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# THE MAIN PILLARS OF A PHYSIOTHERAPIST'S CONTRIBUTION TO DEVELOPING, IMPLEMENTING, AND ASSESSING METHODS DESIGNED FOR IMPROVING POSTURAL CONTROL IN OLD AGE

**Ph.D. thesis**

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## ABBREVIATIONS

| | |
|---|---|
| ADL | Activities of Daily Living |
| AI | Automaticity Index |
| ANOVA | Analysis of Variance |
| BBS | Berg Balance Scale |
| BMI | Body Mass Index |
| CAI | Cognitive Ambulatory Index |
| CFD | Compression of Functional Decline |
| CI | Confidence Interval |
| COP | Centre of Pressure |
| CV | Coefficient of Variation |
| EU | European Union |
| FAC | Functional Ambulation Category |
| FES-I | Falls Efficacy Scale - International |
| FIM | Functional Independence Measure |
| FoF | Fear of Falling |
| FRT | Functional Reach Test |
| HLE | Healthy Life Expectancy |
| HLY | Healthy Life Years |
| HU-BBS | Hungarian Berg Balance Scale |
| IADL | Instrumental Activities of Daily Living |
| ICC | Intraclass Correlation Coefficient |
| ICF | International Classification of Functioning, Disability and Health |
| $LOA_{95\%}$ | Limits of Agreement with 95% confidence interval |
| $MDC_{95\%}$ | Minimally Detectable Change with 95% confidence interval |
| NW | Nordic Walking |
| QoL | Quality of Life |
| SD | Standard Deviation |
| SEM | Standard Error of Measurements |
| TUG test | Timed ‘Up and Go’ test |
| WHO | World Health Organization |
| WWTT | Walking While Talking Test |

# The main pillars of a physiotherapist's contribution to developing, implementing, and assessing methods designed for improving postural control in old age

## 1. Introduction

### 1.1. Ageing societies

The population of developed societies, including Hungary, is ageing. Life expectancy is projected to reach 81.13 years by 2050 from 77.31 years today (Macrotrends, n.d.). In societies of developed countries both life expectancy at birth and at age 65 are indicators of lifespan getting longer. Longer life expectancy (both at birth and at age 65 and regarding both sexes), however, is not necessarily associated with increased time spent in good health (i.e. reduced morbidity) (Martinez et al., 2021).

Furthermore, longer life expectancy is more likely to increase the time spent in poor health, or at least poorer health (by increasing the number of diseases, i.e. with an increase in morbidity) (Choi et al. 2024). Chronic conditions, although cannot be healed, are becoming more successfully managed, with their survival rates improved due to advances in medical and health sciences, which results in a decrease in mortality. Consequently, how long we live is not necessarily in itself associated with a superior quality of life (European Health Expectancies Monitoring Unit, 2005; Eurostat, 2024). The quality of life (QoL), to a large extent, depends on the ability to continue living independently (Ho et al. 2023). In other words, QoL may depend on not being determined by being dependent on others. QoL in old age is rather determined by healthy life expectancy. Healthy life expectancy (HLE) is not years without disease, but life expectancy without disability or significant functional limitation. In the literature, this disability-free life expectancy indicator is also termed as healthy life years (HLY). It measures how many years people of a certain age are expected to live without disability. HLY as a measure of functional health status complements the conventional life expectancy measures. This adds a qualitative aspect (or another dimension) to the quantity of life lived (Welsh et al., 2021).

How long and in what quality we live our lives – with or without further reflection on how many descendants we live on in - is not only a key question for the individual, but it is also a societal issue.

The fertility rate is the average number of children born to a woman in her lifetime. With its fertility rate of 1.58 – a fertility rate below the self-reproduction rate of 2.1 –, Hungary shares the fate of the economically developed countries. The population is in decline (Organisation for Economic Co-operation and Development, 2022; Statista, 2023). Although our life expectancy improves, the degree of functional limitation may highlight a problem: we may live longer, but we are potentially less successful at 'compressing' the duration of functional decline; that is, a longer period of our later life becomes functionally limited (Gore et al. 2018). As our population ages, this may increase the risk that a growing proportion of the population will become functionally dependent. At the same time, a greater proportion of resources should be allocated to social and health services with limited financial resources. This dramatic situation today will worsen in the near future when even fewer young, active adults will be able to take on the role of supporting and managing an increasingly dependent and growing older population, requiring even more time, energy and resources. This may already place a heavy burden on society, but we should not be pessimistic about the future. Instead, the recognition that we need to change our mindset and move from an ageing society to the concept of a longevity society (Scott 2021) should be emphasised. On average in the EU, women aged 65 live 54% of their remaining life expectancy with functional disability, while men of the same age live 46% of their remaining life expectancy with functional disability. Hungary has worse indices for both sexes. At age 65, Hungarian women live 60%, while men live 53% of their life expectancy in dependence due to functional limitations (Organisation for Economic Co-operation and Development, 2023). Despite advances in medical and health sciences, the gap between healthy life expectancy and life expectancy is not narrowing (to the extent) as it would be expected (see Figure 1).

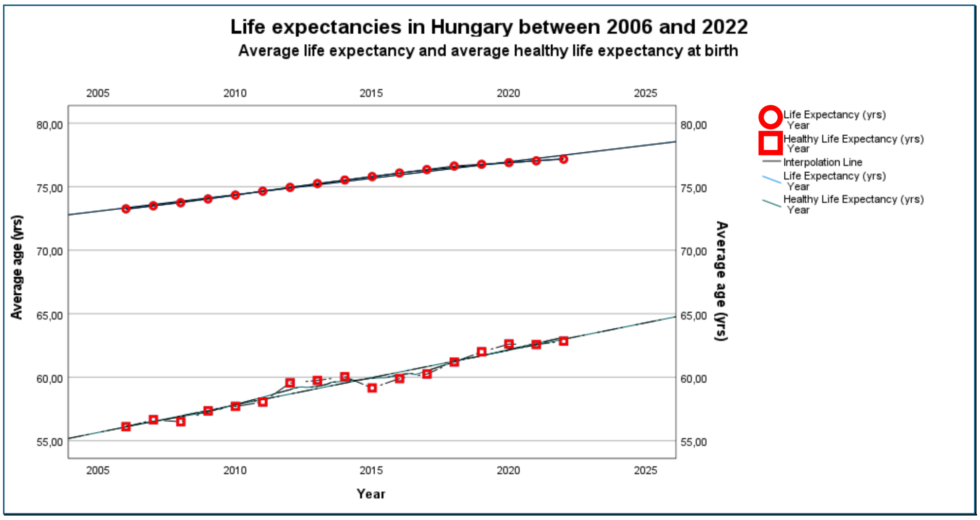


**Figure 1**. Life expectancy (at birth) and healthy life expectancy (at birth) (Hungarian data for the years 2006 to 2022) Own graph based on World Health Organization (WHO) data (World Health Organization, n.d.)

What key concepts and indicators of morbidity are relevant? (Rechel et al., 2020)

The term longer life expectancy refers to having more years to live; however, whether this is more years spent in good or bad health, or some combination of the two, is not necessarily clear (Spiers et al. 2021). Disease prevalence or self-reported health status data are all common measures of health status. Yet, if we want to determine how "healthy" an older person is, in line with the ICF (International Classification of Functioning, Disability and Health), it is best captured by measuring disability or functional impairment. Whether we focus on Europe as a whole or on a more specific area (Hungary, for example), the question if older people are living longer in better or worse health depends to a large extent on the measure used. Most surveys on ageing focus on functionality; namely independence during activities of daily living (ADLs) and instrumental activities of daily living (IADLs). These measures are used to quantify health status and measure changes over time. Even if there are substantial inequities in health care at older age across countries and within a specific country, it is clear that health systems are important contributors to increases in life expectancies, decreases in severe disability, better coping with chronic disease, as well as more sound and proper functioning (Rechel et al., 2020; Spiers et al., 2021).

## 1.2. Towards successful ageing

Over the past decades, the scientific community has made significant efforts to understand the biological basis of ageing and how to increase life expectancy. In recent years, however, the focus has increasingly shifted to extending the quality of old age. Approaches to characterising the quality of later life course are similar, yet slightly different.

All of these emphasise the nature of the condition at this stage of life with some kind of non-negative attitude (Lin et al. 2022; Menassa et al., 2023; Pocock et al., 2022). Successful ageing, healthy ageing, active ageing, positive ageing, productive ageing, vigorous ageing, optimal ageing, effective ageing, independent ageing, and harmonious ageing share this ‘positivity’. The first two (healthy and successful) are the most popular in Hungary.

### 1.2.1. The concept of healthy ageing

Health, as defined in the first page of the World Health Organization (WHO) basic document (World Health Organisation, 2020), encompasses physical, mental, and social well-being. This triple prerequisite indicates the importance of all three aspects in overall health. Also, it points out that health is not merely freedom from disease that enables this well-being. The WHO provides a definition for *healthy ageing* as well, as "the process of developing and maintaining functional capacity to enable well-being in old age" (World Health Organisation, 2021), which puts into perspective what is included in the concept of health. In old age, the prevalence of diseases increases by nature, but the higher incidence of (chronic) diseases per se is not necessarily an obstacle but can be merely a challenge to the older person’s perception of well-being. For some, health can be taken for granted; for others it must be actively protected, preserved, and prevented from turning into an inferior state. Both can be with or without limitations of ADL functions. This is in line with the idea that the prevalence of functional limitations is a better indicator of health in old age than the prevalence of chronic diseases.

Instead of *'compression of morbidity'* (Rechel et al., 2020) it might therefore be more appropriate or purposeful to speak of *'compression of functional decline'* or *'compression of disability'* (Figure 2) in the context of successful ageing (Gore et al., 2018). Compression of functional decline reduces the likelihood of over-dependence on others in later life.

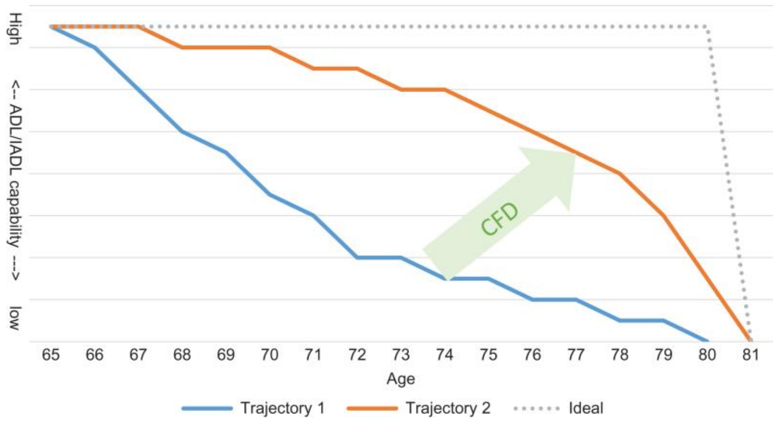


**Figure 2.** Hypothetical model of compression of functional decline (CFD) where the goal is to shift trajectory 1 toward the ideal, resulting in trajectory 2. (Source: Gore et al., 2018)

For this reason alone, efforts to promote functional independence of the older population are therefore a priority.

Lifestyle medicine professionals and their proponents aiming for the prevention of the onset of chronic diseases (such as cardiovascular disorders, diabetes, obesity) are committed to reversing the actual causes of these chronic diseases. These conditions are also considered to be the underlying causes of health impairments responsible for disability and functional dependence in later life (Egger, 2018; Grega et al., 2023).

The main pillars of lifestyle medicine are consuming whole food, following a plant-predominant diet, establishing and maintaining connectedness – i.e. nurturing social networks or connections, a sufficient amount and quality of so-called restorative sleep, mental health management (avoidance of distress), avoidance of harmful substances (in particular alcohol, tobacco), and regular, consistent physical activity.

Unfortunately, for all its welcome, cost-effective recommendations, lifestyle medicine proposes a number of less feasible solutions for the ageing population in Hungary. The Hungarian population shows dismal statistics, whether in terms of conscious, whole-food nutrition, social isolation, or poor sleep quality. There are also dismal figures for mental health condition, the consumption of harmful substances, and the existence of usual physical inactivity.

Referring to Rechel et al. (2020), the combination of healthier lifestyle and advances in medical and healthcare sciences and prevention may explain the reduced morbidity and the improvement in mortality and related consequences. It is of utmost importance that we pursue this path in order to ensure that older adults can fulfil their functional capacity and age successfully (Rechel et al., 2020).

They need to be enabled to reach their full potential, to their own benefit and to the benefit of society as a whole (Little, 2017).

There are ways and means of regaining fitness or maintaining and increasing physical activity; however, in case of older people, the development of various procedures and interventions that is shown to be safe, effective, and even cost-effective is still a professional challenge.

It is therefore worth addressing additional physical activity programmes to ensure that people can choose from a wide range of options.

### 1.2.2. Concept of successful aging

While Becker's (1943) idea[1] can be mentioned as a forerunner, Havighurst coined the phrase "adding life to the years", being the first using these words to describe the term ‘successful ageing’ (Becker, 1943; Havighurst, 1961; Rowe & Kahn, 1987).

According to Moody, “life satisfaction, longevity, freedom from disability, mastery and growth, active engagement with life, and independence” are the ‘key ideas’ for the concept of this successful process (Moody, 2005). Not strictly synonymous with it, but as a precursor to it, successful ageing has been called ‘vital ~’, ‘active ~’, or ‘productive ageing’ (Estebsari et al., 2020). These latter terms suggest that later life can be a period of sustained health and vitality, through which older people make a ‘valuable contribution’ to society, rather than a period of stress and strain in their lives, burdened and determined by disease and dependency (Achenbaum, 2001; Peter et al., 2014).

[1] …[i]t is to be hoped that the next century will add “life to years” as the last one has “years to life” (Becker, 1943)

To clarify the meaning of successful ageing, the components of successful ageing must be determined (Estebsari et al., 2020). A 2006 comprehensive review found 29 definitions in research on the correlates and determinants of successful ageing and interventions to promote successful ageing (Depp et al., 2006). Not only is physical functional capacity one of the most frequently listed components; it leads the list, appearing in 90% of publications. Physical functional capacity is measured in two ways. One measures the degree of difficulty an older person has in carrying out basic activities of daily living and the extent to which they require external assistance. In Hungary, the Barthel Index, the Katz Index, and the functional independence measure (FIM) scales are used. Other methods objectively measure the performance of these basic functional movements under standard(ised) conditions, for instance, walking speed, grip strength, standing up from a chair, and balancing ability.

Even though the notion of *'successful ageing'* is becoming increasingly frequent and prominent in public health discourse (Estebsari et al., 2020), it must be argued that it is not acceptable to consider health in old age as a matter of individual choice alone (Katz & Calasanti, 2015). While there is general support for a certain personal responsibility for health, this cannot be taken to mean that age-related diseases can simply be prevented by healthy lifestyle choices (Harris et al., 2016). Whether older people make individual choices to live a healthier or a less limited later life functionally, to promote more active lifestyle choices for older people, including their participation in regular physical activity programmes is still feasible.

Either in terms of items of different self-reported questionnaires aiming at measuring health status, or in terms of popular measures of disability or functional impairment, it is widely accepted that one of the major contributors/determinants of healthy life expectancy is the robustness of postural control. However, as age advances, postural control declines and contributes to a worse self-perceived general health.

## 1.3. Human postural control and gait

### 1.3.1. Adult postural control

Postural control is the process of regulating the spatial position of the body for both stability and orientation (Horak, 2006; Ivanenko & Gurfinkel, 2018; Leisman et al. 2016; Pollock et al., 2000; Shanbhag et al., 2023; Shumway-Cook & Woollacott, 2016a).

It refers to: 1) on the one hand, controlling that the body's centre of gravity remains above the supporting surface under both static and dynamic conditions (i.e. keeping the vertical projection of the centre of gravity within the so-called stability limit during voluntary maintenance of a body position or during movement); 2) on the other hand, controlling the relation of each body segment to one another and to the environment at any moment in time, in order to achieve the purpose of the movement (i.e. each segment is continuously adapted to the changing conditions of the environment).

As defined above, postural control is influenced by a combination of three factors:

1) the individual; 2) the purpose of the individual's action, i. e. what the task is; 3) and the characteristics of the environment in which the action takes place.

This is illustrated by Shumway-Cook and Woollacott's popular Venn-diagram of three interlocking circles (Nagy, 2017; Shumway-Cook & Woollacott, 2016b).

