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# Faculteit Revalidatiewetenschappen

master in de revalidatiewetenschappen en de kinesitherapie

***Masterthesis***

***Proactive Gait Adaptability in Healthy Older Adults: A Pilot and Feasibility Study***


**Jarne Fastenaekels**
**Seppe Wellens**


Scriptie ingediend tot het behalen van de graad van master in de revalidatiewetenschappen en de kinesitherapie, afstudeerrichting revalidatiewetenschappen en kinesitherapie bij musculoskeletale aandoeningen


**PROMOTOR :**
Prof. dr. Pieter MEYNS

**BEGELEIDER :**
Mevrouw Elisabeth VAN DER HULST


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# Situational context

Fall-related incidents increase with advancing age and are a major contributor to various health complications and elevated morbidity among older adults (Prudham & Evans, 1981; Tinetti et al., 1988). Approximately 28% of community-dwelling older individuals experience at least one fall each year, highlighting the need for effective preventive strategies (Prudham & Evans, 1981).

Previous research has shown that various types of exercise, including balance and/or strength training, can effectively reduce the risk of falling within this population. The effects could be broadly generalized within a population of community-dwelling older adults (Sherrington et al., 2017). However, evidence regarding the long-term sustainability of these effects in real-world settings is still limited (Hamed et al., 2018).

Gait Adaptability Training (GAT) may be a more promising alternative. During this type of training, individuals try to avoid environmental challenges by proactively adapting their gait. Previous research demonstrated that GAT could lead to a significant decline in fall rates within older adults (Nørgaard et al., 2021). Nonetheless, supporting evidence to establish comprehensive guidelines regarding optimal training principles are still required (Nørgaard et al., 2021).

This master's thesis was conducted within the framework of the course *Verdiepende Wetenschappelijke Stage en Masterproef*, within the Rehabilitation Sciences and Kinesitherapy program, with a focus on the research domain of gait and balance. The project is embedded within an ongoing doctoral study by Ms. Liset van der Hulst, with project code R-12956, entitled The effectiveness and generalizability of innovative task-specific training to teach older people skills that make them more resilient against falls (Research). This project runs from October 1st 2022 to September 30th 2026.

The research for this master's thesis was conducted using the CAREN- and GRAIL-systems at Hasselt University and Maastricht University. The following research questions were formulated by the students, in consultation with the supervisor: What is the effect of varying task settings (e.g., object size, approach speed, and appearance time) on overall proactive gait adaptability task difficulty? What is the impact of the combined effects of these settings on task complexity?

This study involves a pilot and feasibility study in healthy older adults aged 65 years and above. It serves as a preparation for a future RCT evaluating the effectiveness and transferability of various task-specific interventions, including GAT, with the goal of reducing fall risk in older adults.

The master's thesis was conducted in duo by Fastenaekels Jarne and Wellens Seppe. Both students contributed collaboratively as well as individually. Jarne Fastenaekels was primarily responsible for drafting the initial versions of the abstract, introduction and results section. Seppe Wellens was primarily responsible for writing the first drafts of the situational context and methodology. Both students were responsible for proofreading and editing each other's work, consistently providing suggestions to optimize various parts of the thesis. Jarne Fastenaekels also conducted the statistical analysis and designed the corresponding tables. Seppe Wellens assisted in preparing the dataset and conducting the statistical analysis. In addition, he contributed to the data collection under the supervision of Ms. van der Hulst. The discussion section was developed collaboratively, with both authors contributing equally. For the second draft, each student revised the sections for which they were primarily responsible. The discussion section was jointly reviewed and modified. Throughout the entire process, meetings were regularly scheduled and both students maintained regular communication to ensure alignment and consistency.

# Proactive Gait Adaptability in Healthy Older Adults: A Pilot and Feasibility Study

Master's thesis - Faculty of Rehabilitation Sciences & Physiotherapy

**S. Wellens & J. Fastenaekels**

## 1. Abstract

**Background:** Falls are a major global public health concern among older adults, causing injuries, hospitalisations, and fatalities. Age-related declines in sensory and motor functions impair balance, increasing the risk of falls. Proactive gait adaptability training (proactive GAT) could be a promising intervention to mitigate this risk, although the optimal task settings (e.g., obstacle size, approach speed and appearance time) are still insufficiently explored.

**Objectives:** The purpose of this study is to examine how varying task settings - such as obstacle size, approach speed and appearance time - affect proactive gait adaptability-task difficulty in older adults.

**Methods:** Using the CAREN-/GRAIL-system, this study evaluated gait adaptability in healthy older adults. Each participant completed 18 randomized treadmill trials with virtual obstacles (varying in obstacle size, approach speed and appearance time). The number of virtual obstacles hit were determined through video analysis and was used to determine the difficulty of the trial.

**Results:** The participants were 73.6 ± 5.5 years of age and were 55% male and 45% female. Only the trials combining the largest obstacle size and fastest approach speed (Trial 15 and 18) elicited significantly more hits than the reference trial, indicating higher difficulty. All other trials showed no significant increase in the number of blocks hit.

