10 METHODOLOGY OF ASSESSING DUAL-TASK GAIT WITH CONSIDERATION FOR LINGUISTIC AND CULTURAL VARIATIONS IN THE KNOWLEDGE LEVELS OF THE PARTICIPANTS

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10.1 Introduction

Walking is a fundamental human locomotor activity. During walking, individuals commonly engage in additional tasks such as conversing, using a smartphone, window-shopping, or planning a route. In these moments, the human nervous system not only governs walking but also manages these concurrent activities, demanding more of its resources compared to situations where walking is the sole focus. Consequently, under conditions involving an additional task, it becomes possible to identify disorders that might not be evident in a traditional gait examination.

The methodology of dual-task gait analysis enables the examination of everyday walking patterns in clinical settings. This approach facilitates the observation of changes in gait patterns resulting from aging, medical conditions, or injuries, and it aids in assessing the effectiveness of interventions designed to enhance locomotion.

The evaluation of gait with an additional task is increasingly utilized in physiotherapy and can be valuable in assessing fall risk, the potential for return to sports after an injury, or the effectiveness of gait re-education.

The objective of this lesson is to introduce best practices for the proper execution of gait testing with an additional task, drawing from a comprehensive review of the literature and our own expertise.

10.2 Methodology of assessing dual-task gait

10.2.1 Dual-task paradigm

To identify differences in gait conditions with an additional task, the dual-task paradigm is utilized. Its premise involves performing each of the tasks first individually and then simultaneously executing both tasks. Each task should have the same conditions during both single and dual-task performance (Pineda et al., 2023) (McIsaac et al., 2015).

10.2.2 Preparation for the examination:

Before starting the examination, it's essential to inform the person being examined about the purpose of the study, how it will be conducted, and assure them that the examination is non-invasive and painless.

If markers will be applied directly to the body (skin) during the examination, it's also important to let the individual know when scheduling the appointment that they should avoid using moisturizing or oily skin products (like lotions or balms) to prevent the markers from coming off.

10.2.2.1 Preparation for gait analysis in the dual-task paradigm:

Before conducting gait analysis in the dual-task paradigm, several steps need to be taken:

- **Interview:** Collect information about the individual's age, existing medical conditions, past injuries, occupation, hobbies, and the reason for undergoing the study.
- **Anthropometric Measurements:** Gather measurements necessary for the specific gait analysis system in use, such as body height and the length of the lower limbs.
- **Additional Measurements:** Include any extra measurements, for example, an assessment of the dominant lower limb (if needed for the study).
- **Attachment of Sensors/Markers:** Securely attach the motion analysis system's sensors or markers to the individual's body and calibrate the system to ensure accurate data collection.

10.2.3 Gait Analysis in Single-Task Conditions (Single Task - ST):

During gait analysis in both single and dual-task conditions, we utilize gait analysis systems to obtain spatiotemporal gait parameters. Depending on the equipment used, it's important to consider its limitations, which can arise from measurement accuracy and cultural factors (such as how and where sensors/markers are attached).

After attaching the sensors/markers of the selected gait analysis system, it is advisable to acclimate the individual to walking in the measurement environment. Our observations suggest that a patient's awareness of having elements of the system attached to their body or that their gait is being recorded can impact their locomotion. A best practice in our motion analysis laboratories is to allow the individual to walk the measurement path multiple times before the actual data recording.

Gait Recording:

Typically, gait analysis is conducted at the participant's preferred walking speed (Langeard et al., 2021). However, there is also the possibility to perform the study at a slow or fast walking pace (Schättin et al., 2016).

To prevent measurement errors during the study, it is recommended to:

- Ensure that only research equipment, and not personal phones or electronic devices, are in use by both the participants and the examiners.
- Limit the number of people in the room to only the individuals being tested and the examiners.
- Secure the area to prevent unauthorized individuals from entering the room where the study is conducted.
- Eliminate external distractions, such as blocking windows, closing doors, and reducing external noises.

The measurement path should be determined with the following considerations:

- The path's length should be suitable for the participant's physical capabilities.
- The participant should be able to walk in a straight line (they can turn around, but this stage is not included in the measurements).
- A measurement path located in a space that is too small can disrupt the results by altering gait parameters due to locomotion initiation or approaching an obstacle like a wall.

- A path that is too short or too long may hinder or prevent the performance of additional tasks in dual-task conditions.

According to the dual-task paradigm, it is essential to ensure the same testing conditions and conduct the same number of walking cycles in both single and dual-task conditions (Plummer et al., 2013). This consistency is crucial for reliable and meaningful comparisons in gait analysis when individuals are performing tasks that require their attention simultaneously.