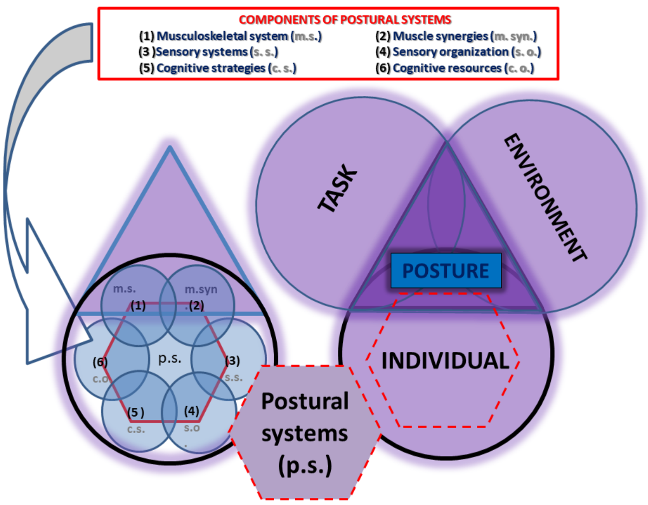


**Figure 3.** The components of postural systems and the relationship between factors affecting posture (based on Shumway-Cook & Woollacott’s original figure (Shumway-Cook & Woollacott, 2016b, p.157) re-edited by András Simon)

In terms of the individual capabilities, postural control is based on the properly coordinated functioning of several organ systems.

In the followings some of the elements of this model, called the system model, will be reviewed.

*Muscle synergies*, also known as balance strategies, are the activation of muscle groups in a specific sequential order. These strategies are used to control our centre of gravity movements. These are the earlier determined ankle, hip, stepping, and the more recently defined reaching and grasping or touching strategies (Horak & Nashner, 1986, Maki & McIlroy, 2006).

The *musculoskeletal system* provides the two prerequisites for successful balance strategies, namely: 1) the appropriate muscle groups contract with adequate force and 2) the joints involved in the movement have sufficient range of motion (Horak & Nashner, 1986).

Through our *somatosensory systems* we perceive the spatial position of the body based on three types of sensory information: 1) visual, 2) vestibular, and 3) somatosensory information.

The visual system provides information about our body, our environment and their relative positions. The vestibular system provides information about the spatial position of the head and the position of the head in relation to the body. The somatosensory system provides information about the position and movement of the body in relation to the supporting surface and about the relationship and location of individual body parts and body segments in relation to each other.

The temporal relationship between sensory perception and motor response is important.

From this approach, we speak of two types of control: 1) *feed-forward control*, in which the nervous system anticipates changes in the equilibrium position and activates the corresponding muscles in advance, and 2) *feedback control*, when the nervous system detecting the imbalance, subsequently compensates for it.

During a processing procedure called *sensory organisation*, the nervous system interprets and prioritises the three types of information received forming an internal representation of the body position, and then devises and produces an adequate motor output.

The *cognitive aspect* (i.e. cognitive resources and cognitive strategies) of postural control includes: 1) planning the movement, 2) the emotional aspects of motivation and movement (anxiety about a previous fall, fear of a possible fall), 3) the individual's problem-solving skills and adaptability to deal with situations encountered during movement, 4) the attentional demand, or automaticity, of movement, which determines the extent to which movement and balance will be affected by cognitive or manipulative activities (e.g., talking, using walking aids) (Osoba et al., 2019; Shumway-Cook & Woollacott, 2016c; Woollacott & Shumway-Cook, 2002).

Successful postural control requires the integrity of each of these systems; damage to any one of them affects the whole purpose of postural control. As we age, the functioning of these systems declines.

### 1.3.2. Ageing and postural control – functional decline

It has long been recognised that muscle mass and strength decline with age (Burr, 1997). The body reaches its peak muscle mass in the thirties, which is maintained for a few years and then progressively decreases from the age of 40 onwards, initially by 8% per decade and then by 15% from the age of 70. Thus, by the eighties, muscle mass is almost half of the youth average. The lower limb is affected more than the upper limb by the decline (Malafarina et al., 2012).

Effective postural control is also influenced by the limited range of motion of the joints (i.e. reduced joint mobility) in old age. Reduced flexibility of the spine leads to the typical age-related misalignment of body posture characterised by increased kyphosis (an increased convexity of the back); a curving of the thoracic spine that causes a shift (displacement) of the centre of gravity towards the heels, away from the stability limit (Gong et al., 2019; Katzman et al., 2010; Roghani et al., 2017). Also, the limited range of motion in ankle joint is of great importance for postural control (Gong et al., 2019; Hernández-Guillén et al., 2021). The range of motion of other joints may also be limited, which, along with the pain, can make it difficult to perform any balancing strategy quickly and effectively (Horak et al., 1989).

As for the age-related changes in muscle synergies, muscle reaction times increase (Fozard et al., 1994; Sturnieks et al., 2008). Blomkvist's research shows that between the ages of 20 and 60 the rate of increase is about 25%, and the muscle reaction time increases at an accelerated rate thereafter for both men and women (Blomkvist et al., 2017). The delayed reaction time increases the muscle latency and results in delayed muscle contraction. The delayed muscle contraction is perhaps most clearly demonstrated by the results of the work from Lin and Woollacott (2002). In this study, three groups were studied: young people, older people with stable balance and older people with poor balance and history of fall. Compared to the young adults' muscle activations, the latencies of both the tibialis anterior and quadriceps are increased in both faller (impaired) and non-faller (non-impaired) groups of the older people (Lin & Woollacott, 2002). In particular, the reaction time of peripheral muscles is delayed, often to an extent that they are activated later than the proximal muscles (Studenski et al., 1991). This was illustrated by Horak's classic experiment to see how muscles are activated when a support surface is moved slowly backwards. The activation pattern of a young man shows an ankle strategy; the distal muscles are activated first, followed by the proximal ones. The pattern in old age, however, starts with the activation of the proximal limb muscles, followed by a delay in the distal ones (Horak et al., 1989). The consequence is that older people use a hip strategy to control their balance even in situations where an ankle strategy would be adequate (Faraldo-García et al., 2016; Horak et al., 1989; Maki & McIlroy, 1997; Manchester et al., 1989). The danger is that shear forces are generated between the sole and the ground, which can lead to the older person slipping (Horak et al., 1989).

In addition to changes in the musculoskeletal and motor systems, many sensory functions of the sensory organs and the nervous system are impaired.

The *visual system* shows a similar decline in functionality. In older individuals, visual field loss is very common, with deterioration in visual acuity, contrast sensitivity, and depth perception (Gittings & Fozard, 1986; Lord & Dayhew, 2001; Saftari & Kwon, 2018; Sturnieks et al., 2008).

The structure and function of the *vestibular system* are also in decline (Coto et al., 2021; Zalewski, 2015). The density of hair cells in the otolith receptors of cristae and maculae (i.e. within the utricle and saccule of inner ear) decreases by about 40% by the age of 70 (Jahn, 2019).

In terms of the *somatosensory system*, the ability to sense vibration, tactile stimuli, and the ability to perceive joint position and motion (kinaesthesia), especially in the lower limb, impairs with age. The age-related decline in tactile sensitivity is due to a decrease in the number of Meissner and Pacinian corpuscles, an increase in the stimulus threshold of the remaining ones, and a reduction of nearly 30% in the number of sensory axons innervating them (Anson et al., 2017; Kalisch et al., 2008; Wingert et al., 2014).

In addition to the decreased sensory input, sensory organisation, i.e. the central processing mechanism of sensory information, is also impaired. The impaired processing mechanism makes it difficult to integrate sensory information, as shown by the difficulty to compensate for contradictory or missing sensory information; consequently, the perception of body position becomes inaccurate. Difficulties arise in adapting to different situations in which the sensory information available for postural control changes. Due to a disturbance in central processing, the sensory information needed for postural control cannot adequately be selected and weighted (Horak et al., 1989; Shumway-Cook & Woollacott, 2016d; Sturnieks et al., 2008).

Regarding the cognitive aspect of postural control, it requires attention, not automatic as was previously thought. The attentional demand of postural control has been demonstrated in a so-called dual task situation, by investigating how postural control is altered when it is associated with an attention-demanding activity (e.g., counting as a secondary – cognitive – task) (Clark, 2015; Plummer et al., 2015; Woollacott & Shumway-Cook, 2002).

Recent research has shown that in old age, as the sensory and motor systems gradually deteriorate, postural control will only be effective and successful with increased attention (Brauer et al., 2001; Brustio et al., 2017). This was also shown by Doumas et al. when they investigated the distance centre of pressure (COP) travels while standing on a stable surface and performing a cognitive task. In the dual-task condition, the COP displacement became 40% greater for the older people – showing instability – compared to when a single-task was performed, while for the young it remained unchanged (Doumas et al., 2008).

As a consequence of declining postural control, gait deteriorates, and the older person fears the occurrence of a possible fall.

### 1.3.3. Characteristics of walking in old age

The ability to walk is not only a succession of steps, but also 1) being able to walk at the right speed, 2) walking at the right speed to reach destinations near or far, 3) the ability to change direction without falling, and 4) walking as automatically as possible, so that the older individual can focus attention on other things (i.e. to be able to carry something in hand or to talk while walking).

Both the spatio-temporal parameters and the kinematic/kinetic characteristics of walking in the older people differ from those of the young.

In terms of spatial and temporal parameters 1) the gait of the older people slows down; 2) their steps become shorter and consequently, the full gait cycle becomes shortened; 3) the stride frequency (cadence) or walking rate (i.e. the number of steps per minute) is also reduced; and 4) an increased walking base (stride width) can be observed; and 5) feet are turned out more (i.e. walking with a larger step angle) (Aboutorabi et al., 2016; Cruz-Jimenez, 2017). Lee et al.'s research shows that, with ageing, gait speed and stride length decrease significantly, while stride width increases significantly (Lee et al., 2017). In addition, the length of the stance phase and the double support phase are increased, along with the proportional reduction in the length of the swing phase (Kaczmarczyk et al., 2017; Kimura et al., 2007).

Not only do the absolute values of the above parameters change with age as previously mentioned, but they also become more variable, i.e. they differ more and more with each stride. In other words, stride-to-stride differences become more inconsistent. These fluctuations between gait parameters give the gait variability, which is a sensitive indicator of postural control during gait, the dynamic stability and thus safety of gait. The greater the difference between strides, the greater the gait variability, which makes walking unstable and increases the risk of falling (Beauchet et al., 2017; Hausdorff, 2005; Hausdorff et al., 2001).

In addition, in old age, the automaticity of walking changes and everyday walking requires much more attention than before. If cognitive or manual activity is associated with walking, automatic control is further compromised. This explains why more than half of all falls in old age occur during such activities (Clark, 2015). An important determinant of independent living, and thus of the so-called healthy life years, is that walking requires as little attention and cognitive control as possible, since in everyday life many activities involve walking while doing another activity that requires attention, such as talking while walking, reading the shopping list while walking between the shelves in a shop or trying to recall it, adjusting or buttoning clothes while walking, or sorting money in a pocket or purse. Similarly, crossing the roadway and observing the direction and speed of approaching vehicles and weighing up the information to make the right decision for the situation can also be considered a dual task. When two activities are carried out simultaneously, the two activities interfere with each other, resulting in poorer performance of one or both the activities. This interference occurs because the attentional capacity to the motor and cognitive tasks is limited (Clark, 2015). The two activities "compete" for attention, the person has to divide attention between the two activities. When the attentional demands of the two activities exceed the person's attentional capacity, the performance of one or both activities becomes poorer, disturbed or less focused, compared to performance when one activity is carried out (in single task condition) (Plummer et al., 2015).

The attentional demands of walking can be examined in the so-called dual task situation. The theory is based on the idea that simultaneous activities compete for the attentional capacity of cortical as well as subcortical control areas (Clark, 2015; Woollacott & Shumway-Cook, 2002). According to the dual task theory, we measure the person's performance in two situations: first, when he/she performs only one task (single task condition) and secondly, when he/she performs two tasks simultaneously (dual task condition). In practice, in the case of walking, we measure how gait parameters change when walking (single task) is combined with another activity that requires attention (e.g., a cognitive or manipulative task as a secondary task; dual task condition). The more the secondary task impairs the performance of what is called the single task, the more attention the single task requires; in other words, the less automatic it is (Bayot et al., 2018). Automaticity is quantified by the automaticity index (AI), which can be calculated using the following formula (Hiyama et al., 2012; Paul et al., 2005):

$$\mathbf{AI} = \frac{gait\ velocity_{single\ task}}{gait\ velocity_{dual\ task}} * \mathbf{100}$$

or **AI = (A / B) x100,** where

**A** represents walking speed during normal walking performed as a single activity, and

**B** indicates walking speed when performing a dual task

Automaticity means that an activity requires little attention. The closer the automaticity index is to 100%, the less the walking speed deviates in the dual task situation, that is, the more automatic the walking is.

### 1.3.4. Fear of falling – as cause and consequence

According to Tinetti and Powell, fear of falling (FoF) is a state that is constantly characterised by anxiety or concerns about the possibility of falling (Tinetti & Powell, 1993). Certainly, FoF can be a justified response in certain situations (e.g., when walking on slippery surfaces results in moving more carefully due to FoF), because it can successfully prevent a fall. This FoF will not affect our actions in the long run or in other situations. FoF becomes pathological when loss of confidence, a persistent feeling of FoF develops (see Figure 4).

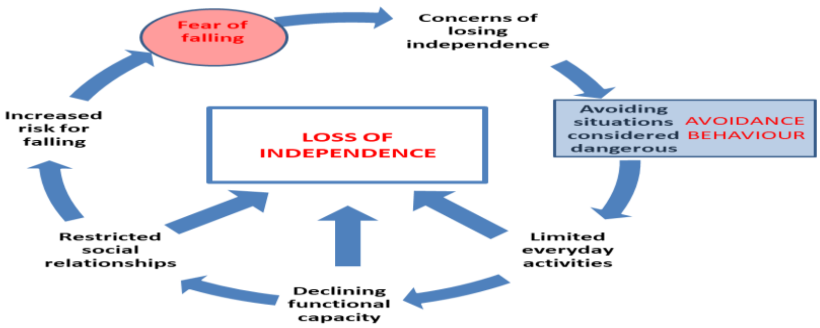


**Figure 4.** Self-perpetuating vicious circle fuelled by fear of falling (modified and edited figure based on Chang et al., 2016, Kovács et al., 2018, and Kovács & Simon, 2023)

It is also associated with the older people limiting their physical activity, which impairs their future functional abilities and increases their risk of being institutionalised (Chang et al., 2016). Fear of falling is a very common phenomenon among older people. Between 20–39% of them report a FoF to some extent (Whipple et al., 2018). Among those who have already experienced a fall, the rate is even higher, at 40–73% (Jung, 2008; MacKay et al., 2021). The variation in the prevalence estimated by each researcher may be due to different ways of measuring the existence and extent of FoF, using different questions. The prevalence was higher in those studies in which the respondent was able to differentiate their response according to the level of fear (Gillespie et al., 2007; Kressig et al., 2001; Zijlstra et al., 2007). If the question on FoF could only be answered yes/no, the prevalence was lower.

### 1.4. Testing postural control

Testing postural control is of particular importance in the work of the physiotherapist, since the results of the postural control examination are the basis for the early identification of older people who need intervention as soon as possible, and the effect of the intervention can be monitored by repeated postural control examinations. The tests most commonly used by physiotherapists are grouped in Table 1 according to the components of the International Classification of Functioning, Disability and Health (ICF) (Grill et al., 2005; Ruaro et al., 2014; Spoorenberg et al., 2015). The model refers to a successful function, in this case successful walking, when apart from 1) structural and functional integrity of the organs necessary for walking, 2) walking is used in the activities of daily living of the older people, such that 3) their social roles in a changing environment can be fulfilled. The majority of the tests most commonly used in geriatric physiotherapy assesses postural control as an activity under standard measurement conditions, not in the patient's usual environment, not in the patient's usual lifestyle. The participation component, on the other hand, expresses whether the older person's postural control makes them capable of fulfilling their roles. This component reflects the quality of the patient's postural control in their familiar environment (Falvai & Kovács, 2010; Könczei, 2009; Kullmann, 2002).

**Table 1**. Testing postural control (non-exhaustive list)

| **STRUCTURE** | **ACTIVITY**<br>*[under standard(ised) condition]* | **PARTICIPATION**<br>*[in usual lifestyle / in familiar environment]* |
|---|---|---|
| Testing sensory system | 10-metre walk | Walking While Talking Test (WWTT) |
| Testing motor system | 2-minute / 6-minute walk | questionnaires (e.g., *Falls Efficacy Scale – International* (*FES-I Hungarian*) |
| | Functional Ambulation Category (FAC) | |
| | *Timed Up and Go test (TUG test)* | |
| | *modified TUG test (mTUG)* | |
| | (modified) Functional Reach Test ((m)FRT) | |
| | *Berg Balance Scale (BBS)* | |

In the subsequent three paragraphs, a concise introduction to the Berg Balance Scale, the Timed Up and Go tests (single and modified), and the Falls Efficacy Scale - International questionnaire will be given.

### 1.4.1. The Berg Balance Scale (BBS)

This 14-item test aiming to assess different aspects of balance was developed by Professor Kathy Berg in 1989. With each item rated 0 to 4 (Berg, 1989) the test provides a maximum score of 56 in the case of perfect ability to control posture both within static and dynamic circumstances. Based on the reported psychometric properties, BBS has a good test–retest and interrater reliability (intraclass correlation coefficient (*ICC*) = .98)[2] and good internal consistency (Cronbach's alpha = .96) (Berg et al., 1992). Its correlation with other tests of postural control and mobility, such as the Timed Up and Go (TUG) test ($r = .76$) confirmed its convergent validity (Berg et al., 1992). According to Shumway-Cook et al. (1997), the BBS was considered to be "the best single predictor of fall status in community-dwelling older adults without neurologic pathology". Clearly, decreasing BBS scores are associated with increased risk of falling; however, as this relationship is non-linear (Muir et al., 2008; Shumway-Cook, 1997a), additional references are needed.