**Conclusion:** This pilot study shows that only combined manipulation of object size and approach speed significantly increases task difficulty, suggesting single-parameter changes may be insufficient.

**Keywords:** feasibility study; fall prevention; gait adaptability; older adults; avoiding obstacles.

## 2. Introduction

Falls are one of the primary causes of injury, hospitalisation and even death among older adults. Due to the continuously ageing population, falls and their consequences have emerged as a global public health concern (Ambrose et al., 2013; Gerards et al., 2017; Stevens et al., 2008).

In 2017, in Western Europe, an estimated 11.7 million adults aged 70 and older sought medical attention for injuries. Among these, 8.4 million (71.9%) cases were attributed to fall-related incidents, with Belgium reporting the highest fall incidence rate (19634 per 100000) (Haagsma et al., 2020).

The high prevalence of falls in older adults can be attributed to numerous physiological changes that occur with aging. Older adults often suffer not only from motor, but also from sensory dysfunctions that increase their risk of falling. These sensory impairments typically involve visual, vestibular, or proprioceptive impairments (Völter et al., 2021).

Visual changes influencing balance can result from factors such as diminished depth perception, a narrowed field of view, reduced visual acuity, decreased light sensitivity, and impaired visual tracking capabilities (O'Connell et al., 2017; Wang et al., 2024). Age-related visual changes can make it challenging for older adults to estimate the distance between themselves and surrounding objects accurately, and may lead to misjudging steps (Grant et al., 2021; Wang et al., 2024).

The vestibular system provides constant feedback to the brain about our orientation in space. This system plays a predominant role in detecting accelerations, gravity and changes in head position (Wang et al., 2024). Age-related changes in the vestibular system can contribute to an increased risk of balance impairments, dizziness, and falls among older adults (Jahn, 2019; Wang et al., 2024).

Proprioception, the ability to perceive the body’s position, movement and orientation in space, is enabled by specialised sensors in the muscles and tendons, called proprioceptors (e.g., muscle spindles and Golgi tendon organs). Proprioception in older adults declines with age (Boisgontier et al., 2016). This decline may reduce accuracy in detecting joint angles and muscle lengths, impairing the brain's ability to coordinate movements with precision (Boisgontier et al., 2016).

These sensory changes and the brain’s ability to re-weight these inputs are critical to provide accurate information to the motor control system (Bugnariu & Fung, 2007). Without them, both proactive and reactive balance control are compromised (Caetano et al., 2016; Peterka, 2002).

Gait Adaptability Training (GAT) has been shown to enhance both proactive and reactive balance control, thereby minimizing fall risk (Nørgaard et al., 2021; Wang et al., 2020). During GAT, participants practice making quick and precise voluntary adjustments to their gait patterns in response to environmental challenges (Nørgaard et al., 2021). GAT can be categorized into two training types: (1) reactive GAT (e.g., responding to unexpected physical perturbations) and (2) proactive GAT (e.g., avoiding incoming virtual obstacles) (Wang et al., 2020; Weerdesteyn et al., 2018). This pilot and feasibility study will focus primarily on proactive GAT.

Although proactive GAT is acknowledged as an effective method for improving proactive balance control, scientific evidence on optimal training parameters (e.g., obstacle size, obstacle speed and appearance time of the obstacle) are still lacking (Nørgaard et al., 2021). Most Randomized Controlled Trials (RCT's) do not specify particular parameters (Nørgaard et al., 2021); others indicate alterations in obstacle size or available reaction time based on the participant, without further explanation (Mirelman et al., 2016). Other studies use physical 3D objects (in contrast to 2D, virtual objects) which cannot be easily tailored in size, only in appearance time and approach speed (Wang et al., 2020). The absence of standardization hinders comprehensive systematic comparisons across studies.

This is a pilot and feasibility study in preparation for a subsequent RCT evaluating the effectiveness and transferability of various task-specific exercises, including GAT, in reducing fall risk among older adults. The purpose of this pilot and feasibility study is to examine how varying task settings (e.g., object size, approach speed, and appearance time) affect overall proactive gait adaptability task difficulty and to evaluate the impact of the combined effects of these settings on task complexity. Our hypotheses are that (1) increasing obstacle size, increasing obstacle approach speed, and decreasing response time will each increase task difficulty, and (2) combinations of these manipulations will interact significantly to increase difficulty even further. Conducting this study in a smaller sample not only allows for the identification and resolution of potential challenges during the performance of the proactive gait adaptability task, but also provides valuable insights into its practicality and feasibility before the subsequent RCT.

## 3. Methods

## 3.1 Study design

This pilot and feasibility study was conducted in healthy, community-dwelling older adults aged 65 and older. Participants performed a proactive gait adaptation task in a Computer Assisted Rehabilitation Environment (CAREN; Motekforce Link, Amsterdam, The Netherlands) or in the Gait Real-time Analysis Interactive Lab (GRAIL; Motekforce Link, Amsterdam, The Netherlands) during which they needed to avoid virtual obstacles projected onto a treadmill.