10.2.4 Researching additional tasks in single-task conditions (Single Task – ST)

Despite the increasing number of scientific reports regarding cognitive task assessment, there is a lack of standards defining the principles of their application. The following tasks are most commonly used in research:

- **Serial counting backward from 50 or 100** (the participant verbally counts numbers, e.g., 100, 99, 98...) (Beauchet et al., 2008) (Beauchet et al., 2007) (Yamada et al., 2011).
- **Serial subtraction of 7 or 3 from a specified number** (the participant provides the results of subtracting from the given number, e.g., subtracting 7 from 376, the patient should list numbers like 376, 369, 362, 355...) (Maclean et al., 2017).
- **Listing animals or professions without repeating names** (the participant lists professions like chef, doctor... or another version involves naming animals starting with a specific letter, e.g., C, then providing names like “cat”, “cow”, “crocodile”) (Freire Júnior et al., 2017).
- **Using a mobile phone**, e.g., the participant writes a text message (Krasovskyi et al., 2017) (Ehlers et al., 2017) (Lin and Huang, 2017).
- **Moving a cup of water** (the participant's task is to transfer a cup of liquid or a tray with cups of water) (McIsaac et al., 2015).
- **DIVA-gait computer test** (a computer program created at the Academy of Physical Education in Krakow by the team of A. Kreska-Korus, E. Golec, A. Wojtowicz, based on the DIVA program by Nęcka, 1994) (this task was presented in **VIDEO 3**).

Course of the Study:

- Explain the additional task to the participant, detailing what it entails. If the study requires it, conduct sessions in which the participant learns how to perform the task.

- Record the progression of the additional task study, and document the results

During the additional task study, the most commonly measured indicators are reaction time and the quantity of correct tasks or the number of errors.

When selecting the type of additional task, remember that it must be achievable under the same conditions as during the dual-task gait analysis. You can find more information on this topic in the section about cross-cultural communication.

10.2.5 Gait analysis in dual-task conditions (Dual Task - DT):

According to the dual-task paradigm, the final stage involves simultaneously performing both tasks (walking and the additional task) under the same conditions in which the single tasks were conducted. The same indicators are recorded for this dual-task performance.

10.3 Development of indicators

10.3.1 Development of gait indicators

To conduct gait analysis with an additional task, it's necessary to develop indicators for each part of the study.

For gait analysis, these indicators will mainly involve spatiotemporal measurements. However, it's important to select a consistent sample for both the single and dual-task conditions. In the analysis, one cycle of gait for each limb from each pass along the path should be considered. To do this, appropriate actions need to be taken within the operating system of the measurement device to identify and include only the chosen gait cycles, recorded in the middle section of the path/measurement (Schättin et al., 2016).

For selected indicators, calculate their average values and standard deviations.

Further analysis may involve considerations such as the dominant and non-dominant limb, limbs affected by pathological processes either directly or indirectly, and so on.

10.3.2 Development of additional task indicators

The most commonly used indicators for additional tasks are:

- Reaction time,
- Quantity of correct responses,
- Number of errors.

To obtain these indicators, you can count correct events (correct counting results, named animals or professions), errors, and determine reaction times. This can be done in three ways:

1/ The least demanding but most error-prone method is counting correct reactions during the study and measuring the study time using a stopwatch. By dividing the study time by the number of correct responses, you can calculate the reaction time.

2/ Recording the study on a Dictaphone and later calculating the number of correct responses and reaction times from the recording. The recorded study can be listened to for error elimination.

3/ Using a computer program that automatically records study results. The DIVA-gait test, for instance, records:

- Detection time (only considering correct reaction time),
- Number of detections,
- Number of errors, including the following error types:
- No alarm: the participant did not activate the reaction button when the signal letter was displayed.
- Double alarm: the participant pressed the reaction button a second time when the signal letter was displayed.
- False alarm: the participant activated the reaction button when the signal letter was not displayed (see **VIDEO 3**).

10.3.3 10.3.3. Gait indicators with an additional task

Distinctive indicators for gait analysis with an additional task include variability of gait cycle time/step time, variability of gait cycle length/step length, Dual-Task Effect, Mean Dual-Task Effect.

10.3.3.1 Variability:

For each of the individuals being studied, you can calculate:

- The variability of gait cycle time/step time (depending on the available data in the gait analysis system).
- The variability of gait cycle length/step length.

