontal, and transverse). Specifically, the hip, knee, and ankle three-dimensional time series from both right and left lower limbs were imported into MATLAB (MathWorks, version R2023b), where we computed their first derivative to obtain the velocity time series of each joint. Velocity of joints' excursion was considered as representative of movement control [29], as numerous studies have highlighted the role of velocity in motor planning [30–32].

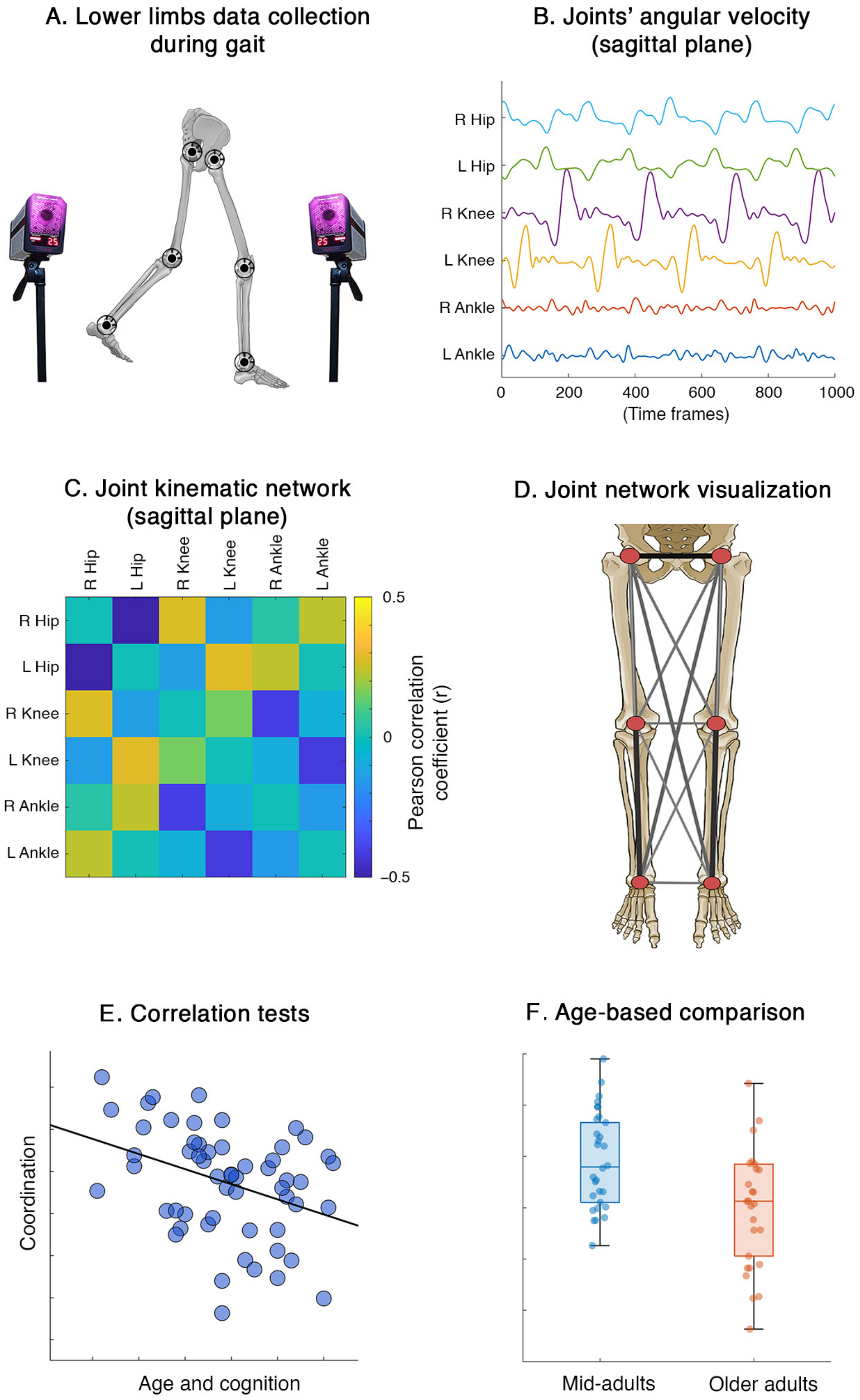

Figure 1. Analysis of the pipeline. (**A**) Gait was recorded using a stereophotogrammetric system. (**B**) Data on joints' angular velocity were collected and analyzed; data on the sagittal plane are displayed in the figure. (**C**) Coordination was estimated via network theory; pairwise Pearson's correlation coefficient was computed among joints' angular velocity time series of a gait cycle to build a matrix named kinectome; for each participant, a kinectome for each plane was obtained by averaging matrices from four gait cycles; the colorbar in the figure was zero-centered to better highlight positive-to-negative differences; values along the diagonal were set to zero, as self-correlation values are

not informative. (**D**) Body network representation; correlation coefficients from the matrix in panel (**C**) were displayed on a skeletal model; the darker and the thicker the lines, the higher the correlation between joints' kinematics. (**E**) Correlation tests were performed between global/joint-specific coordination features and demographic/cognitive characteristics. (**F**) Coordination during gait was compared between mid-adults and older adults.

2.3. Lower Limbs Network

Using network theory, we built kinematic coordination matrices named kinectomes, whose nodes were represented by hips, knees, and ankles. The coordination between pairs of joints was expressed by the edges linking the nodes and was estimated as Pearson's correlation coefficients between pairs of time series. We performed this computation for each plane separately, resulting in three kinectomes per gait cycle for each participant. Our analysis mainly focused on joint excursions in the sagittal plane, as flexion/extension patterns represent the dominant movements during the gait cycle. Afterwards, kinectomes of different gait cycles of the same participant were averaged within the same plane. From kinectomes were extracted two different parameters were extracted: (1) the mean coordination, computed as the average value of a kinectome (excluding the self-correlation values, i.e., the diagonal elements of the kinectome); (2) the nodal strength of each joint, computed as the sum of all edges