This study was conducted at the University Hospital in Maastricht, The Netherlands and at the University of Hasselt, Belgium. The study was approved by the Ethics Review Committee Health, Medicine and Life Sciences (FHML-REC) of Maastricht University (FHML-REC/2024/034 approved on April 16, 2024) and by the Committee for Medical Ethics UHasselt (B1152024000019 approved on November 2, 2024) in accordance with the Declaration of Helsinki.

## 3.2 Participants

Healthy community-dwelling older adults were recruited through flyers distributed at the University of Maastricht and Hasselt, Maastricht UMC+, local fitness and community centres, and posts on social media and websites like *testhelden* (www.testheldmaastricht.nl). Participants aged 65 years or older were eligible for inclusion in this pilot and feasibility study. Exclusion criteria included neurological, sensory, neuropathic, vestibular, or musculoskeletal conditions that adversely affect balance, as well as a history of severe injury and/or surgery to the lower extremities. Participants self-reported whether they were healthy or not. The examiner verbally verified the inclusion and exclusion criteria before the start of the measurements.

## 3.3 Sample size calculation

The aim was to recruit a minimum of 10 participants for this study to provide sufficient feasibility data. To verify whether this sample would provide enough power for the statistical analysis, a sensitivity power analysis for a one-way repeated measures ANOVA was conducted using GPower (Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2021). GPower Version 3.1). Assuming a sample size of 10 participants and 18 repeated measurements per participant, a significance level of 0.05, a correlation among repeated measures of 0.8, and no nonsphericity correction, the analysis indicates that a minimal detectable effect size of 0.15 can be identified with 80% power.

## 3.4 Informed consent

Prior to signing the informed consent, the participant was provided with a comprehensive explanation of the study's content and objectives. The examiner explicitly stated that the participant could withdraw from the study at any given moment without providing any reason. This was followed by an introduction to the CAREN-/GRAIL-system to ensure a clear understanding of its purpose and functionality.

## 3.5 Apparatus

The proactive gait adaptability task was performed on the CAREN or the GRAIL (see Figure 1). The CAREN-system consists of an instrumented dual-belt treadmill, with integrated force plates, mounted on a six-degrees-of-freedom movable platform. The GRAIL-system consists of an instrumented dual-belt treadmill with integrated force plates. The GRAIL platform can either move sideways or produce an uphill or downhill inclination. Both systems are equipped with a three-dimensional motion capture system with 12 cameras (Vicon Motion Systems, Oxford, UK), three two-dimensional video cameras, an overhead projector, a 180° immersive visual display, and an overhead safety harness to ensure participant safety during the task. D-Flow software was used to control the systems and to store the collected data. MATLAB (2024B, The MathWorks, Inc., Natick) was used to process the data and the output was stored in Excel files.

**Figure 1**

*GRAIL- and CAREN-system*

*Note. GRAIL on the left side and CAREN on the right side (Medical, 2025).*

Six reflective markers were precisely attached to the participant's skin or clothing at predetermined locations: spinous process of the seventh cervical vertebra, middle of the sacrum, right and left greater trochanter and nail of the right and left hallux. The three-dimensional coordinates of the reduced marker model were recorded by the Vicon motion capture system at a frequency of 100 Hz. Marker trajectories were filtered by a lowpass, second-order, zero-phase Butterworth filter with a 12 Hz cut-off frequency (McCrum et al., 2020). Previous research has shown that, in comparison to a full-body kinematic marker model, this reduced model is appropriate for measuring dynamic stability parameters, including the extrapolated center of mass (XCoM), within a wide range of age groups, including older adults (Süptitz et al., 2013). The XCoM allows assessment of dynamic stability in stable walking and incorporates both the current position of the center of mass (CoM) and its velocity (Hof, 2008; Hof et al., 2005).

## 3.6 Protocol

Prior to the start of the protocol, the examiner recorded the participant's demographic and anthropometric information, including age, sex, height, weight, foot length and right and left leg length. Height was measured without shoes, foot length was measured with shoes and leg length was measured from the greater trochanter to the lateral malleolus.

The test protocol started with the calibration of the three-dimensional motion capture system and force plates. System calibration was standardized according to the description provided in the Motek CAREN manual (Motek Medical B.V., CAREN Extended System Manual with Gait 2.0 (E2M platform), Version 13.0, Houten, The Netherlands, User manual, Oct. 28, 2021). An identical protocol was applied for the GRAIL-system.

