WP 1

D1.1 – Risk Factors for Falls

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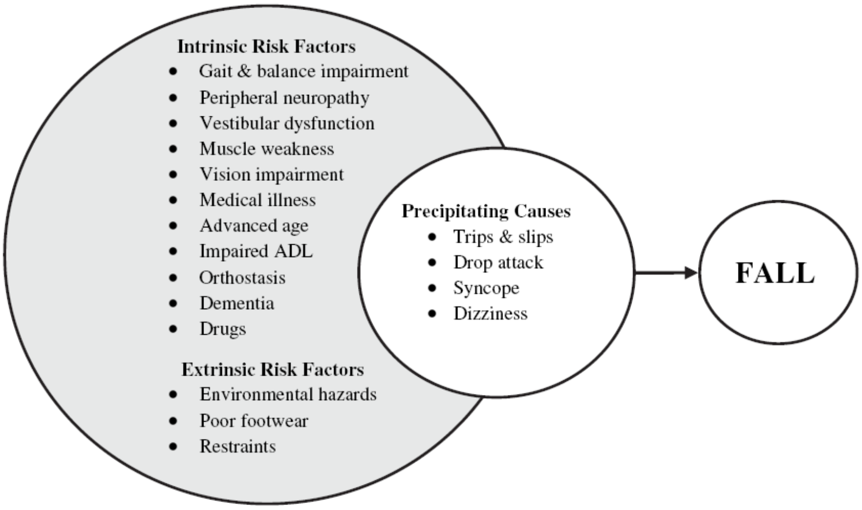
1 Introduction

This deliverable is focused to describe the known and discussed risk factors for falling. The information is gathered from different sources and is also discussed within project partners and will be discussed with users also during the project time.

Results based on the literature review are described also on following chapters. However the literature is reviewed in relation to the project target and also the target group, older people, is been taken into account during this phase. The aim is not to introduce all possible kind of data sources but pick up the most relevant information. One important information world widely is the statistical data in relation to falls, especially the numbers of fallings and the descriptions of the quality and circumstances of falling accidents. Also the monetary estimations are important because the care after falls is not cheap in every case. There are costs for person him or herself and costs for society and resource losses also for an employer, if faller is still in working age. Because the aim of the project is to create new kind of model for prevention of fall and for estimation of the risk factors for falls there is no need to report fall accident based reports on wider views than taken in this report.

Concerning fall risk factors, the *multifactorial and interacting causes of falls* by Rubenstein and Josephson[1] provides an excellent and up-to-date overview:



Causes of falls in older persons: summary of 12 large studies

Cause	Mean (%)[a]	Range[b]
Accident and environment related	31	1–53
Gait and balance disorders or weakness	17	4–39
Dizziness and vertigo	13	0–30
Drop attack	9	0–52
Confusion	5	0–14
Postural hypotension	3	0–24
Visual disorder	2	0–5
Syncope	0.3	0–3
Other specified causes[c]	15	2–39
Unknown	5	0–21

[1] L. Z. Rubenstein, K. R. Josephson, *Falls and Their Prevention in Elderly People: What Does the Evidence Show?*, Med Clin N Am **90** (2006), 807–824.

Risk Factors for falls identified in 16 studies examining multiple risk factors: results of univariate analysis

Risk factor	Significant/total[a]	Mean RR-OR[b]	Range
Lower extremity weakness	10/11	4.4	1.5–10.3
History of falls	12/13	3.0	1.7–7.0
Gait deficit	10/12	2.9	1.3–5.6
Balance deficit	8/11	2.9	1.6–5.4
Use assistive device	8/8	2.6	1.2–4.6
Visual deficit	6/12	2.5	1.6–3.5
Arthritis	3/7	2.4	1.9–2.9
Impaired ADL	8/9	2.3	1.5–3.1
Depression	3/6	2.2	1.7–2.5
Cognitive impairment	4/11	1.8	1.0–2.3
Age >80 y	5/8	1.7	1.1–2.5

The objectives of the multidimensional fall risk assessment is to identify risk factors for future falls and to implement appropriate interventions to reduce fall risk. The multidimensional fall risk assessment can be comprehensive or focused, depending on the target population. Comprehensive multidimensional fall risk assessment is most appropriate for high-risk individuals (e.g., those who have just fallen or have multiple risk factors for falls), whereas a focused assessment generally is more appropriate for individuals of average risk (eg, independent community-living elderly populations).[2]