Both static and dynamic balance, as two aspects of postural control, can be tested by the BBS. Admittedly, the scale primarily targets the static (or, more precisely, the so-called steady-state) postural control in seated and standing posture as well as the so-called anticipatory dynamic aspect of postural control; however, the scale neither involves reactive balance testing nor gait.

There are no advantages without disadvantages; at the same time, knowing the strengths and limitations of the scale, its limitations can be considered when adding appropriate additional tests for further assessment of a particular patient.

[2] For the presentation of the statistical data/variables and for the presentation of the results (in text and tables) the recommended format of APA 7 style is used throughout the dissertation.

### 1.4.2. The Timed Up and Go (TUG) tests (single and modified)[3]

The basic version of the test ($TUG_{single}$) measures the time taken by a person while standing up from a standard armchair (approximate seat height, 46 cm; arm height, 65 cm) on cue, walking to a cone placed at a distance of three metres from the chair, turning back, walking back to the chair, and sitting down again. The person to be tested is instructed to 'walk at a comfortable and secure pace'; while is allowed to wear their regular, well-fitting footwear, use customary walking aids, and take support of the arms of the chair to get up, but no other physical assistance is provided. Before being timed the person undergoes a trial to get familiar with the test. The TUG test is performed consecutively twice under the supervision of a skilled physiotherapist and the average of the two scores (i.e. the time required to fulfil the task measured in seconds) is used for further data analysis. The person is allowed to rest for 30 seconds between the trials, if needed. A stopwatch is used for the measurement, which is started right on the cue and stopped when the person's back is against the backrest. A longer time for the task to complete indicates poorer performance. The TUG test has excellent concurrent (Wrisley & Kumar, 2010) and construct validity (Brooks et al., 2006), as well as excellent test-retest (*ICC* = .99) and inter-observer reliability (*ICC* = .99) (VanSwearingen & Brach, 2001).

A dual task condition can also be created to assess gait automaticity (cf. section 1.3.3). During these modified circumstances (i.e. a modified version of the TUG test) the patient is asked to perform simultaneously the $TUG_{single}$ test either complemented with a cognitive task ($TUG_{cognitive}$) or a manual task ($TUG_{manual}$). Several secondary tasks are used in clinical practice or in the context of research, e.g., counting backwards from a random starting point of 20 to 100 in threes (Shumway-Cook et al., 2000) or performing the task while holding a glass full of water in one's hand.

The automaticity index then can subsequently be calculated to measure the impact of the cognitive and/or manual task on functional mobility. The formula used for calculating the automaticity index is as follows: $TUG_{single}/TUG_{cognitive\ \textit{and/or}\ manual}$ x100

[3] The author of this dissertation indicates here that Section 1.4.2 is an adaptation of the two papers on which the Methods of S1 (Phase 2 - Measurement) (Simon et al., (2023)) and the Methods of S3 (Data collection - Measurement) (Kovács et al., (2019b)) are based; some parts have been left verbatim, others have been revised.

(%). Evaluating the index, the closer the automaticity index is to 100%, the better the performance of the dual task is considered, i.e., the cost of the cognitive and/or manual task on the automaticity of walking is lower (Paul et al., 2005).

### 1.4.3. The Falls Efficacy Scale – International (FES-I) questionnaire[4]

As was mentioned earlier in section 1.3.4, the way in which a person is asked about their concerns can largely determine the prevalence with which they report FoF. Many studies still use a single question, but when evaluating research results, it is important to be aware of how the wording of the question can affect the results.

This problem can be solved by using a standard(ised) questionnaire in all countries to assess the FoF. Over the last two decades, a number of methods have been developed to investigate the phenomenon of FoF. In the earliest studies, older people were asked the binary question "Are you afraid of falling?", with only a yes or no answer option. The disadvantage of this simple method is that it does not measure the degree of FoF (Cameron et al., 2000; Friedman et al., 2002).

Later, more detailed questionnaires were designed, in which the respondent could indicate the extent of their fear on a Likert scale. The first questionnaire (Falls Efficacy Scale, FES) was developed by Mary Tinetti and her colleagues (Tinetti et al., 1990).

Their questionnaire not only measures whether an older person is afraid of falling during activities of daily living, but also measures the extent of this fear and during what kind of activities the fear emerges. This questionnaire has been modified in several cases. The last modification was made in 2004. The most recent version, called FES-International (FES-I), was developed by ProFaNE (Prevention of Fall Network Europe) (in which the scale scoring was reversed) (Yardley et al., 2005).

In this 16-item long version, a total of 16 activities are covered; 10 items of the original FES questionnaire had been slightly reworded for indoor use and 6 additional, more difficult, more challenging outdoor activities had been added. More recently, a short(ened) version of the FES-I questionnaire with 7 questions was developed

[4] The author of the dissertation indicates here that Section 1.4.3 is a partial adaptation of the paper Kovács et al. (2019a) on which S2 Methods (3.2.1 Data Collection - Measurement) is based; the author of the dissertation, as co-author of the indicated study, has adopted some terms verbatim, others have been revised.

(Kempen et al., 2008), two of which ask about concerns raised during the more challenging outdoor activities.

The five indoor activities that the questionnaire examines are dressing, grooming, sit-to-stand from a chair and back, walking up stairs, picking up objects from the floor; while the two more difficult or rather challenging outdoor activities are walking on sloping ground and getting to social events. The answers are indicated on a four-point scale: not at all concerned about falling =1; somewhat concerned =2; fairly concerned =3; very concerned =4. The scores of the responses are summed to form a single index, so that the total score obtained ranges from 16 to 64 for the long version and can be between 7 and 28 for the short version. The lower the total score, the less anxious the (older) person is about falling while carrying out daily activities (Kovács et al., 2018; Yardley et al., 2005). A cut-off score of 23 for the long version and 10 and above for the short version indicates an abnormal level of fear (Delbaere, 2004; Delbaere et al., 2010). The Hungarian version, similarly to the other language versions, has excellent repeated-measure (test-retest) reliability (*ICC* = .831) and internal consistency (Cronbach's alpha coefficient = .93) (Kovács et al., 2018).

The FES-I scale has been translated and validated not only in most European languages, but also in many other languages, for example, Brazilian Portuguese, Chinese (Mandarin, Cantonese, and Taiwanese), Malay, Urdu, Panjabi, and Myanmar (Burmese) (McGarrigle et al., 2023). The free-to-access Hungarian version is available for download and use since 2017. This Hungarian version[5] was used in Study 2 to measure the extent of concerns of falling and its associated factors among older people living at home.

### 1.5. The complex role of the physiotherapist as a companion for older people on the road to successful ageing (World Physiotherapy, 2023)

The triple prerequisite, or – more metaphorically – triple pillars to rely upon are the development, implementation, and assessment of methods and/or measures. Physiotherapists are trained professionals who are able to integrate this triple prerequisite by being able to serve reliable and valid means or measures to support

[5] See enclosed in Supplementary material 11.2a.

adults on their journey towards a successful longer life to live (World Physiotherapy, 2023).

As is required from physiotherapists to fulfil this role, there is a must to carry out a comprehensive assessment and evaluation to assess the needs of geriatric patients, to be able to valuably contribute to maximising functional capacity through optimising mobility and delaying the development of mobility disability limiting functional capacity.

Based on the areas of competence, a physiotherapist's scope of practice (World Physiotherapy, 2023) should be in line with patients' expectations and their activities should be based on the highest possible level of evidence and striving for improvement.

Physiotherapists are able to implement a physiotherapy intervention programme and patient education in partnership with patients; to evaluate and re-evaluate the results of interventions to make clinical decisions about and for patients.

Movement and function are purposeful and affected by internal (physical and/or cognitive-behavioural) and external (environmental, contextual) factors. (Ivanenko & Gurfinkel, 2018; Leisman et al., 2016; Shanbhag et al., 2023)

Human postural control in conjunction with movement – expressing functional capacity as mobility ability –is an essential element of health and wellbeing even in old age and depend on the integrated, well-coordinated functioning of the body at a number of levels (Ivanenko & Gurfinkel, 2018; World Physiotherapy, 2023).

Physiotherapy is concerned with the mobility needs and mobility abilities of individuals and certain populations (e.g., the older people) to maximise and optimise their potential.

In particular, geriatric physiotherapists can target their interventions at this specific, potentially disadvantaged group, which is more likely to face inequalities due to the more severe consequences of ongoing physical and cognitive decline. Physiotherapists who, for example, dedicate themselves specifically to fall prevention programmes for older people can add particular value (World Physiotherapy, 2023).

# 2. Objectives

## 2.1. Study aims

Based on the areas of competence, the physiotherapist's scope of practice (WCPT, 2023) should be in line with the expectations of the patient and must thrive to be evidence based. Accordingly, a physiotherapist working with older people can use appropriate diagnostic methods and interventions both to assess and to improve the older patient's postural control through effective therapeutic physical exercise programmes, helping them to live a longer healthy (disability-free) life.

The dissertation addresses both aspects of appropriate and effective patient care in the daily work of the clinical physiotherapist, targeting both the diagnostic and the therapeutic areas of this work. In the subsequent part of the dissertation, I will describe the process of research in these two areas through three studies.

## 2.2. The objective of Study 1 (S1)

S1 aims to develop the Hungarian version of the Berg Balance Scale via cross-cultural adaptation and to assess its clinimetry in patients living in an institutional setting. The BBS is a widely applied and valid measure of static and dynamic balance (as two aspects of postural control) that has not been adapted and validated in Hungarian.

## 2.3. The objective of Study 2 (S2)

S2 aims to put the FES-I questionnaire into clinical practice to assess fear of falling and to identify the risk groups for falls in old age (in the frame of a cross-sectional epidemiology survey).

## 2.4. The objective of Study 3 (S3)

The aim of S3 is to assess the possible effects of a multimodal exercise programme on gait (originally designed to improve physical fitness) in older participants compared to their inactive peers. S3 employs a retrospective study design.

# 3. Methods

The studies were conducted in accordance with the Declaration of Helsinki. Following a detailed explanation of the aims and procedures of each study, a written informed consent was obtained from all the participants. Also, they were reminded of their right to withdraw at any stage of the study.

### 3.1. Methods of S1[6]

**Development of the Hungarian BBS and assessment of its clinimetrics** *(Cross-cultural adaptation of the Berg Balance Scale into Hungarian and evaluation of its psychometric properties)*

#### 3.1.1. Data collection

Permission to translate the BBS was granted by the developer of the original instrument. We followed the Strengthening the Reporting of Observational Studies in Epidemiology guidelines for observational studies in reporting. The ethical approval was registered under the identification number SE RKEB: 100/2022.

This study was conducted in two phases: 1) translation and 2) evaluation of psychometric properties.

***Phase 1: Translation and cultural adaptation***

Phase 1 was conducted in March and April of 2021[7]. In this phase, a Hungarian BBS was developed using a process proposed by Beaton et al. (Beaton et al., 2000, 2007). (The flowchart of the cross-cultural validation process is presented in the section 'Supplementary materials 11.1'.) The BBS is a performance-based scale rather than a self-reported scale; however, the translation procedures for both types of scales follow the same guideline (Gjersing et al., 2010; Wild et al., 2005). First, the original English

[6] Chapter 3.1. summarises the Methods section of our validation study published in the journal Disability and rehabilitation. (Simon, A., Gyombolai, Zs., Kubik, A. Zs., Báthory, Sz., Sztruhár Jónásné, I, Gergely Fábián, G. & Kovács, É. (2023) Cross-cultural validation of the Berg balance scale to assess balance among Hungarian institutionalised older adults *Disability and Rehabilitation*, DOI: 10.1080/09638288.2023.2232717)

[7] Testing the pre-final version of the Hungarian BBS for comprehensibility was conducted with a timeframe which coincided with the sharp decline of the second wave of the Covid-19 epidemic in Hungary; this pre-final version testing was performed already with vaccinated older participants under mask protection.

version of the BBS was independently translated into Hungarian by two translators producing T1 and T2 Hungarian versions. One of the translators was a bilingual physiotherapist with 5 years of experience in geriatric physiotherapy; the other was a professional translator. In the first consensus meeting, the two translated scales were compared and a preliminary Hungarian version was created. This version was back-translated into English by two native English translators who were blinded to the original English version of the BBS. The translators and two investigators with experience in geriatric physiotherapy compared the original BBS and back-translated English versions to develop a pre-final Hungarian version. This pre-final Hungarian version of the BBS was piloted in a group of 16 older adults by four physiotherapists with 4–5 years of experience in geriatric physiotherapy. Participants for pilot testing were recruited from the target population living in the institution where the study on evaluating the psychometric properties (i.e. Phase 2) was conducted. Their median age was 73.5 years, (12 women and four men with diseases specific to the target group, i.e. osteoporosis [n=5], cardiovascular disease [n=8], pulmonary disease [n=3], diabetes mellitus [n=7], hypertension [n=10], and stroke [n=2]). Physiotherapists and patients were interviewed regarding the comprehensibility of task-related instructions, the scoring terms, and any suggestions for rephrasing for clarity.

***Phase 2: Evaluation of psychometric properties***

***Participants***

Cross-sectional data were collected from a convenience sample of older adults between May 2021 and July 2021[8]. A total of 150 individuals aged ≥60 years living in a long-term care institution located in Budapest, Hungary were recruited.

The inclusion criteria were as follows: ability to walk with or without walking aid, spoke Hungarian as a native language, and having cooperative behaviour. The exclusion criteria were as follows: use of a wheelchair, amputation of the lower limb, having

[8] The timing allowed the measurement to be carried out between the second and third waves of the Covid-19 epidemic in Hungary. It can certainly be assumed that we do not know exactly how this specific social situation in this milieu influenced the characteristics (whether demographic, physical, or mental functions) of the older people in our sample. The short-, medium-, and long-term effects of the Covid-19 epidemic are still a current topic of research.

undergone total hip arthroplasty or hemiarthroplasty in the previous 3-month period, as well as Parkinson's disease and/or severe cognitive impairment.

A total of 89 participants randomly selected from the total sample were re-assessed to examine reliability using the following method. Code numbers were assigned to all 150 participants that were later paired with a list of computer-generated random numbers between 1 and 150. Then, the random numbers were organised in ascending numerical order, and the first 89 participants were included in a subsample for the retest. Two physiotherapists (Rater A and Rater B), who had 5 and 7 years of experience, respectively, in geriatric physiotherapy working at long-term care institutions, examined the participants separately. Rater A performed the first BBS, while Rater B performed the second measurement 2 h later on the randomly selected participants. After a 7-day period, Rater A performed the BBS again on the same randomly selected participants.

***Measurements***

First, the socio-demographic data of participants, including age and sex, as well as health-related data, including body weight, height, history of chronic diseases, use of walking aids, and fall history, were collected from the nursing documentation. A person who had fallen at least once in the past 12 months was considered a faller (Lin & Woollacott, 2002). After the BBS measurement, the functional mobility and status in activities of daily living (ADLs) were assessed.

Functional mobility was assessed using a widely applied measure, the $TUG_{single}$ test (Podsiadlo & Richardson, 1991; Zöllei et al., 2021) according to Section 1.4.2.

The functional status of the participants in ADL was assessed with the Katz index. This index shows the level at which an individual can perform basic everyday ADLs, including bathing, dressing, using the toilet, transferring, bowel and bladder control, and feeding, using a dichotomous scoring (0=dependent [i.e. with supervision, direction, personal assistance, or total care]; 1=independent [i.e. with no supervision]). A total score of 6 points indicates better functional status in ADL (Zöllei et al., 2021, Beecroft, 2000). The Katz index has been shown to have an excellent internal consistency in both older adults referred to a geriatric medicine outpatient clinic (Cronbach's alpha = .838) (Arik et al., 2015) and nursing home residents (Cronbach's alpha = .838) (Gerrard, 2013).

### 3.1.2. Statistical analyses

Continuous data were presented as means and standard deviations (*SD*s); discrete data are presented as numbers and percentages. The distribution of our data based on skewness and kurtosis made parametric tests feasible.

Psychometric characteristics (reliability and validity domains) of the HU-BBS were tested based on the quality criteria proposed by Terwee et al. (Terwee et al., 2007).

To evaluate the floor and ceiling effects, the number of participants achieving the highest and lowest possible scores was determined. The presence of floor and ceiling effects was defined as at least 15% participants reaching the maximum or minimum scores, respectively (Terwee et al., 2007).

Reliability was determined through internal consistency as well as intra- and inter-rater reliability. The internal consistency was assessed by calculating Cronbach's alpha value considering the factor structure of the HU-BBS. Values between .7 and .95 were considered acceptable (Terwee et al., 2007).