This was followed by a familiarisation period in which the participant walked for eight minutes on the treadmill. The goal was, on one hand, to familiarise the participant with walking on a treadmill, and on the other hand, to determine the stability-normalized walking speed (SNWS). The method described by McCrum et al. (2019) was applied to calculate each participant's SNWS. The objective of this procedure was to equalize gait stability among all participants during the task. Research has shown that walking at a predetermined speed leads to greater variation in margin of stability (MoS) between participants in unperturbed and perturbed walking, compared to participants who walked on the SNWS (McCrum et al., 2019). The MoS, a commonly used metric to assess dynamic stability, was determined by evaluating the position of the XCoM relative to the anterior border of the base of support (BoS). The XCoM is defined as the vertical projection of the CoM position, augmented by a velocity-dependent term scaled by the factor $\sqrt{(l/g)}$, in which $l$ is leg length and $g$ represents the gravitational acceleration (Hof et al., 2005). The walking speed of the familiarisation period started at 1.0 meter per second and increased three times by 0.2 meters per second every two minutes, reaching 1.2, 1.4, and 1.6 meters per second. At each speed, the mean anteroposterior MoS at foot touchdown was calculated over the final 10 steps. The SNWS corresponding to a mean MoS of 0.05m was used in this study. According to previous research, this value is considered achievable by healthy adults across a wide age range (Bierbaum et al., 2010, 2011; Süptitz et al., 2012).

The MoS values were derived in MATLAB (2024B, The MathWorks, Inc., Natick) using the XCoM concept as described by Hof et al. (2005), with the anteroposterior MoS defined as the distance between the anterior border of the BoS (i.e. the horizontal component of the toe's projection onto the ground from the corresponding limb) and the XCoM at the moment of foot touchdown.

Prior to the proactive gait adaptability task, participants completed several additional assessments that were not relevant to the current study. These included an active control task and an auditory stroop task, followed by a short break.

The proactive gait adaptability task lasted up to 12 minutes and consisted of walking on the treadmill and avoiding white blocks projected on the treadmill surface. Each block matched the width of a single treadmill belt. The aim was to hit as few blocks as possible. Different task settings and combinations were tested: the size of the projected blocks, the speed at which the blocks approached and the appearance time of the blocks. Size of the blocks varied between 0.5, 1 or 1.5 x the foot length. The speed of the approaching blocks varied between 0.5, 1 or 1.5 x the treadmill speed. Appearance time varied between one or two strides in advance. In total, 18 trials with fixed parameters were tested in random order (see Table 1 for the parameter combination of each trial). Trial 1 was designated as the reference trial, as it was designed to be the easiest trial consisting of the smallest object size, the slowest approach speed, and the earliest appearance time. For each trial, six obstacles were projected onto the treadmill in a random sequence, but always three on the left side and three on the right side of the treadmill. Each participant encountered a total of 108 obstacles.

The test protocol ended with a verbal questionnaire (see Appendix A) which assessed the feasibility of the task and aimed to better understand the collected data. The questionnaire included open-ended questions and Likert scale items ranging from one to seven, regarding the clarity of instructions, the participant's enjoyment and levels of anxiety experienced during the task.

**Table 1**

*Trial Setting Combinations*

| Trial number | Object size | Object approach speed | Object appearance time |
|---|---|---|---|
| 1 | 0.5 | 0.5 | 0.5 |
| 2 | 0.5 | 1.0 | 0.5 |
| 3 | 0.5 | 1.5 | 2.0 |
| 4 | 1.0 | 0.5 | 2.0 |
| 5 | 1.0 | 1.0 | 2.0 |
| 6 | 1.0 | 1.5 | 2.0 |
| 7 | 0.5 | 0.5 | 1.0 |

**Table 1** (continued)

| Trial number | Object size | Object approach speed | Object appearance time |
|---|---|---|---|
| 8 | 0.5 | 1.0 | 1.0 |
| 9 | 0.5 | 1.5 | 1.0 |
| 10 | 1.0 | 0.5 | 1.0 |
| 11 | 1.0 | 1.0 | 1.0 |
| 12 | 1.0 | 1.5 | 1.0 |
| 13 | 1.5 | 0.5 | 2.0 |
| 14 | 1.5 | 1.0 | 2.0 |
| 15 | 1.5 | 1.5 | 2.0 |
| 16 | 1.5 | 0.5 | 1.0 |
| 17 | 1.5 | 1.0 | 1.0 |
| 18 | 1.5 | 1.5 | 1.0 |

*Note. Task settings varied across three factors: block length (0.5 ×, 1 ×, or 1.5 × foot length), approach speed (0.5 ×, 1 ×, or 1.5 × treadmill speed), and appearance time (1 or 2 strides in advance).*

## 3.7 Outcome measures

The primary outcome measure assessed during the proactive gait adaptability task was the number of blocks hit. A higher number of blocks hit indicates greater task difficulty. The number of blocks hit was determined by a single examiner through visual inspection of two-dimensional video recordings captured from the rear and lateral views of the participant. Additionally, the previously mentioned verbal questionnaire was administered as a secondary, qualitative outcome measure to investigate the feasibility of the task.