2 Falls in Older People

Joseph Sheldon's classical paper[3] from 1960 is often seen as a starting point for systematic considerations of fal risk factors. Thereafter there are several milestone contributions and here we mention just a few of them. Mary Tinetti[4] [5] [6], e.g. with her co-authors Franklin Williams and Raymond Mayewski, provided new insight for interventions, and Joanna Downton's[7] overview was state-of-the-art at that time. Stephen Lord[8], with his co-authors Catherine Sherrington, Hylton Menz and Jacqueline Close, has provided significant contributions.The Australians and ACSQHC's[9] "Preventing Falls and Harm From Falls in Older People: Best Practice Guidelines for Australian Hospitals, Residential Aged Care Facilities and Community Care 2009"[10] has had a large impact, also within many European countries, e.g as seen by the Finnish THL[11] and

[2] L. Z. Rubenstein, K. R. Josephson, *op. sit.*, pp. 814-815.
[3] J. Sheldon, *On the natural history of falls in old age*, British Medical Journal (1960), 1685-1690.
[4] M. E. Tinetti, T. F. Williams, R. Mayewski, *Fall Risk Index for elderly patients based on number of chronic disabilities*, Am J Med **80** (1986), 429-434.
[5] M. E. Tinetti, M. Speechley, S. F. Ginter, *Risk factors for falls among elderly persons living in the community*, N Engl J Med **319** (1988), 1701-1707.
[6] M. E. Tinetti, D. I. Baker, G. McAvay, E. B. Claus, P. Garrett, M. Gottschalk, M. L. Koch, K. Trainor, R. I. Horwitz, A multifactorial intervention to reduce the risk of falling among elderly people living in the community, N Engl J Med 331 (1994, 821-827.
[7] J. H. Downton, *Falls in the Elderly*, Edward Arnold, 1993.
[8] S. Lord, C. Sherrington, H. Menz, J. Close, *Falls in Older People*, Cambridge University Press, 2007.
[9] http://www.health.gov.au/internet/safety/publishing.nsf/Content/Home
[10] http://www.health.gov.au/internet/safety/publishing.nsf/Content/fallspreventionguidelines
[11] http://www.thl.fi/en_US/web/en

IKINÄ[12] for fall prevention, and Pajala's report[13], frequently referring to the Queensland and Australian approach.

Rubentein's and Josephson's overview[14] is also very useful for AiB's approach to presenting fall risk factors.

There are several definitions of a fall, including those by Kellogg, ProFaNE and WHO. The definition of a fall and the more precise meaning of falls ascertainment will be dealt with in more detail in deliverable D1.2 on fall risk modelling. In this deliverable we will mainly focus on risk factors.

It is easy to agree upon risk factors being part of **balance, dizzyness, posture and gait**, with **drugs and cognitive impairment** adding to that list of conglomerates of risk factors. Various **medical and psychological factors** need to be added, **incontinence** cannot be neglected, and **environmental factors** are by many seen as the most important ones.

For screening and assessment purposes, all of these are frequently seen as risk factors *per se*. However, they are not explicit risk factors. They are names for bundles of risk factors, where some factors are more specific, and others are more general.

In these discussions we also need to clearly distinguish between what is a measurement or observation, and what is an assessment based on observations and measurements. We do not measure dizzyness or gait, but rather we assess dizzyness and gait with respect to specific observations based e.g. on syncope for dizzyness or tripping for gait. It is important to see that interventions focus explicitly on syncope and tripping, thereby only implicitly on dizzyness on gait.

It is further difficult to say what is a cause and what is a symptom. Fear of falling as a psychological factor is not only associated with previous falls but also with functional decline and frailty. The latter in turn affects gait, and functional decline may be partly caused by balance problems. Risk factors arranged in simple relational structures inevitably leads to circles and not only chains, which obviously makes logical assessment rather difficult to perform.

Having said all that, AiB will, dispite these complexities and subtleties, provide a risk factor framework, also and eventually to be based on a formal ontology and typing system[15], which, on the one hand, enables fall risk modelling (D1.2), and, on the other hand, facilitates the development of the AiB support system for risk assessment (D2.1). Further, a more strict and ontological view on characteristics may also shed some light upon understanding the structure on cohort studies. In fact, evidence based research for falls are not always comparable, as the characteristics used in respective studies are not necessarily comparable.