To calculate this variability, you can use the following:

$$V = \frac{SD}{m} * 100\%$$

V - variability, SD - standard deviation, m - mean.

It is essential to pay special attention to the precision of measurements, which is particularly important for the reliability of variability. Regarding the dual-task paradigm, it's crucial to replicate the testing conditions during both single and dual-task gait analysis. The repeatability of the sample size and obtaining unaltered gait indicators unaffected by other events, such as the initiation of gait or the presence of external individuals, is key.

10.3.3.2 The Dual-Task Effect

The Dual-Task Effect is calculated for each of the indicators according to the following formula (Plummer-D'Amato et al., 2012):

$$\alpha DTE = \left| \frac{\alpha DT - \alpha ST}{\alpha ST} \right| * 100\%$$

α DTE- Dual-Task Effect for indicator α

α ST - the value of the indicator under single-task conditions,

α DT - the value of the indicator under dual-task conditions.

The α indicator can be any of the indicators studied in walking or in the additional task (e.g., Dual-Task Effect on walking speed or Dual-Task Effect on reaction time).

When interpreting the indicator's values, it's important to be particularly attentive: for speed, an increase in the indicator will signify greater task efficiency, but in the case of reaction time, it will indicate decreased task efficiency.

10.3.3.3 Mean Dual-Task Effect

Mean Dual-Task Effect is calculated according to the following formula:

$$mDTE = \frac{\alpha DTE + \beta DTE}{2}$$

m DTE - Mean Dual-Task Effect,

α DTE - Dual-Task Effect for indicator α (gait indicator)

β DTE - Dual-Task Effect for indicator β (additional task indicator)

The Mean Dual-Task Effect is most commonly calculated for gait speed and reaction time. It can also be applied to other indicators, but it's essential to note that one must relate to walking, and the other to the additional task.

In cases where an increase in one indicator represents improvement while an increase in the other signifies a decrease in task efficiency, applying this formula indiscriminately can lead to a misrepresentation of the result. In such a situation, for the second indicator, you should place a minus sign (-) before conducting the operation. This scenario occurs when the Mean Dual-Task Effect is calculated for gait speed and reaction time.

In situations where both Dual-Task Effects show the same directional change (e.g., gait speed and the number of correct task completions), it's necessary to consider whether this alteration represents an improvement or a decline in task performance efficiency.

10.3.4 Interpreting results

To interpret the results of gait analysis with a dual task, you should consider the following aspects.

10.3.4.1 Assessment of spatiotemporal gait indicators in relation to normative values

Norms for specific gait indicators are available in the literature concerning gait analysis in single-task conditions. If the person being examined experiences disruptions in their gait pattern due to changes in range of motion, muscle strength, etc., these factors will influence gait indicators, both in single-task and dual-task conditions. The application of the dual-task paradigm allows for the evaluation of gait under the additional cognitive load, helping identify disruptions that may not be detected in traditional gait assessments. Assessing gait with a dual task reflects locomotion as it occurs in everyday life.

Walking speed is considered a fundamental gait indicator. It holds significant clinical importance due to its simplicity. Schmid (2012) and colleagues have indicated that a minimum walking speed necessary for societal functioning is around 0.8 m/s. When analyzing gait, it's also essential to consider factors such as stride frequency and stride length, as these indicators have a profound impact on walking speed.

10.3.4.2 Analysis of additional task indicators

In gait analysis with a dual task, the most commonly analyzed indicator is the average reaction time. In our own studies conducted using the DIVA-gait test, this indicator has proven to be the most sensitive measure of the additional task. Our experiences suggest that in cases of outlier results, it's advisable to consult with a psychologist for further interpretation and insights.

10.3.4.3 Analysis of gait indicators with an additional task

The Dual-Task Effect and Average Dual-Task Effect are referred to as absolute indicators (expressed in percentages). In addition to these, the variability of the gait cycle is also analyzed.

10.3.4.3.1. Dual-Task Effect

The Dual-Task Effect allows the assessment of the magnitude of change in a specific indicator, expressed as a percentage. It enables the evaluation of a chosen variable between different assessments and a comparison to identify where the most significant changes occur.

For example, if an individual exhibits a reduction in stride length by 0.1 meters and a decrease in speed by 0.1 m/s when an additional task is introduced, it can be challenging to determine which change is more substantial. However, if we calculate the Dual-Task Effect for stride length and find it to be 16%, and the Dual-Task Effect for gait speed is 10%, we can conclude that the greater changes have occurred in stride length.