belonging to a given node (excluding the self-correlation value). While the first parameter is a global one, describing the whole lower limb joint coordination with a single score, the nodal strength is a joint-specific parameter able to represent the degree of synchronization of a single joint with respect to the whole system (i.e., lower limbs). For instance, if a joint's angular motion is closely aligned in timing and amplitude with the movements of other joints, its nodal strength will be higher, indicating greater coordination in the kinematic network. Conversely, a low nodal strength indicates that the joint varies more independently from the others, and therefore can be considered less coordinated within the kinematic network. Thereafter, we carried out correlation tests between these parameters and both demographic and neuropsychological variables. We also divided our sample around the 60-year threshold, creating a mid-adult (MA) and an older adult (OA) group, in order to test for potential age-related differences in coordination. Although there is no universally accepted age threshold in movement studies, several gait and movement studies have adopted 60 years, as age-related changes in balance and gait often begin around this age [5,33,34]. Our aim was to detect early changes in coordination in a healthy population, justifying our choice of 60 years as a cutoff.

2.4. Statistics

Correlation tests were performed using Pearson's correlation coefficient test. The strength of the association, based on the correlation coefficient (r), was considered as follows: from 0 to 0.19 very weak, 0.20 to 0.39 weak, 0.40 to 0.59 moderate, 0.60 to 0.79 strong, and 0.80 to 1.00 very strong [35]. Comparison between groups was assessed through a permutation test by randomly shuffling group labels 10,000 times. In each permutation, the groups were randomly mixed, resulting in a distribution of differences that could occur by chance alone. A significant threshold of $p < 0.05$ was set, and the outcomes were corrected using the False Discovery Rate (FDR) [36] method for each analysis.

3. Results

We conducted correlation tests between the average value of each participant's kinectome (mean coordination) and both demographic and neuropsychological variables on each anatomical plane, but only on the sagittal plane did we find significant results. As described in Figure 2, we found that the mean coordination observed on the sagittal plane was significantly correlated with the participants' age ($r = -0.37 \mid p = 0.006 \mid \mathrm{pFDR} = 0.023$) and with the cognitive scores assessed with the MMSE test ($r = 0.32 \mid p = 0.015 \mid \mathrm{pFDR} = 0.03$).