An important distinction is also to be made concerning community and residential living, and falls happening in hospital wards. Risk modelling should be targeted with respect to these distinctions, and will be considered in deliverable D1.2.

Interventions will be briefly covered already at this stage as the **<u>framework of interventions must structurally match the framework of risk factors</u>**. There are groups of interventions,

[12] http://www.thl.fi/fi_FI/web/pistetapaturmille-fi/iakkaat/ikina-opas
[13] http://www.thl.fi/thl-client/pdfs/923b49af-ca1a-4c44-a14c-505319cac74e
[14] L. Z. Rubenstein, K. R. Josephson, *loc. sit.*
[15] P. Eklund, Category theoretic ontology for representation of assessment scales and consensus guidelines in elderly care, In: Fuzziness and Medicine: Philosophy and Application Systems (Ed. R. Seising), Springer, 2012, to appear.

and distinctions have to be made at least between intervention actions, intervention agents and intervention strategies.

We need also be very careful about not confuse risk factors with interventions, e.g. in the situation of drugs. There are drugs that may cause dizzyness, and there are drugs that are therapeutic agents helping to ameliorate situations involving dizzyness. The discussion on drugs used for symptoms caused by other drugs is obviously more of a questrion on iatrogenic causes and is mostly outside the scope of this deliverable, as would be an analysis of physiotherapeutical strategies being themselves risk factors for falls.

This deliverable is complemented with various aspects of technologies that can be used in connection with measurements and interventions.

3 Epidemiology and Risk Factors

In this section risk factors are presented according to a hierarchical listing.This hierarchical structure, however, is not necessarily a correct and complete ontological structure of risk factors. In fact, the hierarchical listing is even unappropriate as, on the one hand, it doesn't explicitely reveal overlaps, and, on the other hand, it does not come with any typing whatsoever of the risk factors. The latter means that there is no distinction made between risk factors and clusters and groups of risk factors.

The hierarchical listing serves at this point and in this particular deliverable as a summary of risk factors extracted from the relevant literature on risk factors for falls. The listing aims to be fairly broad and reasonable covering, and kind of a *consensus listing* not only from the aims and objectives of AiB point of view, but also mor ebroadly from European fall risk factor ontology point of view.

Generall concerning falls it is, according to Downton[16], interesting to distinguish between the following:

- ✓ Who falls and why
- ✓ How do falls occur
- ✓ When and where do falls occur

We will in this deliverable concentrate on risk factors so we concentrate mostly on "Who falls and why".

Risk factors or groups of risk factors mentioned means that well-known and accepted evidence-based observations are available and well documented. Evidence may be strong, moderate or weak, and this deliverable does not aim at completeness in referencing. Our point is that evidence-based result must be respected, but at the same time we remark distinctively that the literature for risk factors for falls is very much traditionally statistics based, and therefore provides basically only weak support for the development of typing and more formal logic based risk modelling (D1.2).

General and specific fall risk factors can be grouped and clustered from different viewpoints, and detail can be provided with various depth. Overlap and dependencies exist, and must be logically considered in risk assessments.

[16] J. Downton, *loc. sit.*

In the end, fall risk factors are related directly or indirectly to imbalance and posture, and we have aimed at exposing those risk factors that are clearly observable or measurable, and for which correlation, either quantified or qualified, with fall has been shown in studies. References to studies has been mostly omitted in this deliverable.

Socio-demographic factors:

- ✓ Age
- ✓ Gender
- ✓ ADL
- ✓ History of falls
- ✓ Walking aid
- ✓ Living alone
- ✓ Social inactivity

[Age]
Age is directly associated with number and severity of falls[17]. The risk for falls also is nearly double for individuals who are older than the age of 80. Age-related physiological and biological changes and the increasing prevalence of multiple risk factors associated with age can affect overall mobility resulting in a decline of overall physical fitness, increasing falls risk.