Comparing the Dual-Task Effects for gait performance indicators (e.g., gait speed) and the additional task (e.g., reaction time), we can determine the attention-sharing strategy employed by the nervous system and which task experienced more significant changes.

10.3.4.3.1 Mean Dual-Task Effect

The Mean Dual-Task Effect is an indicator that assesses the efficiency of performing both tasks simultaneously in comparison to performing them in single-task conditions. It informs us whether the nervous system possesses sufficient resources to control the simultaneous execution of both tasks. A worsening of this indicator indicates that operational capacities have been exceeded, resulting in a decreased efficiency in task performance.

Plummer and Eskes (2013) emphasize the importance of distinguishing attention allocation strategies. They provide an example that interpreting the Mean Dual-Task Effect with the same value can indicate different types of attention allocation. It may reflect changes in both tasks concurrently, but it can also signify situations where there is only a reduction in the efficiency of either gait or the additional task.

The Average Dual-Task Effect allows for comparisons of walking abilities under dual-task conditions across different study groups. It can be utilized to identify conditions where the most significant changes occur and to assess the effectiveness of therapeutic interventions.

10.3.4.3.2 Variability

Variability in stride length and stride time indicates the extent to which these indicators change during locomotion, expressed as a percentage. Larger changes suggest poorer motor control of gait. Although this area requires further research, it appears that measures of variability in stride length and stride time can be considered sensitive risk indicators for falls during walking (Herman et al., 2020) (Maki, 1997). Gabell and Nayauk (1984) found that variability in stride length and stride time did not exceed 6% in healthy individuals.

10.3.4.3.3 Interpreting Results – summary

A specific interpretation of the results in gait with an additional task involves considering the following aspects:

1. The Average Dual-Task Effect indicates whether the individual has the neural resources to perform both tasks simultaneously.
2. Analysing the Dual-Task Effects for both tasks allows for the determination of the strategy being employed (whether gait and/or the additional task is affected).
3. Variability indicators determine if there has been a deterioration in motor control. If the magnitude of variability exceeds the norm, it is associated with an increased risk of falling.
4. A gait speed below 0.8 m/s can identify individuals with limited societal functioning (Schmid et al., 2007).
5. Analysing gait and additional task indicators can help understand the mechanism of motor control during gait with an additional task.

10.4 Communication with the patient

Effective communication with the patient plays a pivotal role in the context of gait testing with an additional task, as it can influence the outcomes. The choice of the supplementary task during the test may also be influenced by language, culture, or the individual's level of knowledge and skills. Familiarity with modifications to the test methodology creates the opportunity to adapt it in accordance with the patient's cultural sensitivities. Furthermore, certain approaches to locomotion testing may be incompatible with specific worldviews. Simultaneously, understanding the limitations of the methods employed enables the selection of the most suitable approach for testing or accurately interpreting the results.

In this course, we will present various options for tailoring the test methodology to meet the diverse needs of patients, along with recommendations for effective patient communication.

During the assessment of gait with an additional task, several areas can be sensitive to cross-cultural communication.

10.4.1 Communicating information to the patient and issuing instructions during the course of the study:

During gait assessments with an additional task, the identification of the strategy used to allocate attention between the tasks is crucial. It is essential to evaluate whether gait, the additional task, or both are affected. When explaining the purpose and process of the assessment to the participant and providing instructions, it's important not to suggest that one of the tasks is more important than the other (Maclean et al., 2017). Additionally, care should be taken to avoid situations that may evoke emotional responses in the participant, as emotions can also influence the assessment results (Gross et al., 2012).

This approach ensures that the participant does not feel pressured or anxious about the tasks and can perform them as naturally as possible, which is essential for obtaining accurate results during gait assessments with an additional task.

10.4.2 Selection of an Additional Task

Current scientific research results do not provide an answer to the question of which additional task is the best choice during gait assessments with an additional task.

Culture, understood as the entirety of material and spiritual heritage handed down from generation to generation, has a significant impact on human development, the type of information acquired, and competencies. Most of the additional tasks used are based on the participant's skills and knowledge, which can influence the results obtained. For example, if the task involves naming animals starting with a given letter (differently in single and dual tasks), the task's effectiveness, measured by the number of named animals and average reaction time, depends on the participant's knowledge. Their knowledge may be related to their education, hobbies, upbringing in various cultural contexts, and language. In different languages, both the number of animal names starting with a particular letter and the time to pronounce them differ. Therefore, when selecting an additional task and interpreting the results obtained, caution is necessary. It is advisable to choose tasks that do not pertain to areas of knowledge or skills that are particularly developed or limited in the participant (e.g., backward counting is not recommended for individuals with dyscalculia or accountants, and naming animals is not suitable for biologists). It's also important to remember that each additional task places a different burden on the nervous system. Therefore, results obtained from assessments using different additional tasks are not directly comparable.