To examine the relative reliability, the intra- and inter-rater reliabilities were determined by calculating the intraclass correlation coefficient (*ICC*) in a two-way random effects ANOVA model. To examine the absolute reliability, first the standard error of measurement (*SEM*) for repeated measurements was determined. Then, the *SEM* was used to calculate the minimally detectable change at 95% confidence level ($MDC_{95\%}$) using the 2.77 × *SEM* formula. In addition, Bland–Altman plots were used to visualise the level of agreement between the inter-rater and test-retest measurements by plotting the difference between the HU-BBS scores against the means of the related HU-BBS scores. The 95% limits of agreement were estimated as ±1.96×*SD* of the mean difference scores (Bland & Altman, 1986).

Construct validity of the HU-BBS was assessed through convergent, discriminant, and known-group validity. For convergent validity, associations between the HU-BBS score and functional status in ADL (measured with Katz index), functional mobility (measured with $TUG_{single}$ test), as well as age, were analysed by calculating Pearson's correlation coefficient (*r*). The predefined hypotheses were that the HU-BBS would show a strong positive correlation (≥ .70) with Katz index and a strong negative correlation (≥ .70) with the $TUG_{single}$ test and age (Donoghue et al., 2009;

Lampropoulou et al., 2016; Ottonello et al., 2003; Sahin et al., 2008). The discriminant validity was assessed by comparing the HU-BBS scores between women and men. The predefined hypothesis was that their HU-BBS scores would not be different (Halsaa et al., 2007). The known-group validity was demonstrated by determining the difference in the HU-BBS between older adults who had fallen and those who had not, using an independent samples t-test. We hypothesised that the HU-BBS score would be lower among people who had fallen at least once in the previous year (Bogle Thorbahn & Newton, 1996; Viviero et al., 2019).

The sample size was determined by the guideline provided by Terwee et al. (Terwee et al., 2007), which stated that the sample size should be 10 times the number of the items but should be at least 100. Considering the number of items in the BBS, 150 older adults were involved in the study. For reliability, 89 older adults were chosen to achieve the expected *ICC* of .70 with a power level of .80 and significance level of .05 and considering a dropout rate of 10% (Arifin, 2018; Walter et al., 1998). All the calculations, except those for intra-and inter-rater reliabilities, were based on the data from the first measurement.

Statistical analyses for all three studies were performed with the predictive analytics software IBM SPSS Statistics (Version 19)[9].

Similarly, the level of significance was set at $p < .05$ in all three studies.

[9] IBM SPSS Statistics (Version 19). SPSS Inc. Released in 2009. PASW Statistics for Windows, Version 18.0. Chicago: SPSS Inc.

### 3.2. Methods of S2[10]

**Investigating the fear of falling among community-living older adults: putting the FES-I questionnaire into practice** *(A questionnaire- based survey to identify and assess risk factors of concerns of falling among community-dwelling older adults)*

### 3.2.1. Data collection

***Participants***

Participants were recruited in February and March 2018 from senior citizens' clubs, churches, and advertisements in district newspapers. A total of 204 participants were people aged 60 and over who were able to walk with or without a walking aid. We excluded those who were living in institutional settings, such as nursing homes, or who had a sensory or cognitive communication disability that would have made them unable to complete the personal data sheet and questionnaire. Number of ethical permission: ETT TUKEB 336932/2016/EUK.

The questions on the personal data sheet were used to obtain data on demographic characteristics (age, sex, and marital status), medication (medicines taken regularly), and health status (diabetes mellitus, osteoporosis, cardiac, respiratory, lower limb musculoskeletal, neurological (Parkinson's disease, stroke) diseases affecting mobility).

***Measurements***

Data collection was acquired through a self-administered questionnaire and physical measurements at the recruitment site (club hall, secular or religious community centres, churches, parishes).

The personal data sheet[11] also included the short FES-I questionnaire, a version of which has been validated in Hungarian (Kovács et al., 2018), as discussed in Section 1.4.3.

To assess functional mobility, the $TUG_{single}$ test was used (see Section 1.4.2).

[10] Chapter 3.2. presents the Methods section of our crosss-sectional epidemiology survey published in Hungarian in the journal Orvosi Hetilap. Linguistic adaptation from Hungarian to English was conducted by András Simon (author of this dissertation) (Kovács, É., Erdős, R. L., Petridisz, A. N., Rozs, F., & Simon, A. (2019a). Az eleséstől való félelem otthon élő idősek körében [Fear of falling among community-living older adults]. *Orvosi hetilap*, *160*(5), 191–197. https://doi.org/10.1556/650.2019.31267 Hungarian)

[11] The personal data sheet (including Short FES-I Hungarian) for S2 is enclosed in Supplementary materials 11.2a & 11.2b.

### 3.2.2. Statistical analysis

For descriptive statistics of the sample, mean, standard deviation, absolute and relative frequencies were calculated. Data normality was determined on the basis of the skewness of the distribution and the results of the Shapiro-Wilk test. The continuous data obtained for the following variables were dichotomised as follows:

(1) fear of falling (FoF) (0 = not perceived or normal if total score <10; 1 = abnormal if total score ≥10) (Delbaere et al., 2010);

(2) fall history (0 = no history of falls (labelled 'non-faller'); 1 = if at least one fall in the past year (labelled 'faller') (cf. section 1.3.2.). A fall was defined as an event during which the individual unexpectedly and unintentionally fell from a higher level to the ground or a lower surface (Nevitt et al., 1989; Lamb et al., 2005);

(3) functional mobility measured by $TUG_{single}$ test (0 = age-appropriate; 1 = if it took more than 12 seconds to complete the movement sequence) (Bischoff et al., 2003);

(4) medication use (0 = if taking up to 3 of the following medicines regularly: benzodiazepines, antidepressants, antipsychotics, diuretics, antiarrhythmics, non-steroidal analgesics; 1 = if taking more than 3 medications (Rubinstein, 2006; Rubinstein & Josephson, 2006).

To compare our data, we used a two-sample t-test for data with a continuous normal distribution and a z-test for our observational data. We then used binomial logistic regression ('enter' method) to analyse the relationship between the dependent variable (FoF) and the independent variables (factors hypothesised to be related to FoF: age, sex, number of chronic diseases, functional mobility, previous falls, regular medication). The relationship between FoF and the independent variables was assessed by calculating an odds ratio (OR), which indicates whether or how strong the relationship is between the factor and FoF. The significance of the relationship was assessed using the 95% confidence interval (CI); a result was considered significant if it did not include the value 1. The explanatory power of the multivariate model was characterised by Nagelkerke's $R^2$, which indicates the percentage of the variance of the dependent variable explained by the model with independent variables.

### 3.3. Methods of S3[12]

**Assessing the effects of a multimodal exercise programme on gait parameters** *(A retrospective study on how cognitive dual-task challenges gait stability of inactive and active older people compared to young inactive persons)*

### 3.3.1. Data collection

***Participants***

This retrospective study was carried out in May 2017. The inclusion criterion was the ability to walk without an assistive device. Exclusion criteria were either neurological or vestibular disorders or surgery either on the lower limbs or spine in the past two years.
A total of 57 community-dwelling people were recruited in the study. Participants considered to be physically active older people (n=20) were defined by their age (60 years or older) and by their participation in a geriatric exercise programme for at least six months. Consequently, age-matched older individuals (n=20) recruited through an advertisement in a local newspaper were considered as inactive older people if they had not participated in any exercise programme in the previous six months. Age matching meant that the maximum age difference between participants in the physically active and physically inactive groups was allowed to be 5 years.

Another group was used to control for age-related changes in gait parameters. This was a group of physically inactive young people, defined as subjects aged 35 years or younger who had not participated in any activity programme in the previous six months (n=17).

***Measurements***

The degree of variability was calculated as the *coefficient of variation (CV)*; it is the ratio of the standard deviation to the mean expressed as percentage ([SD/mean]×100). The higher the value of the ratio, the greater level dispersion around the mean is expressed (Verghese et al., 2009).

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[12] Chapter 3.3. presents the Methods section of our third study published in The Journal of sports medicine and physical fitness in 2019 (Kovács, É., Simon, A., Petridisz, A. N., Erdős, R. L., Rozs, F., & Virág, A. (2019b). Gait parameters in physically active and inactive elderly as well as young community-living people. The Journal of sports medicine and physical fitness, 59(7), 1162–1167. https://doi.org/10.23736/S0022-4707.18.09205-8) with some shortened descriptions and textual revisions in line with section 1.4.2. of this dissertation. Editing and paraphrasing was undertaken by András Simon (author of the dissertation).

Treadmill *gait analysis* made by Zebris FDM-T treadmill system (Zebris Medical GmbH, Germany) was employed to measure the following gait parameters: step/stride length, step/stride time, step width, and double support ratio. Subjects walked continuously on the treadmill for two minutes at a constant speed of 1.11 $ms^{-1}$. Based on the scientific literature, this speed corresponds to the average gait speed of the given older population (Bohannon & Williams Andrews, 2011).

They were asked to walk in their own regular footwear (i.e. well-fitting walking shoes, with a maximum heel height of 3 cm) (Kressig & Beauchet, 2006).
To assess *gait automaticity*, two versions of the TUG test were taken by the participants. Each of them underwent a $TUG_{single}$ and a $TUG_{cognitive}$ in random order. The description and instructions of the TUG tests were identical to those provided in section 1.4.2., except that, according to the inclusion criterion, no walking aid was allowed to be used. Similarly, the automaticity index was calculated to measure the impact of the *cognitive task* on functional mobility described in Section 1.4.2., using the formula as follows: $TUG_{single}/TUG_{cognitive}$ x100 (%). Evaluating the index, the closer the automaticity index was to 100%, the better the performance of the dual task was considered, i.e., the cost of the cognitive task on the automaticity of walking was lower (Paul et al., 2005).

### 3.3.2. Intervention

***The multimodal (geriatric) exercise programme[13]***

The 60-minute multimodal geriatric programme was a combination of aerobic, strengthening, flexibility, and balance exercises, with a five-minute warm-up and cool-down period each. The exercises were performed under the supervision of a physiotherapist (with considerable expertise in physiotherapy for older people). The detailed content of the multimodal geriatric exercise programme is described elsewhere (Virág et al., 2018). This multimodal geriatric exercise programme was complemented by a Nordic Walking (NW) exercise programme. The maximum possible intensity of NW was moderate, i.e. the individual had no difficulty speaking while walking or the Borg rating perceived exertion was 12–14 (McDermott & Mernitz, 2006).

[13] See the elements of this multimodal exercise program enclosed in Supplementary materials 11.3.

### 3.3.3. Statistical analysis

The mean and standard deviation of the data were chosen to describe the sample.

For exploring differences among the three groups, one-way independent ANOVAs were preliminarily planned to be conducted. Since the assumption of homogeneity was violated for gait variability data, the Welch's adjusted F statistics (or Welch's ANOVA) were used to determine the differences between groups and a non-parametric post-hoc test with Games-Howell method was used to perform multiple pair-wise comparisons between the relative values of the groups.

# 4. Results

## 4.1. Results of S1[14]

A total of 150 participants were involved in this study. The characteristics of the study sample are displayed in Table 2.

**Table 2.** Demographic and clinical characteristics of the participants in the whole study (N=150) and the test-retest subsample (n=81)

| Characteristics | | Values | | *p* value |
|---|---|---|---|---|
| | | Whole study | Test-retest subsample | |
| Age (years), | mean ± *SD* | 74.2 ± 8.17 | 73.8 ± 8.58 | .570 |
| | median ($Q_1$; $Q_3$) | 75 (70; 79) | 74 (65; 79) | |
| Female, n (%) | | 108 (72) | 57 (70.4) | .807 |
| BMI (kg/m$^2$), mean ± *SD* | | 27.98 ± 4.61 | 27.9 ± 5.02 | .897 |
| Medical history, n (%) | | | | |
| Osteoporosis, | | 48 (32.0) | 24 (29.6) | .710 |
| Cardiovascular disease | | 75 (50.0) | 38 (46.9) | .570 |
| Pulmonary disease | | 21 (14.0) | 11 (13.6) | .844 |
| Diabetes mellitus | | 72 (48.0) | 37 (54.7) | .718 |
| Hypertension | | 107 (71.3) | 56 (69.1) | .683 |
| Stroke | | 23 (15.3) | 13 (16) | .821 |
| Fall history, n (%) | | 81 (54.0) | 41 (50.6) | .512 |

*SD*, Standard Deviation; $Q_1$, lower quartile; $Q_3$, upper quartile; BMI, Body Mass Index

[14] Chapter 4.1. summarises the Results section of our validation study published in the journal Disability and rehabilitation (Simon, A., Gyombolai, Zs., Kubik, A. Zs., Báthory, Sz., Sztruhár Jónásné, I, Gergely Fábián, G. & Kovács, É. (2023) Cross-cultural validation of the Berg balance scale to assess balance among Hungarian institutionalised older adults *Disability and Rehabilitation*, DOI: 10.1080/09638288.2023.2232717) with some minor revisions in line with section 1.4.2 of this dissertation.

#### 4.1.1. Phase 1: Translation and adaptation

***Forward translation and the preliminary version***

During the forward translation stage, some minor linguistic differences have arisen. Regarding item 3, since the meaning of safely and securely in Hungarian is the same, only one word was used in the sentence as follows: ‘képes biztonságosan ülni 2 percig’ (literal translation: able to sit safely for 2 min). Concerning items 8 and 9, ‘inch’ was converted to cm as follows: 10 in to 25 cm; 5 in to 12 cm; 2 in to 5 cm; 1–2 in to 2–5 cm.

***Backward translation and the pre-final version***

During the backward translation stage, some comprehension problems have emerged. These problems were resolved by the Expert Committee. Concerning items 10 and 11, there was a difficulty with the meaning of the term ‘turn’. It was unclear whether ‘turn’ referred to turning of the trunk only, while the feet remained on the floor or whether it meant that small steps should be taken. Considering the aim of these two tasks and the results of the Greek, Turkish, and Brazilian studies, the instructions for these items were modified. In item 10, the following phrase was added at the end of the first sentence: ‘anélkül, hogy a lábát felemelné a talajról’ (literal translation: without lifting your foot off the floor). In item 11, the following phrase was added at the end of the first sentence: ‘kis lépésekkel’ (literal translation: taking small steps). Furthermore, the terms ‘supervision’ and ‘assistance’ required clarification. In our study, similar to the Brazilian study, supervision was defined as ‘standing close to the subject without touching them’, while assistance was defined as ‘touching or giving a firm external support to avoid falls’. After resolving the aforementioned minor comprehension problems, a pre-final version of the BBS was created. During piloting, no confusing terms or difficulties in understanding were reported: hence, the pre-final Hungarian version was considered as the final Hungarian version of the BBS[15].

[15] See enclosed in Supplementary materials 11.4.

### 4.1.2. Phase 2: Assessment of the psychometric properties of HU-BBS

There were no floor or ceiling effects because only five participants (3%) obtained the highest total score of 56 points, while none of the participants achieved the lowest score.

***Internal consistency***

Cronbach's alpha coefficient was .929 for the first factor, .915 for the second factor, and .943 for the whole scale.

***Inter- and intra-rater reliability***

Of the 89 people originally selected, 81 completed the re-tests. The analyses of inter- and intra-rater reliability indicated excellent reliability (Table 3).

**Table 3**. Results of reliability analyses

| n=81 | *ICC* | 95% CI | *SEM* | $MDC_{95\%}$ |
|---|---|---|---|---|
| Inter-rater reliability | .988 | .982 – .993 | 0.889 | 2.46 points |
| Intra-rater reliability | .984 | .976 – .991 | 1.046 | 2.89 points |

CI, confidence interval; *ICC*, intraclass correlation coefficient; $MDC_{95\%}$, minimally detectable change with 95% confidence interval; *SEM*, standard error of the measurement

The Bland–Altman plots of the inter- and intra-rater reliabilities are presented in Figures 5 and 6. The mean inter-rater difference was 0.284, with 95% limits of agreement ranging from −2.193 to 2.744. Two outliers (2.47%) were identified. The mean intra-rater difference was 0.259, with 95% limits of agreement ranging from −2.657 to 3.162. Four data points (4.93%) lay outside this range.