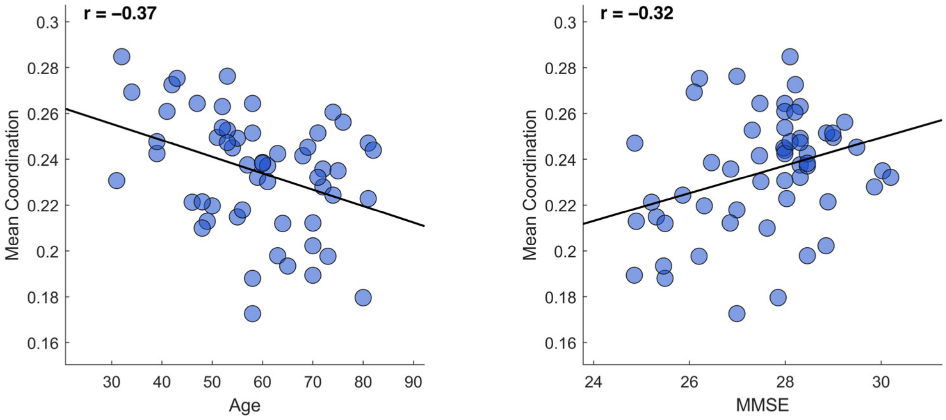

Figure 2. Mean coordination correlation tests. The figure displays the correlation plot between mean lower limb coordination and both age (**left panel**) and Mini-Mental State Examination (MMSE) scores (**right panel**). Each dot represents an individual participant. The tests were performed using Pearson's correlation coefficient with significance set at $p < 0.05$ after false discovery rate correction.

Then, we further analyzed gait coordination by repeating the correlation tests, focusing on individual joints. Hence, from each participant's kinectome, we extracted the nodal strength values of hips, knees, and ankles. In this case, we found significant negative correlations between the nodal strength of both knees on the sagittal plane and the participants' age (right knee, $r = -0.48 \mid p < 0.001 \mid \mathrm{pFDR} = 0.002$) (left knee, $r = -0.36 \mid p = 0.007 \mid \mathrm{pFDR} = 0.041$) (Figure 3), while no significant correlation was found between joints-specific coordination values and the MMSE scores. Further analysis was conducted to investigate whether the greater correlation between nodal values and knees also caused the overall correlation. Excluding the kinematics of the knee, the correlation was no longer significant.

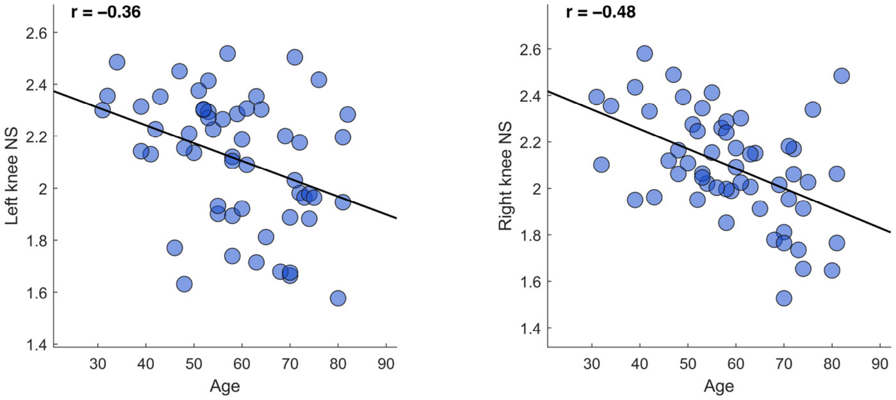

Figure 3. Joints' coordination correlation tests. The figure displays the correlation plot between age and both left (**left panel**) and right (**right panel**) nodal strength values. Each dot represents an individual participant. The tests were performed using Pearson's correlation coefficient with significance set at $p < 0.05$ after false discovery rate correction.