In our own research, to avoid cognitive tasks related to the participant's knowledge and skills, we use the computer program DIVA-gait. When employing this tool, the type of alphabet typically used by the participant in their daily life should be considered (a cultural factor). While the Latin alphabet is commonly used, the DIVA-gait program can be applied to all alphabets that include uppercase and lowercase letters.

10.4.3 Selection of research method with respect to the client's cultural needs

Religious beliefs and individual sensitivity can make gait assessments challenging when using systems that require exposure of significant areas of the body. The consequence may be a refusal to participate in the study or a high level of stress that could affect the results. Having various measurement systems facilitates the optimal adjustment of the study conditions to the patient's needs.

A patient has the right to medical care, taking into consideration respect for the attitudes, values, and customs presented by them. This also applies to beliefs related to their religious affiliation. The pre-interview is an opportune moment to establish a diagnostic and therapeutic plan with the patient. The patient should be informed about the purpose of the planned procedure, how to prepare for it, and have the opportunity to ask questions. If the patient does not accept the planned treatment for religious reasons, it is good practice to emphasize that we respect their worldview. During the conversation, it is helpful to determine whether the issue lies with the entire procedure or just a specific element. We should present alternative options to the patient, which may involve modifying the procedure or exploring other forms of treatment. It is important to communicate the consequences of changing the diagnostic and therapeutic plan, such as lower treatment effectiveness, more general outcomes, or a longer duration of the procedure. It is crucial for the patient to consciously decide on the planned treatment, understanding the consequences of their choices.

One example of the impact of religious beliefs on the rehabilitation process could be the reluctance of nuns to undergo examinations in underwear or swimwear. It's important to note that this situation may vary depending on the particular convent to which the nun belongs and her individual beliefs. Therefore, having a conversation with each patient and determining an

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plan, such as lower treatment effectiveness, more general outcomes, or a longer duration of the procedure. It is crucial for the patient to consciously decide on the planned treatment, understanding the consequences of their choices.

Useful solutions might include:

- If a nun is unwilling to remove her habit but lower limb exercises are planned, suggesting the use of training pants could allow for more comfortable exercises without exposing the habit.
- If a nun does not accept removing her habit or veil but it hinders physiotherapy (e.g., a plastic element of the veil obstructs neutral head positioning in a treatment bed opening), asking if it's possible for the nun to use a mission dress during medical procedures, as it is more comfortable to use.
- Some nuns may accept removing their habit with a limited number of people present (e.g., individual baths or exercises, treatments in separate rooms, or therapy conducted only by female physiotherapists).
- There are also nuns for whom the issue is not the removal of the habit itself but the societal reaction to this fact; That's why they prefer to come to the clinic already dressed in civilian clothing (other than their religious habit).

10.5 Suggestions on cooperation with other members of the therapeutic team and people from the patient's close environment

To ensure high-quality research, collaboration in a multidisciplinary team is essential, involving physiotherapists, physicians, biomechanics, and psychologists.

If research results indicate significant disturbances in dual task gait, it may be necessary to refer the patient for further diagnostics (e.g., in situations where low cognitive function is suspected – which may be a symptom of dementia). However, if we observe a high risk of falls, we provide information to the physiotherapist responsible for the patient about the need for implementing appropriate therapy. Both the patient and the family, caregivers, or nurses should be aware that avoiding dual tasks during walking is essential to reduce the risk of falls.

10.6 Benefits of using gait testing methodology with an additional task

10.6.1 Importance of dual-task gait assessment in older adults

By 2050, approximately 400 million people worldwide will be over the age of 80 (Fong and Feng, 2018). Older adults experience a faster decline in lower limb function compared to upper limb function. Reduced mobility translates to fewer activities of daily living that a patient can perform independently (Zhang et al., 2018). This results in a decreased quality of life and the need for support from family or institutional care. Gait speed decreases with age. Smith et al. (2016) state that normal gait speed (under single-task conditions) is 1.29 m/s for individuals aged 60–69, 1.19 m/s for those aged 70–79, and 0.96 m/s for those over 80 years old. The measurement of gait speed is recognized by the British Geriatrics Society as one of the key indicators of functional decline and frailty, playing an important role in the long-term assessment and monitoring of older adults.