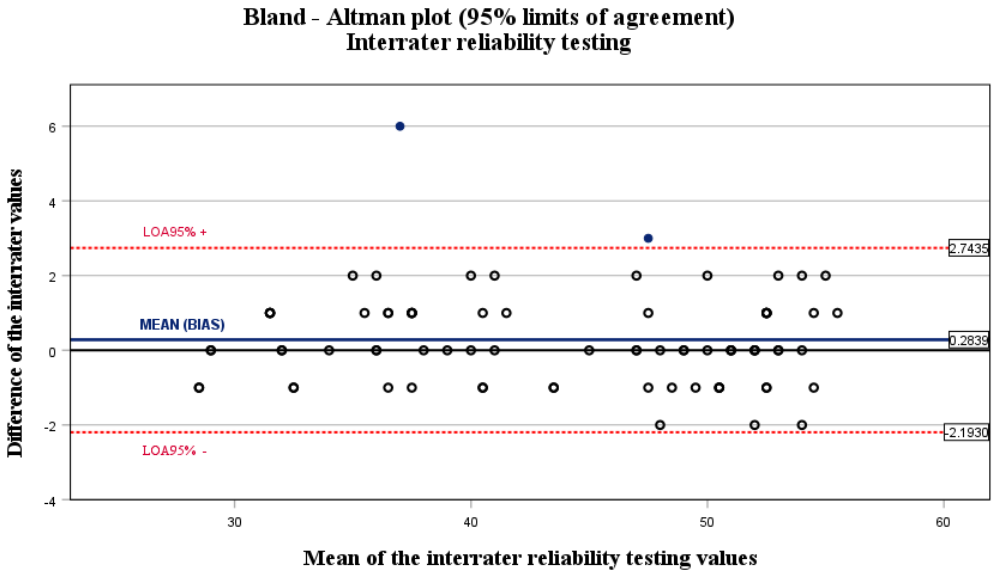


**Figure 5.** Bland–Altman plot showing differences of measurements against their means for inter-rater reliability. The solid line represents the mean difference (bias) between the two scores, and the dotted lines represent the 95% limits of agreement ($LOA_{95\%}$). (Own graph; source: Simon et al., 2023)

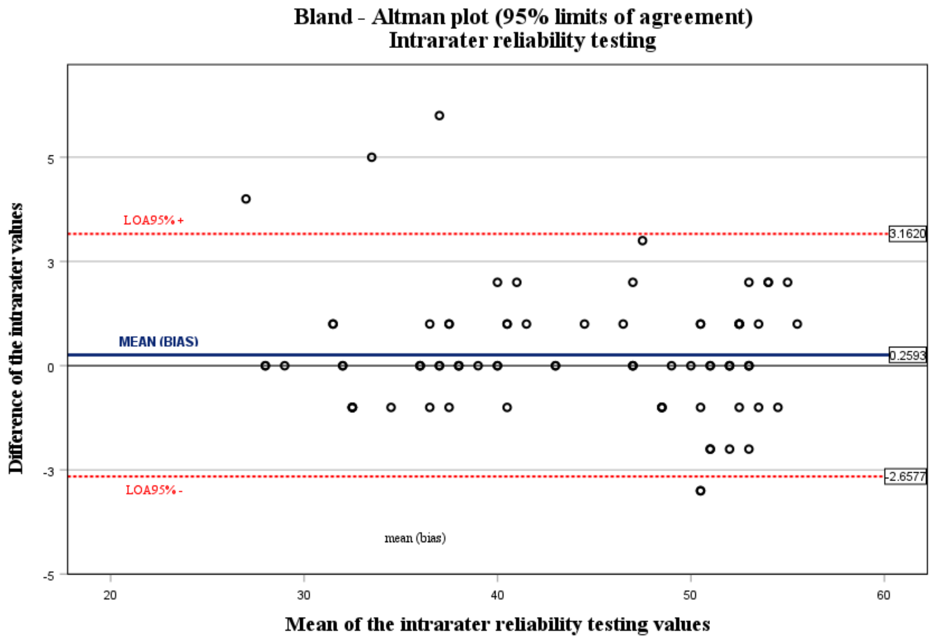


**Figure 6.** Bland–Altman plot showing differences of measurements against their means for intra-rater reliability. The solid line represents the mean difference (bias) between the two scores, and the dotted lines represent the 95% limits of agreement ($LOA_{95\%}$). (Own graph; source: Simon et al., 2023)

### *Construct validity*

The HU-BBS showed a strong positive correlation with the functional status in ADL, a strong negative correlation with the TUG test, and a moderate negative correlation with age (Table 4).

**Table 4.** Correlations between the BBS scores and functional mobility and status in ADL and age

| | BBS scores | |
|---|---|---|
| | *r* | *p* value |
| $TUG_{single}$ test | - .824 | < .0001 |
| Katz index | .833 | < .0001 |
| Age | - .606 | < .0001 |

ADL, activity of daily living; BBS, Berg Balance Scale; $TUG_{single}$, basic version of the Timed Up and Go test

The HU-BBS score did not differ between women and men (mean ± *SD* for women: 42.5 ± 8.06 points vs mean ± *SD* for men: 44.93 ± 8.41 points; $p = .104$). There were no significant differences between sexes for fall and medical history except for osteoporosis, which was more frequent in female participants (Table 5).

**Table 5.** Comparison of medical history and fall history between sexes

| Characteristics | | Values | | *p* value |
|---|---|---|---|---|
| | | Male individuals (n=42) | Female individuals (n=108) | |
| Age (years) | mean ± *SD* | 72.29 ± 7.29 | 74.88 ± 8.2 | .081 |
| | median ($Q_1$; $Q_3$) | 73 (64; 78) | 75 (70; 79) | |
| Osteoporosis, n (%) | | 6 (14.3) | 42 (38.8) | .008 |
| Cardiovascular disease, n (%) | | 15 (37.7) | 60 (55.5) | .051 |
| Pulmonary disease, n (%) | | 7 (16.6) | 14 (12.9) | .761 |
| Diabetes mellitus, n (%) | | 17 (40.5) | 55 (50.9) | .359 |
| Hypertension, n (%) | | 27 (64.3) | 80 (74.1) | .339 |
| Stroke, n (%) | | 6 (14.3) | 17 (15.7) | .808 |
| Fall history, n (%) | | 21 (50) | 60 (55.5) | .751 |

*SD*, Standard Deviation; $Q_1$, lower quartile; $Q_3$, upper quartile

The HU-BBS score was significantly lower for older adults who had fallen than for those who had not (mean ± *SD* = 36.91 ± 5.36 points; vs mean ± *SD* = 50.54 ± 3.48 points; $p < .0001$).

## 4.2. Results of S2[16]

Of the 204 people who filled in the questionnaire, 4 did not complete the $TUG_{single}$ test on functional mobility, so we analysed data from 200 people with a mean age of nearly 73 years; the youngest was 60 years old and the oldest was 93 years old. The proportion of women was 91%. Almost two thirds of the sample lived alone (n=127). More than 40% of participants had osteoporosis (n=84) or musculoskeletal disease (n=88) affecting the lower limb, and one fifth (n=40) had cardiac disease. Other characteristics and the group with and without FoF are shown in Tables 6 and 7.

**Table 6.** Sample characteristics (n=200)

| | Mean (*SD*) / Median ($Q_1$; $Q_3$) or n (%) |
|---|---|
| **Age (years)** | 72.4 (*7.5*) / 71 (65; 77) |
| ***Sex*** | |
| Women | 182 (91) |
| Men | 18 (9) |
| Living alone | 127 (63.5) |
| BMI (kg/$m^2$) | 26.8 (*4.3*) |
| Fall history | 54 (27) |
| ***Chronic diseases*** | |
| Hypertension | 128 (64) |
| Osteoporosis | 84 (42) |
| Musculoskeletal disease affecting the lower limb | 88 (44) |
| Cardiac disease | 40 (20) |
| Diabetes mellitus | 32 (16) |
| Respiratory disease | 18 (9) |
| Neurological disease affecting the lower limb | 8 (4) |
| **Pathological fear of falling** | 61 (31) |

$Q_1$, lower quartile; $Q_3$, upper quartile; BMI, Body Mass Index

[16] Chapter 4.2. summarises the Results section of our crosss-sectional epidemiology survey published in Hungarian in the journal Orvosi Hetilap. Language adaptation from Hungarian to English and some clarifications to synchronise with section 1.4.2 of the dissertation were made by András Simon (author of this dissertation) (Kovács, É., Erdős, R. L., Petridisz, A. N., Rozs, F., & Simon, A. (2019a). Az eleséstől való félelem otthon élő idősek körében [Fear of falling among community-living older adults]. *Orvosi hetilap*, *160*(5), 191–197. https://doi.org/10.1556/650.2019.31267 Hungarian

**Table 7.** Comparison of the group with no fear of falling and the group with a pathological fear of falling

| | No fear of falling (n=139) | Fear of falling (n=61) | *p* value |
|---|---|---|---|
| Age (years), mean ± *SD* | 69.2 ± 5.8 | 79.4 ± 5.9 | < .001 |
| Females, n (%) | 130 (93.5) | 52 (85.2) | .060 |
| Functional mobility ($TUG_{single}$ test), mean ± *SD* | 10.11 ± 2.2 | 15.5 ± 3.3 | < .001 |
| Performance on TUG test above normal (12 s), n (%) | 25 (33.8) | 49 (66.7) | < .001 |
| Takes more than three medications regularly, n (%) | 39 (28) | 30 (49) | .004 |
| Number of chronic diseases, mean ± *SD*<br>median ($Q_1$; $Q_3$) | 1.6 ± 1.1<br>2 (1; 2) | 2.9 ± 1.4<br>3 (2; 4) | < .001 |
| Fall history, n (%) | 28 (20) | 26 (42) | .001 |

*SD*, Standard Deviation; $TUG_{single}$, basic Timed Up and Go test; $Q_1$, lower quartile; $Q_3$, upper quartile;

FoF was common for a total of 61 people (31%; male: n=9; female: n=52). Given that 91% of the sample was female, binary logistic regression analysis was also performed adjusting for sex. Since sex had no significant effect, there was no significant difference between the raw and sex-adjusted regression parameters of the multivariate models (Table 8).

**Table 8.** Results of logistic regression analysis of the association between demographic and health factors and the prevalence of fear of falling

| | Odds ratios and 95% confidence interval; raw values | Odds ratios and 95% confidence intervals; sex-adjusted values |
|---|---|---|
| Age | 1.27 (1.16–1.39) | 1.26 (1.15–1.38) |
| Sex | | 0.41 (0.05–3.44) |
| Number of chronic diseases | 2.37 (1.45–3.87) | 2.27 (1.37–3.77) |
| Functional mobility ($TUG_{single}$) worse than threshold (12 seconds) | 9.02 (3.29–24.68) | 9.05 (3.29–24.92) |
| Fall history | 0.76 (0.27–2.16) | 0.81 (0.28–2.36) |
| Taking more than three medications | 0.46 (0.14–1.51) | 0.48 (0.15–1.61) |

$TUG_{single}$, basic Timed Up and Go test

The graphic representation of the results yielded by the adjusted multivariate model is shown in Figure 7[17]. The horizontal axis with logarithmic scaling is the odds ratio (OR) axis. The vertical line through value 1 corresponds to the null hypothesis, where the factor of interest is unrelated to the FoF. Points to the left of the vertical line indicate a protective effect, while points to the right indicate a threatening effect. When the horizontal bar, the confidence interval bar, for the points is diagonal to the vertical line,

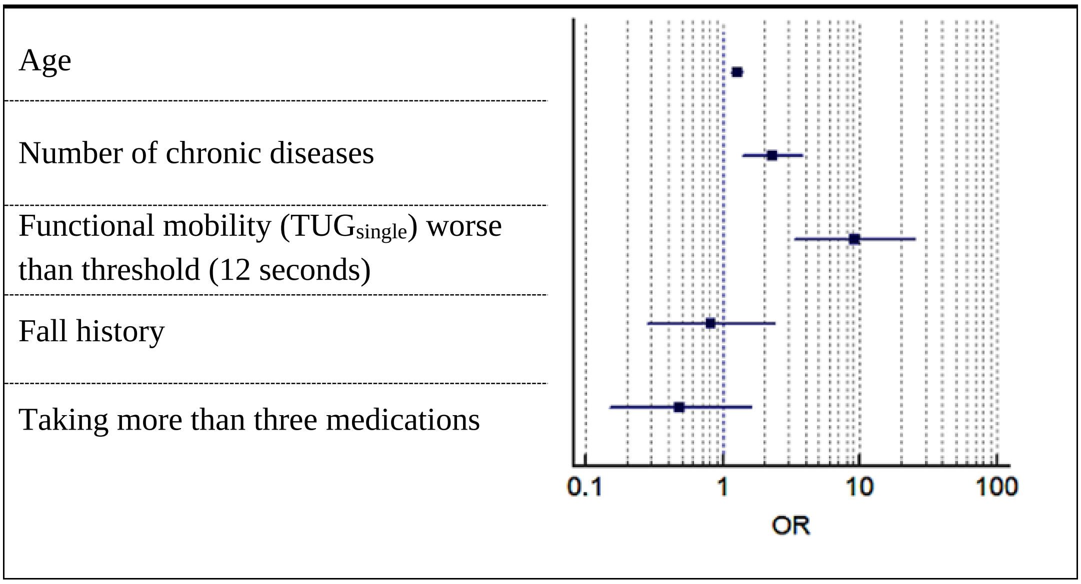


**Figure 7.** The effect of independent variables on fear of falling. (Source: Kovács et al., 2019a)

There is also a significant association between the number of chronic diseases in old age and FoF. Each additional disease more than doubles the probability of having an abnormal FoF. A significant association between functional mobility and FoF was also confirmed. If for an older person it takes longer than the population threshold of 12 seconds to complete the $TUG_{single}$ test, they are more than nine times more likely to develop FoF. The effects of having fallen within the previous year and of taking medicines more than three of the active ingredients examined were not found to be significant.

Our sex-adjusted model with factors showing a significant association explains almost 70% of the variance of the dependent variable (Nagelkerke's $R^2$ = .695).

[17] For the graph presented MedCalc Statistical Software version 18.5 (MedCalc Software bv, Ostend, Belgium; https://www.medcalc.org; 2018) was used.

### 4.3. Results of S3[18]

Sociodemographic data and physical characteristics of the three groups are shown in Table 9. There was no significant difference between the two groups of older individuals in the above characteristics.

**Table 9.** Sociodemographic data and physical characteristics of older and young individuals (data are presented as mean and standard deviation for continuous data and frequency and percentage for categorical data)

| Variables | | Physically active | Physically inactive | Physically inactive | *p* value[a] |
|---|---|---|---|---|---|
| | | older group | older group | young group | |
| | | (n=20) | (n=20) | (n=17) | |
| Age (years) | mean ± *SD* | 69.4 ± 4.7 | 68.7 ± 5.5 | 22.5 ± 2.8 | .650 |
| | median ($Q_1$; $Q_3$) | 68 (66; 73) | 68 (62.75; 72.75) | 22 (21; 24) | |
| Living situation, n (%) | | | | | |
| In family | | 9 (45) | 5 (25) | 7 (41) | |
| Alone | | 11 (55) | 15 (75) | 10 (59) | .320 |
| Female, n (%) | | 17 (85) | 19 (95) | 2 (12) | .605 |
| BMI (kg/m$^2$) | mean ± *SD* | 27.4 ± 3.8 | 28.9 ± 4.6 | 25.2 ± 4.2 | .266 |
| | median ($Q_1$; $Q_3$) | 27.2 (24.94; 29.74) | 27.6 (26.59; 32.29) | 25.1 (21.55; 28.45) | |
| ***Medical history,*** n (%) | | | | | |
| Diabetes mellitus | | 0 | 1 (5) | 0 | > .999 |
| Cardiological disease | | 2 (10) | 3 (15) | 0 | > .999 |
| Pulmonological disease | | 3 (15) | 1 (5) | 0 | .605 |
| Hypertension | | 9 (45) | 14 (70) | 0 | .110 |
| Osteoporosis | | 7 (35) | 7 (35) | 0 | > .999 |

*SD*, Standard Deviation; $Q_1$, lower quartile; $Q_3$, upper quartile;
[a] between the two older groups

[18] Chapter 4.3. predominantly summarises the Results section of our third study published in The Journal of sports medicine and physical fitness in 2019. (Kovács, É., Simon, A., Petridisz, A. N., Erdős, R. L., Rozs, F., & Virág, A. (2019b). Gait parameters in physically active and inactive elderly as well as young community-living people. The Journal of sports medicine and physical fitness, 59(7), 1162–1167. https://doi.org/10.23736/S0022-4707.18.09205-8). Some minor editing and paraphrasing was done by András Simon (author of the dissertation), mainly to meet the formal requirements and to synchronise with section 1.4.2 of the dissertation. Additionally, the quartile values (*Q1*, *Q2* (median) and *Q3*) have been added (based on the original dataset) to Tables 9 and 10 to meet the requirements of the in-house defense committee as documented in the in-house defense report.

#### 4.3.1. Gait variability

Based on the results of Welch's adjusted F-statistics and, where appropriate, the Games-Howell method, the following statements were made.

There was a statistically significant difference in step length variability between the groups ($F(2, 28.01)=30.947$, $p < .001$). The results of the post hoc test showed that the inactive older group had significantly higher step length variability compared to both the active older group ($p = .007$) and the young group ($p < .001$) (Table 10; Figure 8A). Simultaneously, there was also a significant difference between the active older group and the young group ($p < .001$).