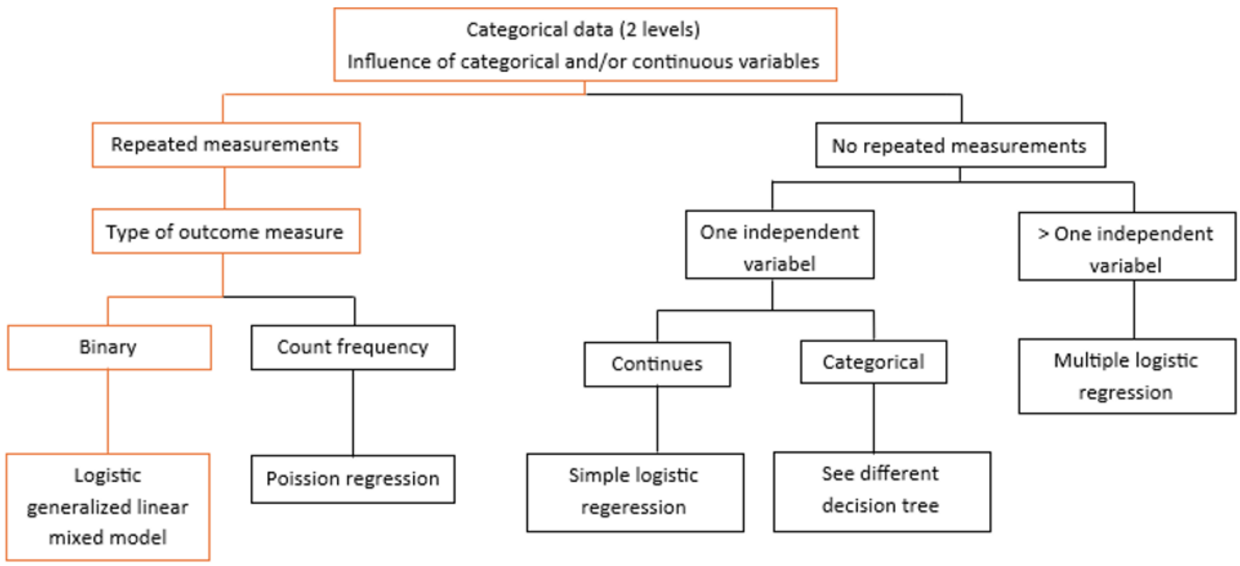
## 3.8 Data analysis

To analyse the effect of the independent variables (trial number, see Table 1) on the binary dependent variable (hit (1) or no hit (0)), a logistic generalized linear mixed model (L-GLMM) with a binomial distribution and logit link function was fitted (see Figure 2). Trial 1 was designated as the reference trial, as it was designed to be the easiest. Thus, variations in task complexity in following trials might be easily identified. Significance level was set at α = 0.05. To account for the repeated-measures structure, participant ID was used as a random effect. When a given measurement for a participant was missing, that single observation was removed from the analysis. However, all other available measurements from the same participant were maintained rather than excluding the participant completely.

At last, to examine the pairwise comparisons, a Tukey HSD-test was performed. This test systematically performs all possible pairwise comparisons (e.g., trials 1 with trial 2-18, trial 2 with trial 3-18, trial 3 with trial 4-18, …) and adjusts the significance threshold to account for the number of pairwise comparisons, thus minimizing Type I errors.

Statistical analyses were performed using JMP®, Version *17* (SAS Institute Inc., Cary, NC, 1989–2025).

**Figure 2**
*Decision Tree Statistical Analyses*




*Note. Orange indicates the path followed to the desired statistical analyses.*

## 5. Results

### 5.1 Exclusion of data

Initially, eleven healthy, community-dwelling older adults participated in this pilot and feasibility study (see Table 2). However, participants three and nine were excluded due to the absence of video recordings, caused by a technical issue with the video server, which made it impossible to determine the number of blocks hit. Additionally, due to technical issues, data from Trials 13-18 for participant one were missing and omitted from the analysis. For participant seven, data from Trials 1–3, 6–7, 9–10, 12–13, and 16–18 were missing and excluded.

**Table 2**

*Participant Characteristics*

| Characteristics | Mean | Standard deviation |
|---|---|---|
| Age (years) | 73.55 | ± 5.47 |
| Height (cm) | 165.68 | ± 6.38 |
| Weight (cm) | 70.45 | ± 13.76 |
| Foot length (cm) | 28.06 | ± 2.08 |
| Left leg length (cm) | 81.59 | ± 4.28 |
| Right leg length (cm) | 81.81 | ± 5.07 |
| Stability-normalized walking speed (m/s) | 1.09 | ± 0.14 |
| Sex (*n*) | Male (*n* = 6) | Female (*n* = 5) |

## 5.2 Logistic Generalized Linear Mixed Model (L-GLMM)

In order to perform the L-GLMM, all the assumptions are required to be met. Random intercept Best Linear Unbiased Predictors (BLUPs) were obtained for each individual, and their distribution was assessed for normality. A quantile–quantile plot indicated no significant deviations from the reference line. Overdispersion was evaluated via the Chi-squared test relative to degrees of freedom ($X^2/DF = 0.98$). Consequently, all assumptions were met.

Table 3 summarizes the estimated effect of each trial on the number of blocks hit, along with standard errors, p-values, and 95% confidence intervals. The intercept represents the reference trial, Trial number 1. Out of all the trials compared to the reference trial, only Trial 6, 15, and 18 showed significant variations; the remaining 14 trials showed no significant differences. Trial 15 and 18 produced a significant increase in blocks hit and Trial 6 was associated with a significant decrease in blocks hit. Notably, Trial 6 had the highest standard error relative to its estimated effect compared to all other trials. These results are further illustrated in Figure 3, which displays the boxplots for all 18 trials.