[Gender]
Female older adults are more likely to sustain a nonfatal fall than males[18]. This higher rate may be attributed to generally lower muscle strength and lower levels of physical activity in females. However, the age-adjusted fatality rate due to falls is higher for males than for females, perhaps due to the cause or severity of the fall, as males tend to fall from greater heights or may be in poorer health at the time they fall.

[History of falls]
Older adults who have experienced one or more falls have three times the risk of falling again within the following year compared to participants with no history of falls[19]. Although recurrent falls in an individual frequently are due to the same underlying cause (eg, gait disorder, orthostatic hypotension), they also can be an indication of disease progression (eg, parkinsonism, dementia) or a new acute problem (eg, infection, dehydration). Furthermore, older adults who have sustained a fall decrease their overall level of physical activity possibly inducing a gradual decline in mobility that further interferes with the potential to obtain a full recovery and return to prior functional status.

[Living alone]
Elliot et al.[20] investigated the relationship between living alone status and fall-related variables among community-dwelling. They found a relationship between living alone status and experiencing a fall: the percentage reporting a fall was appreciably larger for those living alone

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[17] *Stevens JA. Falls among older adults-risk factors and prevention strategies. Falls Free: Promoting a National Falls Prevention Action Plan. Research Review Papers. Washington, DC: The National Council on the Aging; 2005.*

[18] *Davis MA, Neuhaus JM, Moritz DJ, Lein D, Barclay JD, Murphy SP. Health behaviours and survival among middle-aged and older men and women in the NHANES I Epidemiologic Follow-up Study. Prev Med. 1994; 23: 369-376.*

[19] *Rubenstein LZ, Josephson KR. The epidemiology of falls and syncope. Clin Geriatr Med. 2002; 18: 141-158.*

[20] *Elliott S, Painter J, Hudson S. Living Alone and Fall Risk Factors in Community-Dwelling Middle Age and Older Adults. J Community Health 2009; 34: 301–310.*

(52%) than for those living with others (48%) in both genders in all age groups except for the 61–70 year old adults where the percentage was less.

Postural control:

Postural stability can be defined as the ability of an individual to maintain the position of the body, or more specifically, its centre of mass, within specific boundaries of space, referred to as stability limits. Stability limits are boundaries in which the body can maintain its position without changing the base of support. Regardless of the task being performed, maintaining postural stability requires the complex integration of sensory information regarding the position of the body relative to the surroundings, and the ability to generate forces to control body movement. Thus, postural stability requires the interaction of musculoskeletal and sensory systems. The musculoskeletal component of postural stability encompasses the biomechanical properties of body segments, muscles and joints. The sensory components include vision, vestibular function and somatosensation which act to inform the brain of the position and movement of the body in three dimensional space. Linking these two components together are the higher-level neurological processes enabling anticipatory mechanisms responsible for planning a movement, and adaptive mechanisms responsible for the ability to react to changing demands of the particular task.

A growing body of evidence indicates that normal ageing is associated with impairments in each of these systems, and that this impaired function manifests as an impaired ability to maintain balance when performing a range of functional tasks. Generally, the more challenging a task is to the postural control system, the greater the effect of age and the stronger the relationship to falls.

- ✓ Impaired postural stability
    - Standing
    - Leaning
    - Stepping
    - Perturbation and its control
- ✓ Gait pattern of limb movement and gait characteristics
    - Level walking
        - Gait velocity
        - Variability in cadence
        - Step length
    - Stair walking
    - Tripping and slipping
    - Stepping over and obstacle avoiding
- ✓ Muscle strength
- ✓ Reaction time

[Standing]
Normal standing is characterised by small amounts of postural sway, the control of which requires an integrated reflex response to visual, somatosensory, and vestibular inputs. Control of postural sway when standing involves continual muscle activity and requires an integrated reflex response to visual, vestibular and somatosensory inputs. When any of these inputs are removed, postural sway increases. There is some evidence that peripheral sensation is the most important sensory system in the regulation of standing balance in older adults. Factors found to be highly correlated with increased sway include reduced extremity muscle strength, reduced

peripheral sensation, poor near visual acuity and slowed reaction time[21]. Sway reportedly increases significantly with age and has been demonstrated as a useful predictor of falls in older people[22,23]. People who fall exhibit greater sway both with their eyes open and closed. The differences between fallers and non-fallers, however, is particularly evident when subjects stand on a medium-density foam rubber mat, which decreases ankle support and alters proprioceptive feedback from the foot and ankle. Other standing tests reveal similar differences between fallers and non-fallers. Near tandem standing (standing with one foot in front of the other)[24], unipedal standing (standing on one foot)[25], and forward leaning ability[26] have all been demonstrated to discriminate between fallers and non-fallers.