There was also statistically significant difference between the groups in terms of step time variability ($F(2, 27.25) = 12.406$, $p < .001$). The post hoc test showed that the inactive older group had significantly higher step time variability compared to both the active older group ($p = .002$) and the young group ($p < .001$). Conversely, the difference between the active older group and the young group was not statistically significant ($p = .172$). (Table 10; Figure 8B)

Regarding double support ratio variability, there was a statistically significant difference between the groups ($F(2, 29.37)=7.204$, $p = .003$). According to the results of the post hoc test, the variability of the double support ratio was significantly higher in the inactive older group compared to both the active older group ($p = .036$) and the young group ($p = .001$). The difference between the active older group and the young group, however, was not statistically significant ($p = .206$). (Table 10; Figure 8C)

**Table 10.** Gait parameters and automaticity index in the three groups

| Variables | Physically active older group (n=20) | Physically inactive older group (n=20) | Physically inactive young group (n=17) |
|---|---|---|---|
| Step length variability (%) | | | |
| mean ± *SD* | 11.2 ± 4.9 | 18.5 ± 8.8 | 5.2 ± 1.6 |
| median ($Q_1$; $Q_3$) | 10 (7.48; 13.35) | 16.9 (10.43; 25.67) | 4.87 (4.46; 6.53) |
| Step time variability (%) | | | |
| mean ± *SD* | 6.1 ± 4.1) | 16.8 ± 11.7 | 4.3 ± 1.0 |
| median ($Q_1$; $Q_3$) | 4.33 (4.01; 5.63) | 17.4 (6.88; 22.07) | 4.05 (3.71; 5.03) |
| Double support ratio variability (%) | | | |
| mean ± *SD* | 7.9 ± 3.6 | 13.3 ± 10.5 | 5.0 ± 1.4 |
| median ($Q_1$; $Q_3$) | 6.56 (5.04; 9.96) | 8.18 (5.65; 20.5) | 6.18 (4.85; 6.55) |
| Step width variability (%) | | | |
| mean ± *SD* | 15.1 ± 6.1 | 18.8 ± 9.2 | 15.4 ± 7.6 |
| median ($Q_1$; $Q_3$) | 13.33 (10.84; 16.66) | 15.38 (8.52; 24.28) | 15.38 (9.72; 18.18) |
| Automaticity index (%) | | | |
| mean ± *SD* | 89.4 ± 7.9 | 81.6 ± 6.8 | 89.5 ± 6.4 |
| median ($Q_1$; $Q_3$) | 91.6 (83.63; 96.57) | 83.15 (74.20; 86.44) | 90.00 (85.16; 94.22) |

*SD*, Standard Deviation; $Q_1$, lower quartile; $Q_3$, upper quartile

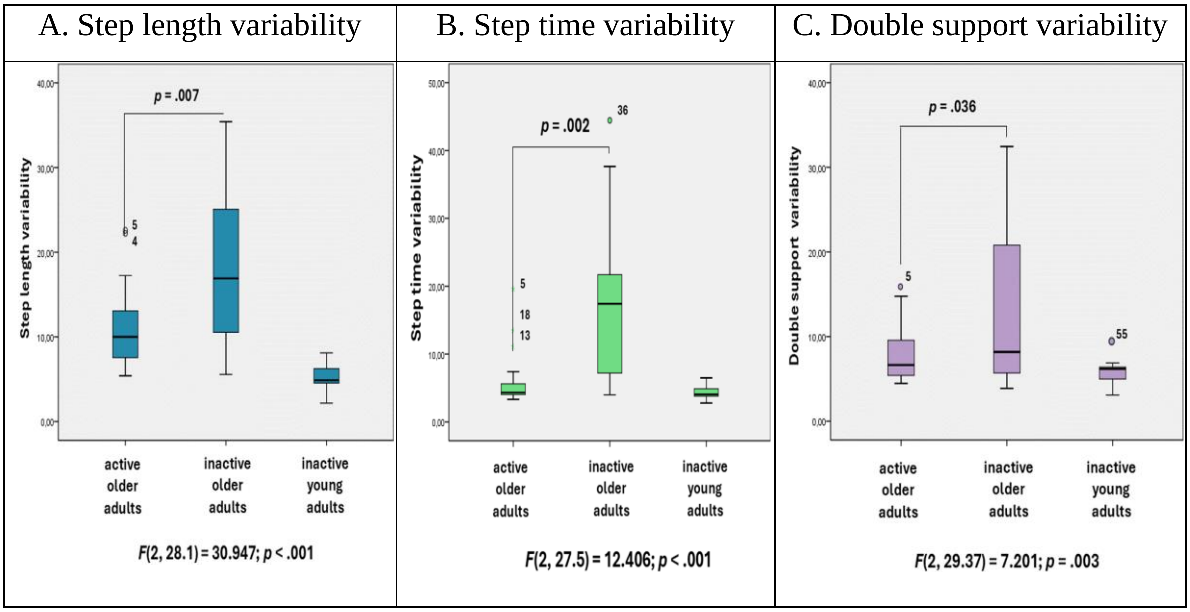


**Figure 8**. Gait parameters with statistically significant differences.

(Own graph; based on data of Kovács et al., 2019b)

For step width variability, the Welch's ANOVA showed no difference between groups ($F(2, 32.26)=0.957$, $p = .338$).

### 4.3.2. Automaticity Index

In terms of Cognitive Automaticity Index (CAI), a statistically significant difference among groups ($F(2, 54)=7.881$; $p = .001$) was revealed. Post hoc tests verified that the CAI in the inactive older group was significantly lower compared to the active older group ($p = .006$) and the young group ($p = .003$). Conversely, no significant difference was proved between the active older group and the young (inactive) group ($p = .998$). (Figure 9)

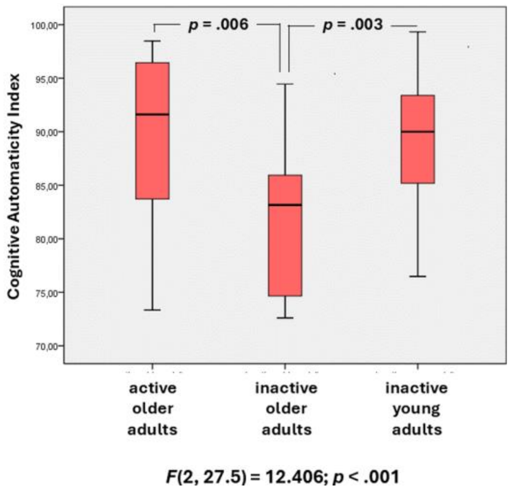


**Figure 9**. Cognitive Automaticity Index

(Own graph; based on data of Kovács et al., 2019b)

# 5. Discussion

The research at the core of this dissertation demonstrated the physiotherapist's role in the development and validation process of a national version of an existed and widely used measurement tool via cross-cultural adaptation to the Hungarian language and investigating its psychometric properties. We also investigated how to identify older people at risk of falling implementing a valid measurement tool already adapted to the Hungarian language. Furthermore, as the third pillar of the physiotherapist's contribution to special exercise therapy aiming to improve postural control, we assessed whether a programme that primarily aims to improve fitness variables could have an impact on parameters relevant to fall risk. The following section provides a discussion of each of our results yielded from each study.

## 5.1. Discussion of the results from S1

Our study primarily aimed to develop a BBS adapted to the Hungarian language for the population of older people living in long-term care facilities. Our further investigation has demonstrated the validity and reliability of the HU-BBS measure.

The problems of understanding that arose during cultural adaptation were only a few minor ones. As has been detailed in Methods section, some instructions and scoring terms have been adapted by changing or refining phrases to a certain degree to make the task easier to conceive and to be accurately performed by the Hungarian participants.

The psychometric properties of the HU-BBS (both reliability and validity domains) were found to be similar to those of the original (English) BBS and of its subsequent adaptations to other languages (Berg et al., 1992; Halsaa et al., 2007; Jung et al., 2006; Lampropoulou et al., 2016; Matsushima et al., 2014; Miyamoto et al., 2004; Ottonello et al., 2003; Sahin et al., 2008; Salavati et al., 2012; Wang et al., 2006).

The Cronbach's alpha coefficient, which indicates the internal consistency of the scale with a value between .7 and .95, represents a higher index of consistency (Terwee et al., 2007). In our study, the Cronbach's alpha for the whole scale was .943. This value is in line with the results of Turkish ($\alpha$ = .98), Italian ($\alpha$ = .95), Japanese ($\alpha$ = .933) and Persian ($\alpha$ = .90) studies, but slightly higher than the value published in the Norwegian study ($\alpha$ = .87) (Halsaa et al., 2007; Jogi et al., 2011; Matsushima et al., 2014; Sahin et al., 2008; Salavati et al., 2012).

According to the Bland-Altman analysis the absolute reliability of the test-retest was confirmed, as the 95% confidence interval included the zero-difference line and a meaningful majority of the values were within the limits of agreement. Another absolute reliability index, the $MDC_{95\%}$, with its 95% confidence interval, indicates the minimum change in an individual's score on a measurement instrument that should be observed for a change in score to be attributed to something other than simple random measurement error (Beninato and Portney, 2011). A score higher than the $MDC_{95\%}$ is attributed to a true change in the subject's condition and not to measurement error (Beninato & Portney, 2011). In our study, the HU-BBS $MDC_{95\%}$ was 2.89 points and 2.46 points for intra- and for inter-rater reliability, respectively.

As far as the construct validity is concerned, all the hypotheses previously proposed were confirmed. We assumed that the correlation between HU-BBS and ADL functional status will be at least .70. A strong positive correlation was found. The same correlation was also reported in validation studies of the Italian (.64) (Ottonello et al., 2003) and Turkish (.750) (Sahin et al., 2008) versions. We also hypothesised that HU-BBS would show a strong negative correlation with the TUG test. Confirming our assumption, a strong negative correlation was found. This result is in line with the previously published results for the Greek (- .781) (Lampropoulou et al., 2016) and Turkish (- .750) adaptations (Sahin et al., 2008). We also hypothesised that the BBS scores are negatively correlated with age. Similar to the Norwegian study (Halsaa et al., 2007), we found a moderate negative correlation between HU-BBS and age. Furthermore, it was also hypothesised that there would be no difference between the HU-BBS scores of women and men. Like the Norwegian study, we also found similar BBS scores for women and men (Halsaa et al., 2007). We also hypothesised – using the terms of Lin & Woollacott (2002) applied in section 1.3.2. and 3.2.2. of this work as well – that the HU-BBS score would be lower among ‘fallers’ (those who had fallen at least once in the previous year than among ‘non-fallers’ (those who had not fallen). We found that HU-BBS scores were significantly lower among participants who had a history of falls, confirming our preliminary hypothesis. Studies examining differences in BBS scores between participants labelled faller and those who were labelled non-faller have reached the same result (Bogle Thorbahn & Newton, 1996; Viveiro et al., 2019).

S1 has some limitations. One of them is that all participants were recruited from a long-term care facility. Thus, older people living in the community were not represented in the cohort. Furthermore, participants were recruited from a single institution, which may also affect the generalisability of our results. Another limiting factor is that we did not examine the responsiveness of HU-BBS. In addition to the limitations mentioned above, we excluded older adults with severe dementia and Parkinson's disease from our sample, which may also have affected the generalisability of our results. In addition, a previous study by Downs and colleagues highlighted that the Berg Balance Scale score of individuals who are unable to stand independently and those who are able to is characterized by a cut-off score of 20 points (Downs et al., 2014). This means that the $MDC_{95\%}$ found in our study cannot be generalised to people with a very poor balance skill. Since falls can potentially lead to FoF, limited activity and poorer balance, a prospective study may show a low BBS score as a predictor of fall risk. Future studies with a larger, representative, stratified Hungarian sample would provide normative data for several subgroups, including those excluded from the present study forming the basis of this dissertation.

### 5.2. Discussion of the results from S2

In S2, the contribution of physiotherapists to improving postural control in older people was presented from another aspect. The next pillar of the intervention to improve postural control is the identification of FoF using an already adapted questionnaire survey. With FoF being a major risk factor for functional decline and a major driver of loss of postural control, there is a great need to identify individuals with this burden of FoF. Consequently, in this section we demonstrate the implementation of FES-I questionnaire to identify older people at higher risk for fall.

We investigated the relationship between demographic factors (age, sex) and health-related factors (chronic diseases, functional stability, falls within the previous year, medication) and FoF among Hungarian older people living at home. Our results suggested that age, chronic diseases, and poor functional mobility can increase the risk of developing FoF, while associations with sex, fall history, and medication use were not confirmed.

The literature suggests that FoF affects a significant proportion of older people. Murphy and Williams (on a sample over 72 years) estimate the prevalence at 24%, Arfken (on a sample over 66 years of age) at 29%, and Vellas (on a sample over 60 years of age) at 32% among community-dwelling older people with independent living. In a survey of a large sample of 70+ years of age, Zijlstra found a prevalence of 54.3% (Arfken et al., 1994; Murphy et al., 2002; Vellas et al., 1997; Zijlstra et al., 2007a).

We found a prevalence of 31% in our sample.

Several studies have also investigated whether FoF among older people is correlated with demographic (age, sex) and health-related (comorbidities, physical functional ability, falls) factors.

### 5.2.1. Correlation with age and sex

Research shows that FoF is associated with age and sex, although the results are not consistent. Some of the results suggest that the phenomenon is more common among women and that its prevalence increases with age. According to Arfken's results, 21% of women and 14% of men aged 66–70 years and over have FoF, while over 81 years these rates rise to 45% and 21% (Arfken et al., 1994). Zijlstra reports that the risk of developing FoF increases by nearly 80% over the age of 80 (*OR*: 1.79, 95% CI: 1.49–2.16) (Zijlstra et al. 2007a), and Kempen reports that women are more likely to have FoF (*OR*: 2.28, 95% CI: 1.41–3.69) (Kempen et al., 2009).

In contrast, two other studies have found no correlation between age and FoF (Howland et al., 1993; Kressig et al., 2001). Furthermore, Howland found no significant difference in prevalence between the two sexes (Howland et al., 1993).

### 5.2.2. Correlation with comorbidities

Individuals with certain neurological conditions (stroke, Parkinson's disease), hypertension, arthrosis, and osteoporosis are more likely to report a FoF (Cumming et al., 2000; Friedman et al. 2002; Fletcher & Hirdes, 2004). Fletcher's cross-sectional study investigated the extent to which comorbidities associated with ageing contribute to limiting the daily activities of older individuals. He showed that heart disease contributed by 36% (*OR*: 1.36, 95% CI: 1.04–1.49), arthritis by 45% (*OR*: 1.45, 95% CI: 1.17–1.80), osteoporosis by 55% (*OR*: 1.55, 95% CI: 1.13–2.12), and glaucoma or cataract by 30% (*OR*: 1.30, 95% CI: 1.01–1.67) to the increase in the likelihood that an older adult would refrain from physical activities that they would otherwise be able to do for FoF (Fletcher & Hirdes, 2004). Medication use was also significantly correlated with FoF. Friedman has shown that those who regularly take more than four medications are 68% more likely (*OR*: 1.68, 95% CI: 1.34–2.12) to have an unjustified fear of falling (Friedman et al., 2002).

### 5.2.3. Correlation with physical functional status

Most studies have shown a significant correlation between FoF and more unstable balance and poorer walking ability. Older people with FoF had significantly weaker lower limb musculature and poorer gait test scores (Gillespie & Friedman, 2007). In Arfken's study, 91% of older people with FoF had at least one of the functional impairments (difficulty walking, inability to walk upstairs unaided, visual impairment, perceived poor health, and use of walking aids). In contrast, only 59% of those without FoF had any of the above (Arfken et al., 1994). This is confirmed by Vellas' study, in which older people with FoF were significantly more likely to have a walking (31.9%) or balance disorder (31%) compared to those without FoF (7.4% and 12.8%) (Vellas et al., 1997). In Kressig's prospective study, those with a walking speed of less than 0.9 m/s were three times more likely to develop FoF (*OR*: 3.1, 95% CI: 1.9–5.1) (Kressig et al., 2001). Brouwer's results showed that older people with FoF had a 12% lower walking speed, significantly weaker lower limb muscle strength and had more difficulty getting up from a chair (Brouwer et al., 2004). However, in Lach's 2-year follow-up study, there was no evidence that the risk of developing FoF was higher in those who needed help to walk upstairs (*OR*: 1.03, 95% CI: 0.51–2.05), used a walking aid (*OR*: 0.11, 95% CI: 0.14–1.56), or had poorer balance (*OR*: 1.06, 95% CI: 0.79–1.43) (Lach, 2005).

### 5.2.4. Correlation with falls

Studies show a correlation between falls and FoF. In a 12-month follow-up study, Arfken showed that 9% of people with FoF had a history of a fall with a fracture, compared with only 0.5% of people without FoF (Arfken et al., 1994). Kempen reported that a fall within the previous six months increased the risk of FoF by almost 50% (*OR*: 1.49, 95% CI: 1.01–2.20) (Kempen et al., 2009). Zijlstra found that older people who had a fall within the year prior to the survey were almost six times more likely to develop FoF again (*OR*: 5.72, 95% CI: 4.49–7.43) (Zijlstra et al., 2007[a]). This is confirmed by Lach who, in a 2-year follow-up study, showed that more than two falls increased the likelihood of an older person developing a fear of another fall by almost four times (*OR*: 3.90, 95% CI: 1.14–13.37) (Lach, 2005).