**Table 3**

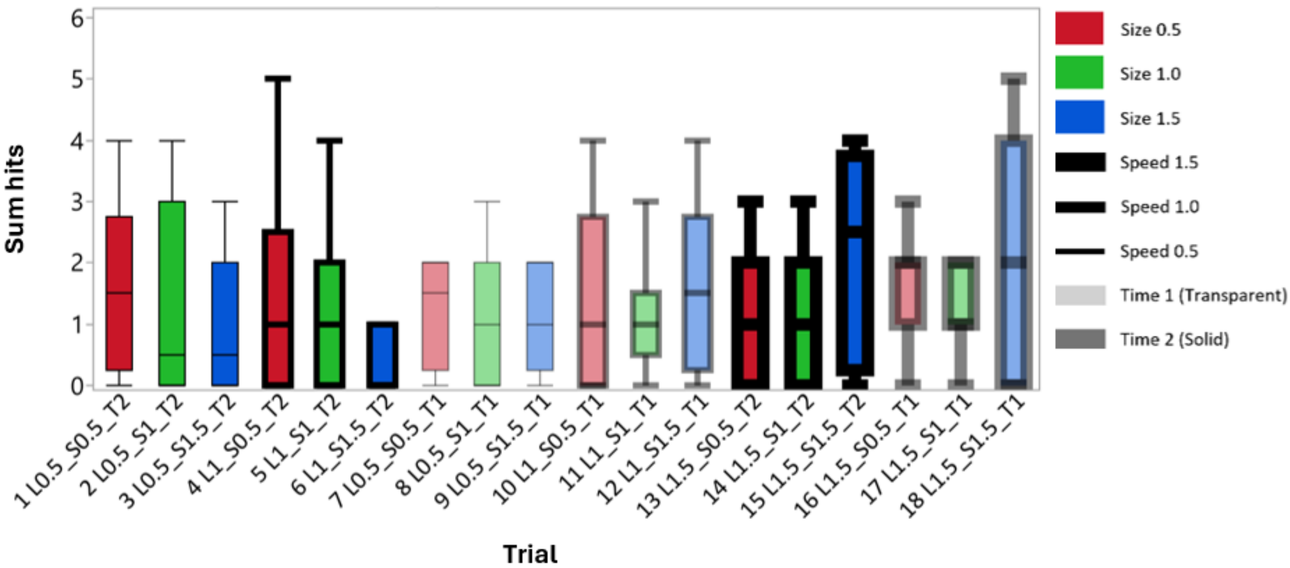
*Effects of Trials on Number of Blocks Hit*

| Trial nr. | Estimated effect | Std. error | p-value | 95% lower | 95% upper |
|---|---|---|---|---|---|
| Intercept | -1.29 | 0.20 | **.0002*** | -1.75 | -0.84 |
| 2 | 0.11 | 0.34 | .739 | -0.56 | 0.78 |
| 3 | -0.29 | 0.38 | .441 | -1.04 | 0.45 |
| 4 | 0.20 | 0.31 | .527 | -0.42 | 0.81 |
| 5 | -0.25 | 0.35 | .477 | -0.93 | 0.44 |
| 6 | -1.41 | 0.57 | **.014*** | -2.53 | -0.29 |
| 7 | -0.01 | 0.35 | .974 | -0.70 | 0.68 |
| 8 | -0.38 | 0.36 | .295 | -1.09 | 0.33 |
| 9 | -0.15 | 0.36 | .688 | -0.86 | 0.57 |
| 10 | 0.11 | 0.34 | .739 | -0.56 | 0.78 |
| 11 | -0.25 | 0.35 | .477 | -0.93 | 0.44 |
| 12 | 0.34 | 0.32 | .290 | -0.29 | 0.98 |
| 13 | -0.14 | 0.39 | .711 | -0.90 | 0.61 |
| 14 | -0.23 | 0.37 | .533 | -0.95 | 0.49 |
| 15 | 0.67 | 0.31 | **.029*** | 0.07 | 1.27 |
| 16 | 0.21 | 0.35 | .538 | -0.47 | 0.89 |
| 17 | 0.44 | 0.34 | .199 | -0.23 | 1.11 |
| 18 | 0.67 | 0.33 | **.042*** | 0.03 | 1.32 |

*Note. Abbreviations: nr = number, std. = standard*
**p<.05. **p<.01.*

**Figure 3**

*Boxplots of Scores for All 18 Trials*




*Note. Each trial is labelled on the y-axis as follows L = size (0.5 x, 1.0 x, or 1.5 x foot length); S = speed (0.5 x, 1.0 x, or 1.5 x treadmill speed); and T = appearance time (1 or 2 strides in advance). For example, Trial 1 = 1 L0.5_S0.5_T2.*

## 5.3 Tukey HSD

None of the pairwise comparisons, using the Tukey HSD-test, reached statistical significance. This was probably due to the high number of pairwise comparisons being made (adjusted p-values).