[Leaning]
Another approach to assess postural control is to measure sway when the subject is placed at the perimeter of their stability limit or to measure the dimensions of the stability limit itself. When postural sway was assessed in young and older women in normal relaxed stance and when the subjects leaned forward at the waist approximately 45 degrees, that sway was greater in the older group in both conditions, but particularly so when leaning forward, suggesting that the older women were less able to stabilize their posture when approaching the perimeter of their stability limit[27]. In order to establish age-related differences in functional base of support, the ability of women aged 20–91 years to reach as far forward and backward as possible when standing was evaluated[28]. Decreased functional base of support was evident after the age of 60 years, and declined 16% per decade thereafter. Older subjects could only regain balance from relatively small initial leaning positions compared with the younger subjects, further suggesting that the ability to control the centre of mass diminishes with age.

[Stepping]
To avoid a fall, a three-stage response is required: perception of a postural threat, selection of an appropriate corrective response and proper response execution. To gain a single measure of this complex, multisystem response, Lord et al. have devised a test of choice reaction time that requires subjects to perform quick, correctly targeted steps in response to visual cues[29]. The subject stands on the choice stepping reaction time apparatus, which comprises a 0.8 m^2 nonslip black platform containing four white rectangular panels (32 cm x 13 cm). Two panels are situated in front of the subject (one in front of each foot), and one panel is situated on each side of the subject (adjacent to each foot). The subject is given practice trials where he is instructed

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[21] *Lord SR, Clark RD, Webster IW. Postural stability and associated physiological factors in a population of aged persons. J Gerontol 1991; 46(3): M69–76.*

[22] *Lord SR, Clark RD, Webster IW. Physiological factors associated with falls in an elderly population. J Am Geriatr Soc 1991; 39 (12): 1194–1200.*

[23] *Lord SR, Ward JA, Williams P, Anstey KJ. (1994b). Physiological factors associated with falls in older community-dwelling women. J Am Geriatr Soc 1994; 42(10): 1110–1117.*

[24] *Lord SR, Rogers MW, Howland A, Fitzpatrick R. Lateral stability, sensorimotor function and falls in older people. J Am Geriatr Soc 47 (9): 1077–1081.*

[25] *Vellas BJ, Wayne SJ, Romero L, Baumgartner RN, Rubenstein LZ, Garry PJ One-leg balance is an important predictor of injurious falls in older persons. J Am Geriatr Soc 1997; 45(6): 735–738.*

[26] *Duncan PW, Studenski S, Chandler J, Prescott B. Functional reach: predictive validity in a sample of elderly male veterans. J Gerontol 1992; 47(3): M93–M98.*

[27] *Hasselkus BR, Shambes GM. Aging and postural sway in women. J Gerontol 1975; 30(6): 661–7.*

[28] *King M, Judge J, Wolfson L. Functional base of support decreases with age. J Gerontol 1994; 49(6): M258–263.*

[29] *Postural stability and falls. In Lord SR, Sherrington C, Menz HB (edits.). Falls in older people. Risk factors and strategies for prevention. Cambridge, Cambridge University Press 2001.*

to step on to the two left panels (front and side) with the left foot only and the two right panels (front and side) with the right foot only. The panels are then illuminated in a random order, and subject is instructed to step on to the panel which is illuminated as quickly as possible but in a safe manner so as not to lose balance. The authors found that those with a history of falls had significantly increased choice reaction stepping times compared with those who reported no falls. Furthermore, ability to perform this test well was dependent upon adequate visual contrast sensitivity, lower limb extension strength, simple reaction time, and standing and leaning balance control.

[Perturbation and its control]
Although evaluation of standing sway and reach has provided useful information regarding the interaction of musculoskeletal and sensory components of postural stability, it can only provide limited information regarding the ability to react to changing demands of a particular task. To assess this component of postural stability more closely, a number of investigations have been performed in which the subject is mechanically perturbed by applying a direct force to their body, or by tilting or translating the surface upon which they stand. Compared with younger people, older people generally have more difficulty generating efficient postural responses to unexpected perturbations, often requiring multiple corrective steps to reestablish postural stability[30]. These techniques have provided considerable insight into the mechanisms underlying reflex responses to unexpected threats to stability; however, their ability to predict falls is limited.