Additionally, there is a clear relationship between gait speed and falls. A significantly lower risk of falls has been demonstrated in individuals walking at a usual speed greater than 1.00 m/s (Smith et al., 2016). Older adults tend to reduce gait speed under dual-task conditions, lengthen gait cycle time and double support time compared to younger individuals, and show increased variability in gait cycle time and stride length (Springer et al., 2006; Hollman et al., 2007; Zhang et al., 2018; LaRoche et al., 2014; Hupfeld et al., 2022). LaRoche et al. (2014) found that deterioration in dual-task gait was correlated with cognitive function levels. Unfortunately, norms for spatiotemporal gait parameters under dual-task conditions or the dual-task effect have not yet been established. One main reason is the high variability in methodologies used, particularly the use of different additional tasks, resulting in considerable discrepancies in indicators.

The greater dual-task effect in older adults appears to be partially related to age-related brain atrophy, with the frontal cortex atrophying earlier and faster than other brain regions. Hupfeld et al. (2022) hypothesize that aging increases reliance on alternative (i.e., non-motor) neural resources, such as the frontal cortex, to compensate for brain atrophy in sensorimotor regions. Thus, deficits in the latter may contribute to reduced dual-task gait efficiency. Their neuroimaging studies indicated extensive age-related atrophy in cortical, subcortical, and cerebellar regions, particularly in areas involved in sensorimotor processing (e.g., precentral and postcentral gyrus). This identified potential compensatory relationships between better-preserved brain structure in regions not classically associated with motor control (e.g., temporal cortex) and preserved dual-task walking abilities in older adults. This suggests the temporal cortex's role in maintaining behavioral functions during aging, especially when other brain regions responsible for locomotor control (e.g., sensorimotor cortex, basal ganglia, and cerebellum) are largely atrophied. Additionally, they indicated a relationship between less specific subcortical atrophy (i.e., larger lateral ventricles) and greater decreases in gait speed under dual-task conditions.

The discovery of the dual-task interference phenomenon in gait among older adults has driven the development of new therapeutic programs. Although a universal treatment scheme has not been defined, Tait et al. (2017) suggest that the optimal training dose should last from 1000 to 3000 minutes, conducted 1-3 times a week. It should include both physical and cognitive training, and sensory exercises are also beneficial. Cognitive and physical training may stimulate similar neurobiological processes, evoking a synergistic response. They increase cerebral blood flow and induce angiogenesis in the cortex and cerebellum. Both forms of training can contribute to the plasticity of related areas and increase brain volume. Exercise may also protect blood vessels and neural tissue by counteracting the age-related increase in circulating inflammatory biomarkers linked to cognitive decline and dementia. Physical exertion-induced release of growth factors such as BDNF (brain-derived neurotrophic factor) and IGF-1 (insulin-like growth factor) also plays a significant role in neurogenesis, angiogenesis, and synaptic plasticity (Tait et al., 2017).

The use of dual-task gait methodology can be useful in identifying older adults with mild cognitive impairment. Zhou et al. (2021) reported that changes in gait parameters under dual-task conditions could be observed before cognitive changes. At this stage, conventional functional assessment tests would not be sensitive enough to detect these changes (Zhou et al., 2021).

Increasing importance is attributed to dual-task gait assessment methodology as a marker of fall risk, emphasizing that it is more sensitive than clinical tests (Kressig et al., 2008; Commandeur et al., 2018; Wayne et al., 2015). Wayne et al. (2015) emphasized that the dual-task effect size is higher in older adults who fall compared to non-fallers and that gait cycle variability during dual-task walking may be a particularly sensitive predictor of falls in older adults (Kressig et al., 2008).

Hupfeld et al. (2022) indicate that poorer dual-task walking skills are associated with increased fall risk, functional decline, frailty, disability, and mortality. Dual-task gait assessment methodology thus plays an important role in diagnosing older adults. Older adults exhibit age-related changes and a higher prevalence of diseases. Both factors can lead to a deterioration in dual-task gait indicators. In summary, significant dual-task effects should prompt the therapist to conduct a thorough diagnosis to determine the causes and implement a program to improve dual-task gait.

10.6.2 Examples of the application of dual-task gait methodology in neurology

Introducing a dual-task paradigm into gait assessment in stroke survivors helps identify long-term impairments that are not detected in other clinical evaluations (Kemper et al., 2006). Compared to single-task gait, dual-task gait is characterized by a reduction in gait speed (Bowen et al., 2001; Canning et al., 2006; Plummer-D'Amato et al., 2010), lower cadence (Canning et al., 2006; Plummer-D'Amato et al., 2010), increased cycle time (Plummer-D'Amato et al., 2008), and increased double support time (Bowen et al., 2001).