## 5.4 The questionnaire

Participants consistently interpreted the obstacle-avoidance task as "evading white blocks" and predominantly characterized it as entertaining and suitably difficult. Qualitative comments indicated enthusiasm and slight tension, especially when challenges arose suddenly or unpredictably, while genuine worry was minor. The instructions received a clarity rating of 6.8 out of 7, while some participants recommended clarifying whether to step over or around obstacles. The task generated positive engagement, induced moderate arousal without excessive fear.

# 6. Discussion

This pilot and feasibility study examined the effects of changing obstacle size, approach speed, and appearance time - individually and in combination - on proactive gait adaptability task difficulty and task complexity. These preliminary results will inform a forthcoming RCT designed to optimize gait-adaptability training in healthy older adults.

Only the trials combining the largest obstacle size and fastest approach speed elicited significantly more hits than the reference trial, indicating higher difficulty. In accordance with our second hypothesis, this suggests that concurrent increases in both obstacle size and approach speed contribute more substantially to task complexity than either parameter alone - contrary to our first hypothesis. Notably, varying appearance time did not appear to influence task performance.

These interpretations are consistent with prior research conducted by Mirelman et al. (2013). In their virtual reality-augmented treadmill training program for older adults, task complexity was systematically increased by simultaneously adjusting multiple parameters, including obstacle size, frequency, and approach velocity. Their training design implies the motor-cognitive system is more effectively challenged when multiple task elements are varied in combination, although this was not directly tested.

Findings by Harley et al. (2009) further support this interpretation, showing that older adults' performance in dual task obstacle crossing was influenced by both obstacle size and concurrent cognitive load. Age-related differences in stepping behaviour were most apparent when task demands increased along multiple dimensions. Importantly, they noted that cognitive interference effects only emerged once an attentional threshold was exceeded. This is particularly relevant to our finding that reduced appearance time - intended to increase time pressure - did not significantly affect task difficulty. Prior studies have shown that older adults exhibit slower reaction times and tend to delay responses to ensure movement accuracy (Hardwick et al., 2022; Salthouse, 1979; Smith & Brewer, 1995; Starns & Ratcliff, 2010). It is therefore possible that even the shortest appearance time in our study remained well within the adaptive limits of our participants' reaction times, even at the highest approach speeds.

Trial 6 – which consisted of a block size equal to foot length, an approach speed of 1.5 times the treadmill speed, and an appearance time of two strides in advance – resulted in significantly fewer hits than the reference trial, suggesting it was less difficult. This was unexpected, as the reference trial had been designed to be the easiest, with the assumption that no other condition would lead to fewer hits. However, due to the high uncertainty surrounding the estimated effect of this trial, these findings should be interpreted with caution.

Based on the questionnaire, the obstacle-avoidance protocol proved feasible for implementation within the target population. The assessment of instructional clarity was positive, suggesting that the procedural framework is comprehended effectively. Participant engagement remained consistently high and the difficulty level was suitable, provoking just mild arousal without excessive anxiety. These findings support the practical feasibility of the task design and procedural instructions for implementation in larger-scale trials.

## 6.1 Clinical relevance

These findings have direct relevance for developing fall-prevention interventions for older adults. By demonstrating that only the combination of the largest obstacle size and highest approach speed significantly increases task difficulty, clinicians can tailor gait-adaptability exercises to optimally challenge patients' proactive control without exceeding their ability. In practice, the results suggest that rehabilitation programs should manipulate at least two task parameters at the same time, rather than just size or timing, in order to produce meaningful training stimuli. Furthermore, the absence of increased difficulty as appearance time was reduced suggests that even rapid obstacle presentations may be safely introduced once patients have mastered more demanding size-speed combinations. Finally, implementing such dose-specific protocols may improve the transfer of training to real-world ambulation, reduce fall risk, and improve functional independence in the geriatric population. This latter statement should be investigated in future studies.

## 6.2 Strengths

This study has some methodological strengths. First of all, using SNWS across individuals, reducing inter-individual variability that commonly arises when walking speed is self-selected or predetermined (McCrum et al., 2019). Second, the randomized order of the 18 trials across all participants minimized learning and order effects, enhancing the internal validity of the task comparisons. Third, this pilot design allowed early detection and resolution of practical and technical issues - such as system malfunctions and data collection protocols - thereby informing the methodology of the subsequent RCT.

## 6.3 Limitations

Despite the strengths, this study has several methodological limitations. First, eligibility was based on participants' self-reported health status and verbal verification of the examiner, which led to the inadvertent inclusion of one participant who did not fully meet the criteria. Two types of bias may have also been introduced by the self-reporting. For example, external bias induced by social desirability or approval, may influence self-reporting data (e.g., the participant being ashamed about medical history). Moreover, recall bias may compromise the reliability of retrospective reports (e.g., injuries from the past) (Althubaiti, 2016). The fact that these exclusion criteria were not measured objectively may have contributed to sample heterogeneity. For example, previous research has found that age-related hearing loss correlates with heightened dependence on somatosensory input, leading to greater postural instability in challenging situations (Behtani et al., 2023). This variable was neither screened nor controlled for, potentially influencing the homogeneity of the sample.