There is also a mutual relationship between falling and FoF. Older people who fear falling are indeed at higher risk of falling. In Cumming's 12-month follow-up study, the risk of falling was twice as high for those who were afraid of falling than for those who were not (*RR*: 2.09, 95% CI: 1.31–3.33) (Cumming et al., 2000). The temporal relationship between falls and FoF was investigated by Friedman in a prospective study of a sample of 2212 people. He measured the number of older people reporting falls and FoF at the beginning and end of a 20-month follow-up period (Friedman et al., 2002). It showed that those with a history of falls at the beginning of the study were 75% more likely to report FoF 20 months later (*OR*: 1.75, 95% CI: 1.30–2.36).

At the same time, the relationship is reciprocal, too. Those who experienced FoF were 79% more likely to fall by the end of the follow-up period (*OR*: 1.79, 95% CI: 1.33–2.42). Whether older people experienced falling itself or had only FoF, there was a risk of starting a cascade-like process leading to functional decline.

Our research confirms the findings of studies showing that increasing age, chronic diseases in old age, and declining functional mobility are associated with FoF. Therefore, it is necessary to identify older people with multiple chronic diseases and declining functional mobility in older age groups using the easy-to-complete short FES-I questionnaire, in order to determine risk factors for falls among older people through detailed interviews, physical examinations, and systematic exploration of hazards in the home environment (Panel on Prevention of Falls in Older Persons, AGS & BGS, 2011; Rogers et al., 2021). The older person can then be involved in a multimodal programme in the frame of which the role of a physician treating chronic illnesses together with the contributions of a psychologist or psychiatrist via cognitive behavioural therapy can be complemented with a physiotherapist's work in the form of an appropriate exercise programme (Dorresteijn et al., 2016; Zijlstra et al., 2007b).

**Limitations**

A limitation of our study is the selectivity of convenience sampling. People over 60 years of age, highly over-representing the female sex, able to move (even if with an assistive device), and with certain degree of social life were selected, limiting the generalisability of our results to this population in particular.

## 5.3. Discussion of the results from S3

The aim of the third study (S3) was to assess the effects of a multimodal exercise programme on gait in older people. Therefore, gait variability and automaticity were compared between the following groups: 1) physically active older people participating in a geriatric exercise programme; 2) physically inactive ones; and 3) young (inactive) people.

We found that physically inactive older individuals had significantly worse variability in step length, step time, and double support ratio, as well as a significantly worse cognitive automaticity index compared to physically active older and young (inactive) individuals. However, the variability of step width did not differ amongst the three groups.

The results of this study were compared with the results of studies focusing on gait safety through improving gait variability or gait automaticity using a sample of older adults in the community.

Most studies reported positive effects of different exercise programmes on gait characteristics.

Accordingly, in a study by Halvarsson et al. involving a sample of 59 older people (mean age=76 years; female n=58) a significant improvement in dual task performance was demonstrated after a 12-week progressive balance training programme including cognitive and motor secondary tasks (Halvarsson et al., 2011). Similarly, in a sample of 29 older adults (mean age=70.4 years; female n=21) Wang et al. also found a significant improvement in gait variability after a 12-week combined exercise programme that comprised of components addressing endurance, balance, and strength (Wang et al., 2015). A few years later, Wang et al. evaluated the impact of the same 12-week programme on dual task performance (n=27; mean age=70.6 years; female n=20). The automaticity of gait has also been positively affected by this programme (Wang et al., 2018).

Manor et al. found a significant improvement in gait velocity after a 12-week traditional tai chi programme (n=57; mean age=87 years; female n=45) (Manor et al., 2014).

Trombetti et al. investigated the effects of the Jaques-Dalcroze eurhythmia, a 25-week music-based multitask training programme consisting of rhythmic movements (Trombetti et al., 2011). Their sample (n=134; mean age=75.5 years; female n=129) showed a significant reduction in stride length variability. Eggenberger et al. reported similar beneficial effects in a sample of 71 older people (mean age=78.8 years; female n=46) following a six months of multi-component balance and strength training. The training was complemented with virtual reality video game dancing or treadmill walking, and concurrent verbal memory tasks (Eggenberger et al., 2015).

In contrast, some studies have found no improvement in gait parameters after exercise programmes tested in these studies. For example, a previous study showed that gait variability did not change after an eight-week salsa dance programme in a sample of 28 people (mean age=73.5 years; female n=14) (Granacher et al., 2012). In addition, Newell et al. have found that an eight-week supervised Pilates programme had no effect on gait variability in a sample of 9 people (age range=60–76 years) (Newell et al., 2012).

Discrepancies between the results could be explained by different dosages or training volumes (e.g., frequency ranged from once a week to three times a week; duration ranged from eight weeks to six months). In the above-mentioned studies, longer training programmes showed improvements in gait parameters (i.e. gait variability and automaticity); while shorter programmes did not have the same effect (Halvarsson et al., 2015).

The results of this study are consistent with those of others that also reported improvements in gait variability and automaticity.

## Limitations

Some limitations of our study must be considered. First, the majority of participants were female. Possible reasons for the sex disparity in participation, such as women are more willing to participate in physical exercise programmes, are still an open question. Future research may provide the answer. However, this may certainly limit the generalisability of our results for S3. In addition, the retrospective study design used may reduce the strength of the evidence presented. Therefore, further prospective controlled studies are needed to confirm the positive effects of the geriatric exercise programme on gait parameters. Future prospective studies would also benefit from measuring gait parameters on a weekly basis; this regular data collection would provide indirect evidence of the success of the physical activity programme.

## Key contributions of the three studies carried out

Despite the limitations of S1, it should be emphasised that our study is a gap-filler. The BBS is already widely used by clinicians working in geriatric and neurological settings, but the development of a valid and reliable Hungarian version as a result of our validation study will make our own national results internationally comparable.

Our S2 study demonstrated that the easy-to-use, valid, and reliable Hungarian FES-I questionnaire can be implemented to identify older people at higher risk for pathological FoF and to refer them to further investigations and for appropriate interventions in time. These interventions may include movement therapies as well, such as MMEP assessed in S3, to maximise functional capacity and compress functional decline.

The novelty of S3 is that such MMEP, originally designed to improve and maintain fitness variables, has also been shown to have a positive effect on gait variability and gait automaticity. Further controlled studies will provide stronger evidence of the beneficial effects of the programme in this direction. Based on the results of the present study, a targeted sample size analysis can be made to ensure that future research with a control group is conducted with the sufficient number of participants to secure adequate statistical power, while not to unnecessarily exclude any older people who may benefit from the proven effect of the programme on fitness variables.

# 6. Conclusions

The research presented in this dissertation has highlighted the key role that physiotherapists can play in helping older people to maintain their functional abilities, so that they can live independently for as long as possible and at the highest possible level. This key role of physiotherapists is threefold: developing valid and reliable diagnostic tools, implementing diagnostic tools with sound clinimetrics already assessed, and assessing interventions that are proven to be effective for improving postural control. Valuable diagnostic tools can help physiotherapists to identify individuals at risk of functional decline at an early stage, and effective therapeutic procedures can help to successfully improve declining abilities, making the compression of functional decline and thus successful ageing possible.

## 6.1. Conclusions from S1

The BBS is a widely used measurement tool for comprehensively assessing the balance of older adults in various settings. Owing to its ease of use, it can be applied not only among older adults, but also among people with various diseases and health conditions.

Our study shows that the Hungarian version of the BBS, similar to those of other languages, has good clinimetrics. After testing on our sample of institutionalised older people, this instrument has relative and absolute reliability indices akin to those other culturally adapted versions. Based on the investigation of its construct via discriminant, convergent, and known-group validity, it was found to be a valid tool as those of other cross-culturally adapted versions. Therefore, the HU-BBS can be recommended for use in assessing balance in Hungarian people not only in everyday clinical practice, but also in single- and multi-centre scientific studies, which might allow comparison of data cross-culturally.

## 6.2. Conclusions from S2

Fear of falling is considered abnormal when it causes older people to avoid activities they would otherwise be able to do. As a result of a self-perpetuating mechanism, their physical condition is rendered to be poorer, their muscles weaken, their balance control deteriorates, and eventually they lose their ability to care for themselves and become institutionalised. In order to prevent this self-perpetuating vicious circle from developing, persisting, and worsening, it is very important to identify older people who are overwhelmed with unreasonable concerns of falling during their daily activities in a timely manner and to involve them in an adequate prevention programme. The short FES-I questionnaire, which is simple and quick to fill out and validated in Hungarian, is particularly useful for screening older people with multiple chronic conditions. By means of the short FES-I we can identify those who are in the need of further detailed screening, a thorough examination. Based on the results, when identified, they can more easily and quickly be involved in targeted interventions.

### 6.3. Conclusions from S3

The most common and fundamental activity of independent daily living is safe gait. Previous studies have already proved the beneficial effects of diverse exercise programmes on gait safety improvement among older people. Our study demonstrated that the beneficial effects of the multimodal exercise programme employed on gait parameters is similar to those other multimodal exercise trainings, Jaques-Dalcroze eurhythmics, traditional tai chi, or dance-like movements which are already widely used to improve gait safety. Owing to the preferences of the older people influencing their adherence to an exercise programme, it is of high importance that diverse exercise programmes aiming at improving gait safety should be available for this population. The multimodal exercise programme applied in our study certainly enriches the range of available effective geriatric exercise programmes.

Successfully delaying functional decline starts with identifying individuals at higher risk as early as possible. Multimodal programmes have been found to be effective in improving gait parameters that are not only associated with the risk of falling but are also determinants of functional capacity.

In the light of the above, we recommend both the widespread use of HU-BBS and FES-I for screening older patients in clinical settings and the wider availability of multimodal programmes for the older people with a similar design to the exercise programme used in this study. These can make a valuable contribution to successful ageing.

## 7. Summary

The alarming statistics discussed in the introduction show that, as life expectancy increases, more and more older people live their lives with limited functional capacity and dependent on others' help. Physiotherapists have an important role to play in helping older people to maintain their functional abilities to live independently for as long as possible and at the highest possible level. Modern diagnostic tools help physiotherapists in screening individuals at risk of functional decline in a timely manner and, with effective therapeutic procedures physiotherapists can successfully improve skills that are in decline. In the research on which the dissertation is based, we focused on two diagnostic tools and one therapeutic procedure. In this section the findings and contributions made will be summarised.

In S1 the adaptation of the BBS to Hungarian was developed and the clinimetrics of the adapted version were assessed. The novel results of the research with which we have provided the Hungarian physiotherapist profession show that the HU-BBS has as good psychometric properties as the original English and other national versions; therefore, it is possible to evaluate the data obtained from the Hungarian population in the light of the international literature. Furthermore, the role of Hungarian researchers in international research collaboration can be enhanced.

In S2 the clinical implementation of the Hungarian version of the FES-I questionnaire was presented. It has been validated earlier and can be used at ease to identify persons at risk of falling by physiotherapists as well. From the novel results of our research presented in S2 it is clear that older people with multiple chronic conditions and reduced functional mobility in particular should be identified and referred for further detailed investigation in order to engage them in timely targeted movement therapy for fall-prevention (and in cognitive-behavioural therapy if needed).

In S3 the effects of a multimodal exercise programme were assessed on gait parameters, on their variability, and on gait automaticity. It is worth highlighting our interesting novel findings revealed by S3: the multimodal programme developed for improving fitness indicators can also be used to improve gait parameters associated with the risk of falling at the same time. Consequently, our results cast a new light on how this multimodal exercise programme can improve gait safety and thus the functional capacity of older people.

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# 9. Bibliography – list of own publications

## 9.1. Publications that formed the basis of the dissertation

**Simon, A**., Gyombolai, Zs., Kubik, A. Zs., Báthory, Sz., Jónásné Sztruhár, I., Fábián, G. & Kovács, É. (2023) Cross-cultural validation of the Berg balance scale to assess balance among Hungarian institutionalised older adults *Disability and Rehabilitation*, DOI: 10.1080/09638288.2023.2232717

Kovács, É., Erdős, R. L., Petridisz, A. N., Rozs, F., & **Simon, A.** (2019). Az eleséstől való félelem otthon élő idősek körében [Fear of falling among community-living older adults]. *Orvosi hetilap*, *160*(5), 191–197. https://doi.org/10.1556/650.2019.31267 Hungarian

Kovács, É., **Simon, A**., Petridisz, A. N., Erdős, R. L., Rozs, F., & Virág, A. (2019). Gait parameters in physically active and inactive elderly as well as young community-living people. *The Journal of sports medicine and physical fitness*, *59*(7), 1162–1167. https://doi.org/10.23736/S0022-4707.18.09205-8

## 9.2. Publications in the field of geriatric physiotherapy care as first and co-author.

Kovács, É. & **Simon, A** (2023). Az eleséstől való félelem a geriátriai betegek körében: narratív áttekintő közlemény. [Fear of Falling among Geriatric Patients: a Narrative Review.] *Nővér, 36*(6), 12–18. https://doi.org/10.55608/nover.36.0027 Hungarian

**Simon, A.**, Vass, Z., Farkas, V., Gyombolai, Z., & Kovács, É. (2020). Az ülő életmóddal kapcsolatos tényezők idősotthonban élő, járásképes idős személyek körében. [Factors associated with sedentary lifestyle among older people with the ability to walk, living in nursing homes] *Orvosi Hetilap OH, 161*(28), 1175–1180.

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Erdős, R.L., Jónásné Sztruhár, I., **Simon, A**., & Kovács, É. (2020). Factors associated with postural control in nursing home residents: Oral presentation at the 13th Conference of the Hungarian Medical Association of America – Hungary Chapter

(HMAA-HC) at 30–31 August 2019, in Balatonfüred, Hungary. *Developments in Health Sciences*, *2*(4), 104–107. https://doi.org/10.1556/2066.2019.00005

Kovács, É., Sztruhár, I. J., Mészáros, L., Gyombolai, Z., **Simon, A**., & Farkas, V. (2019). Comparative analysis of functional mobility among Hungarian community-living and institutionalized elderly individuals. *Developments in Health Sciences DHS*, *2*(2), 46–50. https://doi.org/10.1556/2066.2.2019.007

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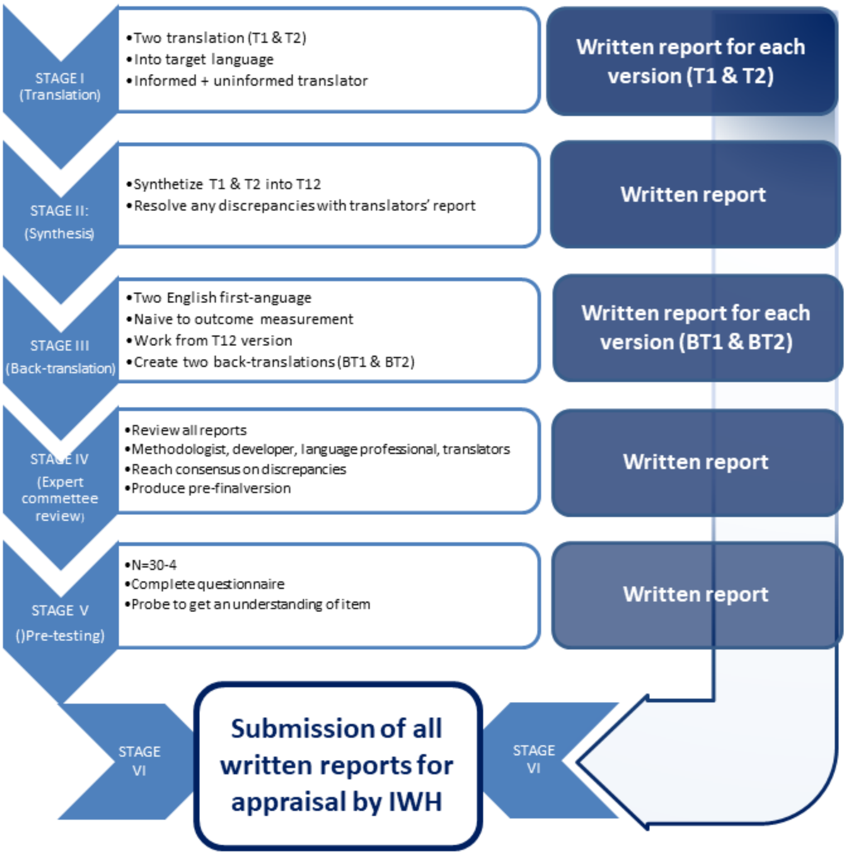
## 11. Supplementary materials

**11.1. Recommended process of cross-cultural validation** (Beaton et al., 2000, 2007; Gjersing et al., 2010)



**11.2a. Personal data sheet (1) for S2 - Short FES-I Hungarian** (Kovács et al., 2018)

**Short FES-I**

Azt szeretnénk megtudni, mennyire foglalkoztatja Önt egy esetleges elesés. Kérjük, képzelje el, hogy az adott tevékenységet a megszokott módon végzi. Ha mostanában nem végzi valamelyik tevékenységet, akkor válaszoljon arra, hogy HA végezné, mennyire foglalkoztatná az elesés. A következő tevékenységek mindegyikénél tegyen keresztet abba a négyzetbe, mely leginkább jelzi azt, hogy ha azt a tevékenységet végezné, mennyire foglalkoztatná az elesés.