Plummer-D'Amato et al. (2010) suggest that loading the paretic limb may be the most attention-demanding phase of the gait cycle in individuals with hemiparesis. This has significant clinical implications. It seems reasonable to focus on re-educating this phase of the gait cycle under single-task conditions to improve the automatism of loading the paretic limb.

Gait impairment, on the other hand, is one of the primary motor symptoms of Parkinson's disease and worsens as the disease progresses, potentially leading to falls and subsequent disability (Zhang et al., 2022). Additionally, the study by Del Din et al. (2019) demonstrated that gait disturbances can be observed approximately four years before diagnosis. Gait analysis in single-task conditions identified the following changes: decreased gait speed, reduced stride length, diminished arm swing amplitude, and increased interlimb asymmetry and gait variability (Del Din et al., 2019; Zhang et al., 2022). Del Din et al. (2019) suggest that these may be among the earliest symptoms of Parkinson's disease. Introducing a dual-task paradigm to gait in early-stage Parkinson's patients significantly reduced gait speed, decreased stride length, increased support and swing phase duration, and increased cycle time variability (Zhang et al., 2022).

Raffegeau et al. (2019) report that the progression of Parkinson's disease affects dual-task gait such that patients with a gait speed higher than 1.1 m/s under single-task conditions experience a greater reduction in gait speed during dual-task walking compared to patients walking below 1.1 m/s under single-task conditions.

Monaghan et al. (2023) indicate that the gait of Parkinson's patients who experience freezing of gait (FOG) differs from those who are free of FOG in terms of higher dual-task effects on measures such as foot angle at ground contact and its variability, stride length, and arm swing range of motion. Researchers suggest that dual-task gait methodology can help identify individuals most susceptible to dual-task walking deficits in daily life and optimal candidates for dual-task gait training.

10.6.3 Dual-task gait assessment in orthopedic patients

There is significant interference between cognitive load and motor tasks in individuals with knee osteoarthritis (Hamacher et al., 2016; Abdallat et al., 2022). A marked increase in the dual-task effect has been noted. Furthermore, pain affected motor performance in patients with knee pain, indicating that many of these patients do not seem to have the cognitive capacity to manage dual tasks without altering either cognitive or motor abilities. It appears that these individuals walk with greater compensatory executive control and less automatism. Conversely, a reduction in pain intensity was associated with an decrease in dual-task effects, suggesting that such a decrease would reduce the risk of tripping and that pain has a detrimental impact on motor-cognitive interaction (Hamacher et al., 2016; Abdallat et al., 2022).

Hamacher et al. (2014) compared dual-task gait in healthy individuals and those experiencing back pain. Higher gait variability indices were observed in patients suffering from back pain. The authors suggested that chronic pain reduces the motor-cognitive capacity to perform dual tasks. Furthermore, they postulated that the harmful effects are caused by central mechanisms, where pain disrupts executive functions, which in turn may contribute to an increased risk of falls. Yogev-Seligmann et al. (2008) noted that the prefrontal cortex is involved not only in executive functions but also in pain processing and prioritizing tasks that require attention (Yogev-Seligmann et al., 2008; Nguyen et al., 2023).

Although the number of publications on dual-task gait assessment in orthopedics and traumatology is significantly smaller than that concerning the elderly or neurological patients, it appears that the dual-task paradigm has important diagnostic value for orthopedic and traumatology patients. It allows for the assessment of gait under conditions similar to daily life environments and may also contribute to identifying patients at high risk of falls. Further research is needed to identify conditions with high dual-task effects, determine the causes of such changes, and develop physiotherapy programs aimed at restoring efficient gait under dual-task conditions.

10.6.4 Application of dual-task gait assessment in sports medicine

Both daily activities and sports necessitate the simultaneous coordination of motor and cognitive tasks by the central nervous system (Howell et al., 2018). During gait, the CNS must receive and process sensory information from the musculoskeletal and vestibular systems along with visual stimuli, manage muscle work, and control the influx of information from the surrounding environment, all while managing additional motor and/or cognitive tasks (Socie & Sosnoff, 2013). During sports activities, the nervous system oversees motor tasks related to locomotion and additional activities (e.g., catching a ball), as well as cognitive tasks related to the strategy employed by the athlete. Dual-task gait assessment can enhance sports medicine by evaluating the allocation of attention in both cognitive and motor domains (Howell et al., 2018). The diagnosis and training of dual-task gait is a new but rapidly evolving field in sports medicine. The assumption that correct gait is a prerequisite for initiating the return-to-running process is already a standard in rehabilitation protocols (Cole, 2016). It seems that restoring the ability to perform dual-task gait may be an important step in returning to training, especially in sports that combine locomotion with additional tasks.