[Level walking]
The maintenance of balance during walking represents a considerable challenge to the postural control system system for two main reasons: two-thirds of the body's mass is situated two-thirds of body height above the ground; and for a major period of the walking cycle, the body is supported by a single limb with the centre of gravity passing outside the base of support. Locomotion can be regarded as consisting of four main subtasks: the generation of continuous movement to progress towards a destination; maintenance of equilibrium during progression; adaptability to meet any changes in the environment; and the initiation and termination of locomotor movements. Each of these tasks is heavily reliant on both the ability to generate force, and the appropriate integration of afferent input from the extremities. Given that ageing is associated with declines in both sensory function and muscle strength, it is clear that gait patterns will change with age and may be associated with postural instability and falling. Different studies have been undertaken to compare gait patterns in young and older people. The most consistent finding of these studies is that older people walk more slowly than young adults, which has been found to be a function of both a shorter step length and increased time spent in double limb support. These temporospatial differences would appear to be a direct result of variation in self-selected walking speed, as when healthy older people and young people are instructed to walk at a specified fixed velocity, no significant differences are apparent. Other gait alterations apparent in older people include reduced hip motion, reduced ankle power and range of motion, smaller vertical and lateral oscillations of the head, increased anterior pelvic tilt and reduced medial toe pressure. Studies which have assessed foot placement have also reported that older people walk with a larger degree of out-toeing. These changes in walking patterns in the older have generally been interpreted as indicating the adoption of a more conservative or less destabilizing gait.

[Gait velocity]
Prospective investigations have revealed that gait velocity may be predictive of falling in older people. Considered by some authors to be a valid measure of postural stability, gait velocity has been reported to differentiate between subjects with a history of falling and those without, with fallers walking significantly slower than non-fallers.

[30] *McIlroy WE, Maki BE. Age-related changes in compensatory stepping in response to unpredictable perturbations. J Gerontol A Biol Sci Med Sci 1996; 51(6): M289–296.*

[Variability in cadence]
Increased variability in certain gait parameters is predictive of falls in older people: fallers have a more variable cadence (stepping rate)[31] and stride-to-stride variability[32] than non-fallers.

[Step length]
The functional importance and predictive value of step width measurement is unclear. While some studies reported that older people with a history of falling walked with a significantly narrower step width than age-matched controls, other investigations reported no difference in step width or an increased step width in fallers compared with non-fallers.

[Stair walking]
Climbing and descending stairs requires physical fitness and coordination. A decline in these, as may occur with aging or illness, increases the vulnerability of users to falling. Not only is a user's ability affected by his or her age, weight, height, strength, and stamina, but also behavioural influences (descending stairs carrying objects or using a mobile phone) and poor design and construction remain important risk factors.

[Tripping and slipping]
Recovery of balance and fall avoidance may be possible if a foot slide can be controlled and eventually stopped, or when a trip is followed by a successful compensatory stepping response, within a short enough time period. Other possible recovery mechanisms for slips and trips may involve grasping responses, if any graspable fixtures are present. These may be combined with joint moment and stiffness control reactions, involving the ankle, knee, and hip joints in particular. The common factor in falls due to slipping and tripping is that a person's recovery attempts for controlling posture fail to restore balance before contact between body and the ground or other object occurs. Slipping in particular, but also tripping in some circumstances, may be related to the frictional characteristics of shoe soles, floor surfaces, and contaminants. Tripping and stumbling have more to do with uneven or discontinuous surfaces or foot contact with obstacles on the floor, however, resulting in unstable and erratic foot trajectories. A trip may occur when the foot is suddenly interrupted during the swing phase. This perturbation increases the maximum trunk flexion angle, walking velocity and maximum hip and knee flexion angles. The most common protective movement outcome in response to an early swing perturbation is an elevating strategy (i.e., flexion of the swing limb), while in response to a late swing perturbation, a rapid lowering of the swing limb to the ground and a shortening of the step length tends to occur. The late swing perturbation appears to pose a greater threat for a fall, because the body mass is already anterior to the stance foot. In this case, the elevating strategy is not possible due to the forward momentum of the body, precluding the stance leg from restoring the body equilibrium. The only option for recovery is to use the swing leg, if the hands have nothing to grasp.