After conducting the main analyses on the entire sample, we also performed post hoc analyses, dividing the sample into two subgroups based on age, comparing coordination values between younger and older participants. The analysis showed that younger adults displayed higher coordination values on the sagittal plane for both the right ($p = 0.001 \mid \mathrm{pFDR} = 0.008$) and left knee ($p = 0.013 \mid \mathrm{pFDR} = 0.04$) (Figure 4).

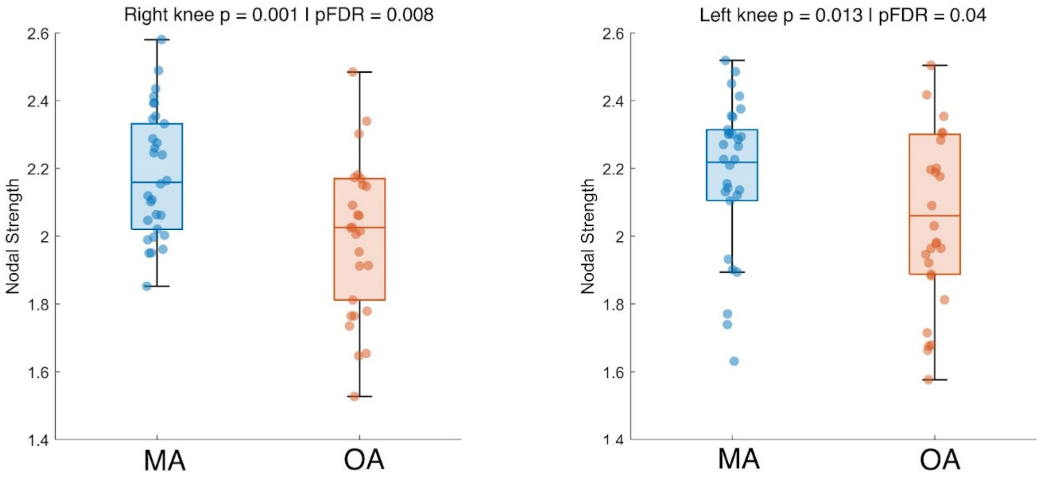

Figure 4. Age-related coordination difference. The figure displays a comparison of right and left knee nodal strength values between mid-adults (MA) and older adults (OA). Each box includes data from the 25th to 75th percentile, while the horizontal lines represent the median value. Individual participants' values are represented by colored dots. Significance set at $p < 0.05$ after false discovery rate correction (pFDR).

It should be noted that the analyses were performed on all three planes, but significant results were found exclusively on the sagittal plane.

4. Discussion

To assess the relationship between motor coordination during walking and factors such as age and cognitive abilities, we collected and analyzed data from fifty-six healthy individuals. After measuring their gait coordination using network theory applied to joint kinematics, we partly confirmed our hypotheses. In summary, our data showed that gait coordination is related to both age and cognition, but when inspecting specific joints, only the knees displayed significant correlations. Furthermore, significant results were found exclusively on the sagittal plane, emphasizing the significance of considering the biomechanical dynamics in this specific direction. Our investigation offers a representation of the intricate interdependencies between age, cognitive function, and limb coordination during walking [37,38].