| | | *Egyáltalán nem foglalkoztat 1* | *Egy kissé foglalkoztat 2* | *Meglehetősen foglalkoztat 3* | *Nagyon foglalkoztat 4* |
|---|---|---|---|---|---|
| 1 | Öltözködik vagy vetkőzik | *1* ☐ | *2* ☐ | *3* ☐ | *4* ☐ |
| 2 | Fürdik vagy zuhanyozik | *1* ☐ | *2* ☐ | *3* ☐ | *4* ☐ |
| 3 | Leül egy székre vagy felkel egy székről | *1* ☐ | *2* ☐ | *3* ☐ | *4* ☐ |
| 4 | Felmegy vagy lemegy a lépcsőn | *1* ☐ | *2* ☐ | *3* ☐ | *4* ☐ |
| 5 | Nyúl valamiért, ami a feje feletti magasságban vagy a talajon van | *1* ☐ | *2* ☐ | *3* ☐ | *4* ☐ |
| 6 | Lejtőn jár felfelé vagy lefelé | *1* ☐ | *2* ☐ | *3* ☐ | *4* ☐ |
| 7 | Társasági eseményre megy (pl. templomba, családi összejövetelre vagy klubba) | *1* ☐ | *2* ☐ | *3* ☐ | *4* ☐ |

## **11.2b. Personal data sheet (2) - data collection for S2** (Kovács et al., 2019)

**Sorszám:…………… Vizsgálat dátuma: ………év ………hó ……nap**

SZÜLETÉSI IDŐ: ……… év

**Az Ön neme:**

| | |
|---|---|
| férfi | □ |
| nő | □ |

**Az Ön családi állapota:**

| | |
|---|---|
| házas, élettársi kapcsolatban | □ |
| özvegy | □ |
| elvált | □ |
| nőtlen/hajadon | □ |

**Egyedül él?**

| | |
|---|---|
| nem | □ |
| igen | □ |

**Történt-e az <u>elmúlt egy évben</u>, hogy elesett?**
Elesésnek számít például az is, ha ülő helyzetből felállva visszahuppan az ágyra/székre, vagy az is, ha az egyensúlyát elveszítve a falnak/bútornak nekiesik.

| | |
|---|---|
| igen | □ |
| nem | □ |

**Ha igen, hány alkalommal? …………………………………**

**Fel tudná-e sorolni , hogy ÖN milyen gyógyszereket szed rendszeresen?**

| | |
|---|---|
| igen | □ |
| nem | □ |

1

**Ha IGEN, kérem, sorolja fel:**

……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………

**Tudomása szerint fennállnak-e Önnél az alábbi betegségek? Többet is bejelölhet.**

| | igen | nem |
|---|---|---|
| szívbetegség | ☐ | ☐ |
| tüdőbetegség | ☐ | ☐ |
| cukorbetegség | ☐ | ☐ |
| Parkinson betegség | ☐ | ☐ |
| magas vérnyomás | ☐ | ☐ |
| agyérbetegség | ☐ | ☐ |
| alsó végtagot érintő ízületi betegség | ☐ | ☐ |
| csontritkulás | | |
| járási segédeszközhasználat | | |
| támbot | ☐ | ☐ |
| járókeret | ☐ | ☐ |
| gurulós járókeret | ☐ | ☐ |

Az alábbi bekeretezett részt a gyógytornász tölti ki!

TUG teszt

| | |
|---|---|
| 1. mérés | …….mp |
| 2. mérés | …….mp |

2

### 11.3. Elements of the multimodal exercise programme applied in S3

| Aerobic exercises: cyclic movement of large muscle groups |
|---|
| ○ Light jogging forwards and backwards<br>○ Opposing arm and leg swings<br>○ Reaching out while jogging<br>○ Turning around while walking and jogging |
| **Resistance exercises: active movements with external load (with limb weight/ankle weight (0.5-1.0-2.0 kg), elastic rubber band (yellow to blue with weighting)** |
| ○ Muscles around hip joint: lower limb lifts in lying, in standing position<br>○ Quadriceps and hamstring muscle groups: half squats & standing up from sitting<br>○ Muscles around the ankle joint: standing on tiptoe and heel<br>○ Abdominal muscles: semi-recumbent from lying after belly button (umbilical) retraction |
| **Stretching exercises: exercises performed up to the limit of normal (active) range of motion** |
| ○ Stretching exercises targeting the muscles around the hip, knee, ankle and shoulder joint |
| **Balance exercises:** |
| ○ Reaching in standing position in different directions<br>○ Steps taken in different directions<br>○ Stepping up forward and sideways<br>○ Single leg stance, semi-tandem, and tandem stance with support (if necessary) and then without support |

**11.4. The Hungarian Berg Balance Scale (Hu-BBS)** (Simon et al., 2023)

## Berg Balansz Skála

**Név:……………………………………………. Dátum:…………………………………….**

**Helyszín:……………………………………… Vizsgáló:………………………………….**

Általános instrukciók:
Kérjük, minden feladatot mutasson be, és/vagy a leírtak szerint adjon utasításokat.
Pontozáskor minden egyes feladatnál a legalacsonyabb értéket jelölje.

*A legtöbb feladatnál megkérjük a vizsgált személyt, hogy egy adott pozíciót meghatározott ideig tartson meg. Fokozatosan egyre több pontot vonunk le, ha az idő- vagy távolsági követelmények nem teljesülnek, ha a vizsgált személy felügyeletet igényel, vagy ha a vizsgált személy letámaszkodik, esetleg a vizsgáló segítségére szorul.*
*A vizsgált személynek meg kell értenie, hogy a feladatok elvégzése közben meg kell tartani az egyensúlyát.*
*A vizsgált személyre van bízva, hogy melyik lábára áll, vagy milyen messzire nyúl. Ha rosszul dönt, az hátrányosan befolyásolhatja a kivitelezést és így a pontot.*
*A vizsgálathoz a következő eszközök szükségesek: stopperóra vagy másodpercmutatóval rendelkező óra, vonalzó, vagy olyan mérőeszköz, amivel 5, 12,5 és 25 cm-t ki lehet mérni. A teszt során használt szék átlagos magasságú legyen. A 12-es feladathoz egy lépcső, vagy egy átlagos lépcső magasságú zsámoly szükséges.*

**1. ÜLÉSBŐL FELÁLLÁS**
*Utasítás: Kérem, álljon fel? Próbálja meg úgy, hogy nem támaszkodik a kezére.*

( ) 4 képes anélkül felállni, hogy a kezére támaszkodna és képes önállóan stabilizálni magát
( ) 3 képes önállóan felállni úgy, hogy segítségként használja a kezét
( ) 2 többszöri próbálkozás után, a kezekre támaszkodva áll fel
( ) 1 minimális segítséget igényel a feláláshoz vagy a stabil véghelyzethez
( ) 0 közepes vagy jelentős segítséget igényel a feláláshoz

**2. TÁMASZKODÁS NÉLKÜLI ÁLLÁS**
*Utasítás: Kérem, álljon meg két percen keresztül anélkül, hogy bármibe kapaszkodna!*

( ) 4 képes biztonságosan állni 2 percig
( ) 3 képes 2 percig állni, de felügyeletet igényel
( ) 2 30 másodpercig képes támaszkodás nélkül állni
( ) 1 több próbálkozásra van szüksége, hogy 30 mp-ig támaszkodás nélkül álljon
( ) 0 képtelen támaszkodás vagy segítség nélkül 30 másodpercig állni

**Ha az alany képes 2 percig biztonságosan állni, tehát a 2. feladatra 4 pontot kapott, akkor a következő, azaz a 3. feladatra automatikusan 4 pontot kap és továbblépünk a 4. feladatra.**

**3. TÁMASZKODÁS NÉLKÜLI ÜLÉS, DE A LÁBAK A PADLÓN VAGY EGY ZSÁMOLYON LEGYENEK**

*Utasítás: Kérem, üljön karba tett kézzel 2 percig!*

( ) 4 képes biztonságosan ülni 2 percig
( ) 3 képes 2 percig ülni, de felügyeletet igényel
( ) 2 30 másodpercig képes ülni
( ) 1 10 másodpercig képes ülni
( ) 0 a hát megtámasztása nélkül még 10 másodpercig sem képes ülni

**4. ÁLLÁSBÓL LEÜLÉS**

*Utasítás: Kérem, üljön le!*

( ) 4 biztonságosan leül, a kezét segítségként csak minimálisan használja
( ) 3 a medence leengedését kézhasználattal kontrollálja
( ) 2 a lábszára nekitámaszkodik a székhez a leülés alatt
( ) 1 önállóan ül le, de a medence leengedése kontrollálatlan
( ) 0 segítséget igényel a leüléshez

**5. ÁTÜLÉS**

*A feladathoz két széket (egy karfás és egy karfa nélkülit) VAGY egy karfás széket és egy ágyat használunk. Az ülőfelületeket úgy rendezzük, hogy a vizsgálati személynek fordulnia kelljen átülés közben.*

*Utasítás: Kérem, üljön át erről a székről (karfás szék) erre a székre (karfa nélküli szék)/ ágyra, majd vissza!*

( ) 4 képes biztonságosan átülni, minimális kézhasználattal
( ) 3 a kezek határozott használatával képes biztonságosan átülni
( ) 2 szóbeli irányítással és/vagy felügyelettel képes átülni
( ) 1 egy személy segítségét igényli
( ) 0 két személy segítségét vagy felügyeletét igényli a biztonságos kivitelezéshez

**6. SEGÍTSÉG NÉLKÜLI ÁLLÁS BEHUNYT SZEMMEL**

*Utasítás: Kérem, hunyja be a szemét és álljon meg nyugodtan 10 másodpercig!*

( ) 4 képes 10 másodpercig biztonságosan állni
( ) 3 képes 10 másodpercig állni, de felügyeletet igényel
( ) 2 képes állni 3 másodpercen át
( ) 1 képtelen 3 másodpercig csukva tartani a szemét, de stabil marad
( ) 0 segítségre van szüksége, hogy ne essen el

**7. SEGÍTSÉG NÉLKÜLI ÁLLÁS ÖSSZEZÁRT LÁBAKKAL**

*Utasítás: Kérem, zárja össze a lábát és álljon meg kapaszkodás nélkül!*

( ) 4 képes önállóan összezárni a lábait és 1 percig biztonságosan állni
( ) 3 képes önállóan összezárni a lábakat és megállni 1 percig, de felügyeletet igényel
( ) 2 képes önállóan összezárni a lábakat, de nem tudja zárva tartani 30 másodpercig
( ) 1 segítséget igényel a tesztpozíció felvételére, de megáll zárt lábbal 15 másodpercig
( ) 0 segítséget igényel a tesztpozíció felvételére, és nem tudja azt 15 másodpercig megtartani

**A KÖVETKEZŐ FELADATOKAT TÁMASZKODÁS NÉLKÜL ÁLLVA KELL ELVÉGEZNI**

**8. ELŐRENYÚLÁS NYÚJTOTT KARRAL.**

*Utasítás: Kérem, emelje előre 90 fokig a karját. Nyújtsa ki az ujjait és nyúljon olyan messzire előre amennyire csak tud (ne csak karral, törzsből, csípőből is nyugodtan dőljön, ha tud!). (A vizsgáló tegyen egy vonalzót a 90 fokban előreemelt kar ujjai elé és az előrenyúlás távolságát mérje, miközben a vizsgálati személy a legmesszebbre dőlt előre. Az ujjak nem érhetnek a vonalzóhoz az előrenyúlás közben!)*

( ) 4 képes biztonságosan előrenyúlni >25 cm-re
( ) 3 képes biztonságosan előrenyúlni >12,5 cm-re
( ) 2 képes biztonságosan előrenyúlni >5 cm-re
( ) 1 képes előrenyúlni, de felügyeletet igényel
( ) 0 segítséget igényel, különben elveszíti az egyensúlyát a végrehajtás közben

**9. ÁLLÓ HELYZETBEN EGY TÁRGY FÖLVÉTELE A FÖLDRŐL**

*Utasítás: Kérem, vegye föl a lábai elé helyezett cipőt/papucsot!*

( ) 4 képes biztonságosan és könnyen fölvenni a papucsot
( ) 3 képes fölvenni a papucsot, de felügyeletet igényel
( ) 2 nem tudja felvenni, de 2-5 centiméterre megközelíti, és közben önállóan megtartja az egyensúlyát
( ) 1 nem tudja felvenni a papucsot és a próbálkozáshoz felügyeletre van szüksége
( ) 0 meg sem próbálja / segítséget igényel hogy el ne essen

**10. HÁTRANÉZÉS A VÁLL FÖLÖTT**

*Utasítás: Kérem, fordítsa a fejét balra, és a bal válla fölött nézzen hátra maga mögé, anélkül, hogy a lábát felemelné a talajról! Ismételje jobbra! (A vizsgálatot végző felemelhet egy tárgyat, hogy ezzel irányítsa a személyt, hogy közvetlenül arra a tárgyra nézzen a háta mögött).*

( ) 4 képes hátranézni mind a két oldalra megfelelő súlyáthelyezéssel
( ) 3 egyik irányba tud csak hátrafordulni, a másik irányban kevesebb a súlyáthelyezés.
( ) 2 csak oldalra fordul, de megtartja az egyensúlyát
( ) 1 felügyeletet igényel a fordulás alatt
( ) 0 segítséget igényel, hogy el ne essen

**11. 360 FOKOS FORDULÁS**

*Utasítás: Kérem, forduljon meg kis lépésekkel teljesen körbe! Szünet. Majd forduljon teljesen körbe a másik irányba is!*

( ) 4 képes biztonságosan 360 fokban megfordulni, mindkét irányba 4-4 másodpercen belül
( ) 3 csak az egyik irányba képes teljesen megfordulni biztonságosan 4 másodpercen belül
( ) 2 képes biztonságosan 360 fokban megfordulni, mindkét irányba de lassan
( ) 1 szoros felügyeletre, vagy szóbeli utasításokra van szüksége
( ) 0 segítségre van szüksége a forduláshoz

**12. ZSÁMOLYÉRINTÉS VÁLTOTT LÁBBAL**

*Utasítás: Kérem, helyezze a lábát felváltva a zsámolyra, 4-4-szer!*

( ) 4 képes önállóan, biztonságosan állni és 8-szor érinteni a zsámolyt 20 másodperc alatt
( ) 3 képes egyedül állni, de a 8 lépést 20 mp-en túl teljesíti
( ) 2 segítség nélkül csak 4 lépést tud teljesíteni
( ) 1 kettőnél több lépésre képes, de minimális segítséget igényel
( ) 0 segítséget igényel, hogy ne essen el / vagy képtelen megpróbálni

**13. ÁLLÁS SEGÍTSÉG NÉLKÜL, EGYIK LÁB A MÁSIK ELŐTT**

*Utasítás: (MUTASSA BE A VIZSGÁLT SZEMÉLYNEK))*
*Kérem, tegye az egyik lábát közvetlenül a másik elé (tandempozícióba)! Ha úgy érzi, hogy nem tudja közvetlenül előretenni, akkor próbáljon meg előrelépni úgy, hogy az elől lévő lábának a sarka a hátul lévő láb lábujjai előtt legyenek. (Ahhoz, hogy megkapja a 3 pontot, a lépés hosszának nagyobbnak kell lennie, mint a másik lábfej hossza és a terpesz szélességének kb. ugyanakkorának kell lennie, mint a személy normális lépésszélessége).*

( ) 4 képes a lábait önállóan tandempozícióba tenni és a pozíciót 30 mp-ig tartani
( ) 3 képes önállóan az egyik lábát a másik elé helyezni és a pozíciót 30 másodpercig megtartani
( ) 2 képes önállóan kis lépést tenni és a pozíciót 30 másodpercig megtartani
( ) 1 a lépéshez segítségre van szüksége, de meg tudja tartani a pozíciót 15 mp-ig
( ) 0 elveszti az egyensúlyát lépés, vagy állás közben

**14. EGYLÁBON ÁLLÁS**

*Utasítás: Kérem, álljon az egyik lábán ameddig csak tud, anélkül, hogy bármibe is kapaszkodna!*

( ) 4 képes önállóan fölemelni a lábát és megtartani >10 mp-ig
( ) 3 képes önállóan fölemelni a lábát és megtartani 5- 10 másodpercig
( ) 2 képes önállóan fölemelni a lábát de legfeljebb 3 másodpercig képes tartani
( ) 1 megpróbálja fölemelni a lábát, de nem képes 3 másodpercig megtartani, azonban az álló helyzetet önállóan megtartja
( ) 0 képtelen megpróbálni, vagy segítség kell, hogy ne essen el.

( ) ÖSSZPONTSZÁM (Maximum = 56)