[Stepping over and obstacle avoiding]
A relatively new approach for the assessment of postural stability in older people is the evaluation of older subjects' ability to step over or avoid obstacles. The rationale behind this approach is that a large proportion of falls are related to trips and slips and thus assessment of level walking may provide only limited information regarding an individual's ability to navigate around potentially hazardous environments. Compared with younger subjects, older people require more time to successfully step over obstacles when walking, clear the ground by a smaller margin when stepping onto a raised surface, take longer to change direction in response

[31] *Lord SR, Lloyd DG, Li SK. Sensori-motor function, gait patterns and falls in community-dwelling women. Age Ageing 1996; 25: 292–299.*

[32] *Maki BE. Gait changes in older adults: predictors of falls or indicators of fear? J Am Geriatr Soc 1997; 45: 313–320.*

to a visual stimulus, and are less able to adjust their stride length to compensate for a heel strike slip when walking. Clearly, the inadequacy of these postural responses places the older person at an increased risk of falling when walking under challenging conditions. Furthermore, evidence indicates that the inadequacy of an older person's postural response may be further exacerbated when his or her attention is divided between multiple tasks. For example, older people are less able to successfully navigate obstacles when verbally responding to a visual stimulus[33], which suggests that with advancing age, the maintenance of stability becomes more cognitively dependent. The available research evidence therefore suggests that older people have difficulty maintaining balance when performing various tasks, and subsequently are at greater risk of losing balance during daily activities.

[Muscle strength]
Both isometric and dynamic muscle strength decrease with age, particularly after the age of 60[34,35]. In men, muscle strength appears to decrease only marginally between 20 and 40 years, but beyond 40 years declines at an accelerated pace, so that hand grip strength is reduced by 16% and leg strength by 28% in men aged 60–69 years compared with men aged 20–29 years. In women, muscle strength appears to decline from an earlier age and at a greater rate, so that over the same age range, hand grip strength declines by 20% and leg strength by 38%. It has also been shown that muscle strength continues to decline significantly beyond the sixties in both sexes. In studies that have used both men and women, it has been found that muscle strength in women is about 60–70% of that in men. Decreased muscle strength is particularly pronounced in the lower limb, which has important ramifications for stability and falls in older people. In large community-based prospective studies, reduced quadriceps strength increases the risk of falls[36,37]. When the strength of four lower-limb muscle groups: knee extensors, knee flexors, ankle plantarflexors and ankle dorsiflexors in residents of nursing homes with and without a history of falls was compared, fallers were weaker than nonfallers in all four muscle groups, with ankle muscle weakness particularly evident in the faller groups[38,39]. These findings indicate that lower limb muscle weakness is a major risk factor for falling in older people.

[Reaction time]
Reaction time is an important component of postural stability. To maintain balance under challenging conditions, it is necessary not only to detect the nature of the perturbation, but also react quickly to correct the imbalance. Reaction time has consistently been reported to increase

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[33] *Chen HC. Schultz AB, Ashton-Miller JA, Giordani B, Alexander NB, Guire KE. Stepping over obstacles: dividing attention impairs performance of old more than young adults. J Gerontol A Biol Sci Med Sci 1996; 51(3): M116–M122.*

[34] *Petrovsky JS, Burse RL, Lind AR. Comparison of physiological responses of men and women to isometric exercise. J Appl Physiol 1975; 38: 863–868.*

[35] *Murray MP, Gardner GM, Mollinger LA, Sepic SB. Strength of isometric and isokinetic contractions: knee muscles of men aged 20 to 86. Phys Ther 1980; 60(4):412–419.*

[36] *Lord SR, Sambrook PN, Gilbert C, Kelly PJ, Nguyen T, Webster IW, Eisman JA. Postural stability, falls and fractures in the elderly: results from the Dubbo Osteoporosis Epidemiology Study. Med J Aust 1994; 160(11): 684–685.*

[37] *Lord SR, Ward JA, Williams P, Anstey KJ. Physiological factors associated with falls in older community-dwelling women. J Am Geriatr Soc 1994; 42(10):1110–1117.*

[38] *Lord SR, Rogers MW, Howland A, Fitzpatrick R. Lateral stability, sensorimotor function and falls in older people. J Am Geriatr Soc 1999; 47: 1077–81.*

[39] *Studenski S, Duncan PW, Chandler J. Postural responses and effector factors in persons with unexplained falls: results and methodological issues. J Am Geriatr Soc 1991; 39: 229–34.*

significantly with advancing age[40], with a median increase of 26% from the twenties to the sixties, and has been reported as an independent predictor of falls[41].