Second, technical malfunctions of the CAREN-system led to incomplete datasets for participants one and seven. For this reason, individual observations with missing data were excluded from the statistical analysis. However, the available measurements from these participants were maintained to avoid unnecessary loss of data. This approach could potentially affect the current results, but was considered preferable to complete exclusion. To maintain continuity in data collection during CAREN-system maintenance, the GRAIL-system was used as an alternative. This deviation from the original study protocol was not foreseen.

Furthermore, the SNWS of participants one and six could not be automatically determined by D-flow due to technical malfunctions. Instead, the SNWS for these participants was estimated by a single examiner through live observation of the MoS in D-flow. This method may have led to a less accurate prediction of the SNWS, potentially resulting in slight deviations in gait stability among the participants (McCrum et al., 2019). This might increase or decrease the task difficulty.

Another issue concerning the SNWS is that it was computed during a cognitive low-load familiarisation trial but then utilized in a higher cognitive load gait-adaptability test (Rizzato et al., 2021). Participants with mild cognitive impairments may possess sufficient cognitive resources to maintain stability at their SNWS during the low-load familiarisation trial, matching the performance of cognitively healthy participants. However, when the cognitive demands rise - such as during the gait adaptability task - those with reduced cognitive reserve may no longer be able to cope effectively. The excessive load could overwhelm their cognitive capacity, resulting in an inability to sustain the same gait stability as the other participants, thus reintroducing inter-individual differences concerning gait stability (Divandari et al., 2023). The absence of objective cognitive assessments may have resulted in a heterogeneous sample, thereby potentially influencing the results.

Fourth, The GPower calculations mentioned before were based on a repeated-measures ANOVA design. These calculations indicated that a minimum sample size of 10 participants was required to ensure sufficient statistical power for the analysis. However, in the final analysis a L-GLMM with a binomial distribution was used. As GPower does not support L-GLMMs with binomial outcomes and random effects, it was not possible to verify whether the initially estimated sample size would be sufficient for this model. Consequently, caution is warranted when interpreting the results, as they may not translate to the bigger population and thereby potentially compromise the reliability and generalizability of the study findings.

At last, because this feasibility study is a component of a broader research project, the participants completed a number of other assessments prior to the gait adaptability task (e.g., an active control task and an auditory stroop task). The results might have been influenced by the physical, mental, or cognitive exhaustion brought on by these additional tasks.

## 6.4 Recommendations for future research

To enhance the methodological quality of future studies, it is recommended that participants' health status should be assessed using objective measures rather than self-reports. This method should minimize the potential risk of bias and makes sure the sample is as homogeneous as possible.

The application of the SNWS was used as recommended, but future research might benefit from determining the SNWS during a motor or cognitive dual-task to ensure a similar degree of difficulty, in terms of cognitive load, between the familiarisation period and the actual gait adaptability task.

Moreover, future research should include more difficult task settings. This could involve trials with greater block size, faster approach speed, and most importantly shorter reaction times. Implementing these more challenging parameters may further clarify the effects of the various parameters and their combinations on proactive gait adaptation.

Importantly, the current study investigated the effects of these different parameters within a population of healthy older adults aged 65 years and older. To fully understand the effects and clinical relevance of these task parameters on gait adaptability, it might be of value to investigate within clinical populations to determine whether similar patterns are observed.

Finally, a larger sample size is recommended in future research to ensure sufficient statistical power, especially when conducting a high number of pairwise comparisons.

### 6.5 Conclusion

This pilot and feasibility study provides preliminary evidence that only the combined manipulation of task parameters, specifically object size and approach speed, significantly increases task difficulty in a proactive GAT-task. Manipulating single parameters may be insufficient to consistently influence performance.

The obstacle-avoidance protocol proved feasible for implementation in the target population. Instructional clarity was favourable and the difficulty level was suitable, provoking only moderate arousal without excessive anxiety.

These findings will inform the design of a subsequent RCT aimed at the development of more effective gait adaptability training interventions for older adults.

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# 8. Appendix

Appendix A: Verbal questionnaire proactive gait adaptability task (English translation)

1. **Could you describe what you had to do?**
2. **What did you think of the task?**
3. **How did you feel during the task?**
4. **Could you elaborate on how you felt regarding nervousness, anxiety, and stress?**
5. **How clear were the instructions for the task?**

| Not at all clear | | | | | | Extremely clear |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| o | o | o | o | o | o | o |

6. **How enjoyable did you find the task?**

| Not enjoyable at all | | | | | | Extremely enjoyable |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| o | o | o | o | o | o | o |

7. **How tense did you feel during the task?**

| Not at all tense | | | | | | Extremely Tense |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| o | o | o | o | o | o | o |

8. **How anxious did you feel during the task?**

| Not at all anxious | | | | | | Extremely anxious |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| o | o | o | o | o | o | o |