The use of network theory for kinematic analysis made it possible to examine movement by revealing higher-order information compared to the analysis of individual body segments, taking into account the influence of different body parts on one another. Initially, we observed a correlation between age and global coordination during gait. However, a more detailed analysis revealed that the contribution of the knees to coordination is predominant and essential in determining this correlation. In fact, when this contribution is excluded, the global coordination no longer shows any significant association. Probably, knee degeneration is more predominant than ankle and hip due to biomechanical compensation. In particular, the knee appears more impacted because it plays a central role in force transmission and coordination between the hip and ankle. It is also more mechanically loaded to age-related degeneration. In contrast, the hip and ankle often retain more functional capacity and adaptability, allowing them to compensate for knee deficits. As a result, their contribution appears less affected, especially in the earlier stages of decline [39–41]. Consistently, when we divided the sample into mid-adults and older adults, the level of knee coordination was found to be significantly different between the two groups, with a higher degree of coordination in young adults. These findings highlight the key role of the knees in gait coordination. We believe that these findings could provide preliminary insight for prevention and health in the older population. However, further studies are needed to understand which kind of intervention (i.e., proprioceptive training, neuromuscular control exercises, balance, and postural control) may help improve knee coordination during gait and positively contribute to primary prevention. Indeed, the negative correlation suggests that, with advancing age, there is a reduction in the overall contribution of the knees to the execution of the gait cycle. This may be due to several factors, including decreased strength and joint range of motion, which could alter the motor coordination pattern with aging [42]. While age-related reductions in joint range of motion are well-documented, this study adds to existing knowledge regarding the concurrent alteration in coordination patterns [43–45]. Altogether, these insights suggest that training, rehabilitation, or functional recovery protocols should focus not only on improving joint range of motion but also on enhancing the movement synergy between different lower limb joints, with particular attention to the knees. The decrease in knee joint synchronization with aging highlights a pertinent concern regarding impaired mobility, susceptibility to falls, and a loss of independence in the elderly demographic cohort [33]. Hence, the aging population's increasing need for gait monitoring in daily life is emphasized to preserve older individuals' mobility [46]. In addition, it should be noted that previous studies also found that age affects hip and ankle coordination more than coordination across the knees [47]. However, the parameters used to measure coordination vary across studies, and this may explain the differences, while at the same time offering different perspectives on the topic that could be integrated for a more comprehensive understanding. While our findings highlight a predominant role of the knees in coordination decline with age, it is important to acknowledge that previous studies have also reported significant age-related alterations in hip and ankle coordination. For instance, studies have shown changes in hip segment coordination during specific gait phases such as terminal swing and midstance, as well as reduced hip proprioception that may affect dynamic balance. Similarly, research has indicated modifications in foot–shank coordination and increased ankle joint co-contraction in older adults, which could impair effective propulsion during walking. These findings support the notion that gait coordination deterioration with aging is not confined to a single joint but involves complex, multi-joint adaptations. Our network-based approach may be particularly sensitive to identifying the most functionally dominant joints in this process (in this case, the knees), but integrating evidence from these previous studies reinforces the value of examining all lower limb joints when assessing motor aging [47–50].

Furthermore, when analyzing the relationship between cognitive abilities, measured by the MMSE test, and lower limb coordination, we found that the correlation was not directly influenced by specific joints, but was related to the overall average coordination. While our analysis did not show a significant correlation between age and cognitive performance, we observed an association between cognitive function and global lower-limb coordination during gait (but not joint-specific coordination). This finding aligns with existing literature emphasizing the role of cognition, particularly executive functions, in managing overall gait coordination. For instance, a study by Hao et al. demonstrated that the general cycle of gait is significantly associated with global cognitive function and executive function, suggesting that cognitive processes are more closely linked to general gait patterns rather than specific joint movements [51]. Furthermore, as suggested by Jo in [52], to maintain balance, cerebellar control does not act on each muscle in isolation; instead, it focuses on controlling the body's center of mass (COM) by integrating vestibulospinal information about trunk verticality. This supports the theoretical model according to which cognition plays a central role in coordinating whole-body movements during walking. Our results support such a model, suggesting that cognitive functioning is more intricately connected to global gait coordination than to joint-specific movements. This suggests that the effects of aging on cognition may indirectly impact the ability to properly coordinate lower limbs during gait [53]. In fact, the literature confirmed indirect effects of aging, such as increased muscle co-activation leads to fatigue and loss of coordination [54]. Whereas direct effects are the degeneration of muscle strength and range of motion due to neuromuscular decline. However, as a direct effect remains neuromuscular decline reduces muscle strength and joint range of motion [55]. This is in agreement with previous research, which affirmed that lower cognitive conditions are related to poorer performance in gait measurements such as speed, rhythm, or stride time and to a great variability [56,57]. Moreover, the relationship between lower limb function and cognitive abilities has already been explored, indicating that lower limb coordination and gait performance can serve as predictors of cognitive disorders in the elderly [58,59]. Kim and Ko compared the lower limb aspects, such as walking speed and balance, with cognitive functions and found an effective correlation. Savica examined specific gait parameters as predictors of cognitive decline and reported that spatial, temporal, and spatiotemporal measures of gait were associated with and predictive of both global and domain-specific cognitive decline. From a neural point of view, the potential cognitive mechanisms influencing global coordination are executive functions such as goal setting, planning, and monitoring integrated with motor control systems to produce smooth and goal-directed movements. Higher-order cognitive areas, notably the dorsolateral prefrontal cortex (dlPFC) and supplementary motor area (SMA), play critical roles in formulating motor plans and sequencing complex actions. These regions communicate with the primary motor cortex (M1), which directly controls voluntary muscle activity. Subcortical structures, including the basal ganglia and cerebellum, are essential for refining these motor commands, facilitating movement initiation, timing, error correction, and adaptation. Thus, cognition shapes global motor coordination by orchestrating a network of cortical and subcortical regions through dynamic interactions, translating intention and plans into coordinated and fluid movements. Our findings confirmed and extended the scope of application using specific joint kinematics as a possible predictor factor. These insights underscore the importance of adopting a multidimensional approach to intervention strategies aimed at preserving and enhancing lower limb coordination in older adults.