Many publications on the use of dual-task gait assessment in sports medicine relate to concussion. Khurana and Kaye (2012) indicate that concussion is a common injury in contact sports such as American and Australian football, rugby, soccer, boxing, wrestling, basketball, field hockey, and lacrosse, presenting a significant challenge for healthcare professionals working with athletes. Research conducted by Howell et al. (2018) on dual-task gait in athletes post-concussion showed that those who exhibited reduced gait speed under dual-task conditions were at a higher risk of injury upon returning to sports. It is noteworthy that the assessment using the Post-Concussion Symptom Scale did not correlate with the extent of dual-task gait disturbances. This suggests that dual-task gait assessment can provide unique and significant information regarding functional recovery after injury (Howell et al., 2018).

Results from dual-task gait assessments indicate gender differences. Adolescent females who sustained concussions were observed to have a lower Dual-Task Effect on cadence compared to males (Howell et al., 2017). This highlights that conducting assessments measuring attention allocation in cognitive and motor domains can provide valuable new data, allowing for more individualized physiotherapy and return-to-training processes for athletes. Lee et al. (2013) emphasize the role of dual-task gait assessment as a diagnostic method that identifies subtle physical and cognitive impairments, which may not be detected by traditional assessment strategies.

Another common injury among athletes is the rupture of the anterior cruciate ligament (ACL) of the knee. This type of injury presents numerous challenges for the medical and coaching teams, starting with the surgical reconstruction of the knee, guiding the athlete through the rehabilitation process, and ensuring a safe return to sports training and competition. Gait can be impaired due to symptoms caused by the ligament damage itself or the consequences of the surgical procedure (pain, swelling, decreased muscle strength). The ACL undergoes significant stress during gait, particularly during the swing phase (Brinnlle et al., 2022).

Individuals with anterior cruciate ligament (ACL) injuries and those who have undergone ACL reconstruction show poorer performance in dual-task gait assessments compared to healthy individuals. This manifests as lower efficiency in performing cognitive tasks and reduced locomotion speed (Abdall at al., 2020; Ness et al., 2020). The cause of these changes may stem from damage to the proprioceptors located in the ACL, which detect changes in tension, speed, acceleration, and direction of movement, and allow for the subconscious determination of the knee joint's position in space (Dhillon et al. 2012).

Kapreli et al. (2009) assert that ligament damage leads to disturbances in neuromuscular control, affects central programs, and consequently impacts motor response, causing significant dysfunction of the affected limb. Brain activation studies using functional magnetic resonance imaging indicate that anterior cruciate ligament (ACL) damage may result in central nervous system reorganization, suggesting that such damage can be considered neurophysiological dysfunction rather than a simple injury to the peripheral musculoskeletal system (Kapreli et al., 2009). Patients with anterior cruciate ligament deficiency had diminished activation in several sensorimotor cortical areas and increased activation in 3 areas compared with controls: presupplementary motor area, posterior secondary somatosensory area, and posterior inferior temporal gyrus. It appears that during walking under conditions of an additional cognitive task, sensory information deficits are compensated for by the involvement of additional areas of the nervous system, which reduces the available attentional resources for performing both tasks simultaneously. As a result, this leads to a deterioration in the efficiency of walking or the additional task.

Abdalla et al. (2020) concluded that the utilization of dual-task paradigms holds the potential to enhance and implement new strategies for rehabilitation programs and various therapeutic options for individuals with anterior cruciate ligament (ACL) injuries.

The potential and challenges for dual-task gait assessment in sports medicine

It seems that dual-task gait assessment has the potential to complement the diagnostics of athletes by providing the ability to allocate attention to both motor and cognitive domains. It allows for the evaluation of motor control in more challenging multitasking conditions, which closely resemble the demands during sports activities. However, it is important to bear in mind that dual-task gait represents a lesser challenge compared to actual sports activities. This methodology enables the monitoring of improvement in dual-task gait, where optimal quality appears to be a significant element in physiotherapy, influencing proper locomotion in daily life and a safe return to sports activities. Finally, dual-task training may yield greater benefits compared to single-task training in terms of skill development in sports (Lee et al., 2013).

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