However, this study has some limitations that should be acknowledged. First, since MMSE is basically a cognitive test, it does not capture the full complexity of executive functions. Future research should consider correlating motor measures with specific neuropsychological tests that assess the various dimensions of executive functioning in a more detailed manner. Second, the definition of the elderly population has evolved, with the threshold for classification often shifting towards 65 years of age and beyond. In the context of future studies, it would be advantageous to investigate these motor–cognitive relationships across diverse age groups within the older adult population (i.e., young-old, old, senior, and oldest-old individuals over 90 years of age), given the heterogeneity of the aging process, which may result in the emergence of distinct patterns across subgroups. Furthermore, it should be underlined that the exclusion of participants with cognitive or motor impairments limits the immediate generalizability of our findings to clinical populations. However, this choice was intentional to establish baseline associations in a healthy population to exploit in future studies. Moreover, based on conventional standards, we point out that although the correlations we found were statistically significant, the strength was weak ($r < 40$)—except for the correlation between age and right knee coordination, which represents a moderate correlation.

5. Conclusions

The results of this research provide insights into the relationship between cognitive abilities, aging, and coordination of the lower limbs during walking. Our findings indicate an association between age and lower limb coordination, particularly evident in the knees. This suggests that as individuals age, there is a potential decrease in the synchronization of knee movements during walking. Furthermore, cognitive status shows a connection with limb coordination, though this association appears to be not joint-specific but related to an overall coordination pattern of the lower limbs. Further studies should focus on the underlying mechanisms of age-related alterations in motor function and cognitive-motor interactions. Indeed, by gaining a deeper understanding of these processes, it is possible to develop targeted interventions to optimize functional mobility and enhance the quality of life for aging populations.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/biomechanics5030043/s1. Figure S1. Distribution of ages across the two subgroups: the histogram shows the frequency of participants within each age interval, while the curves represent the estimated age distribution in the two groups. The mid-adults group shows a peak around 49 years, whereas the older adults group peaks at approximately 70 years.

Author Contributions: Conceptualization, M.D.L. and E.T.L.; data curation, R.M.; formal analysis, M.D.L.; funding acquisition, G.S.; investigation, M.D.L. and E.T.L.; methodology, E.T.L.; project administration, G.S.; software, P.S.; supervision, L.M. and G.S.; writing—original draft, M.D.L.; writing—review and editing, M.D.L., R.M., A.P., E.G. and E.T.L. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data are available on reasonable request to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

PCI	Principal Component Analysis
MMSE	Mini-Mental State Examination
FAB	Front Assessment Battery
BDI	Back Depression Inventory
MA	Mid-Adults
OA	Older Adults
FDR	False Discovery Rate

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