Drugs:

Older adults use an average of 4.5 prescription medications and 2.0 over-the-counter medicines per person on a daily basis, and take roughly 26 different prescription drugs annually. The use of 3 or more medications, including prescriptive or over-the-counter medications, increases the risk of initial or recurrent falls[42,43] and the risk of falling increases with the number of prescription and over-the-counter medications taken concurrently. Certain classes of medications are associated with falls, including antidepressants, antipsychotics, long and short acting benzodiazepines, anticonvulsants, antihypertensives, cardiac medications and analgesics. Some of the more common side effects of medications include blurred or impaired vision, sedation or decreased alertness, confusion and impaired judgment, delirium, compromised neuromuscular function, anxiety, or hypotension leading to dizziness and lightheadedness.

In what follows we have provided some examples of ATC encodings of fall risk related drugs. The examples are intended to show level and structure and some of the than most typical drugs as risk factors.

Concerning drugs it is very common in general discussions to speak of risk factors not being specific enough, deliberately or undeliberately, about the ATC levels of drugs. More specifically, a drug related risk factor may be pointed at on therapeutical subgroup level, such as psycholeptics or antihypertensives, or even anatomical main group level, such as drugs for the nervous or cardiovascular system. However, as *de facto* risk factors, pharmacological and chemical subgroup levels, like anxiolytics or benzodiazedine derivatives, are more important. Sometimes even the chemical substance must be pointed out, like in the case of digoxin. Medication has an impact mostly on postural stability, like e.g. hypnotics and sedatives. The difference between effects e.g. of short-acting and long-acting benzodiazepines is not well known.

An interesting example is depression which itself is a risk factor, whereas also antidepressants are risk factors, even if there are debates about the association between antidepressants and falls. Retrospective studies tend to show less association with falls.

Anti-inflammatory drugs have been mostly studied with respect to the effect of NSAIDs (non-steroidal anti-inflammatory drugs). NSAIDs are non-narcotic as analgesics. Narcotic analgesics have shown to produce some psychomotor impairment.

Pharmacokinetic changes with ageing, such as those related to drug absorption, decreased first pass metabolism and drug clearance in liver (leading e.g. to increased toxicity) or protein binding (some increased free serum concentrations directly affect postural stability), are not entirely well understood[44].

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[40] *Welford AT. Motor performance. In: Birren JE and Schaie KW (edits.). Handbook of the Psychology of Aging. New York 1977, Van Nostrand Reinhold.*

[41] *Lord SR, Clark RD, Webster IW. Physiological factors associated with falls in an elderly population. J Am Geriatr Soc 1991; 39 (12): 1194–1200.*

[42] *Tinetti ME, Baker DI, McAvay G, et al. A multifactorial intervention to reduce the risk of falling among elderly people living in the community. N Engl J Med 1994;331:821-827.*

[43] *Leipzig RM, Cumming RG, Tinetti ME. Drugs and falls in older people: a systematic review and meta-analysis: I. Psychotropic drugs. J Am Geriatr Soc 1999;47:30-39.*

[44] S. Lord, C. Sherrington, H. Menz, J. Close, *op. sit*., pp. 134-135.

- ✓ C cardiovascular system
    - C01 cardiac therapy
        - C01A cardiac glycosides
            - C01AA digitalis glycosides
                - C01AA05 digoxin
    - C02 antihypertensives
    - C03 diuretics
        - C03A thiazide diuretics
            - C03AA thiazides
                - C03AA01 bendroflumethiazide
- ✓ N nervous system
    - N02 analgesics
        - N02A opioids
            - N02AA natural opium alkaloids
                - N02AA59 codeine, combinations excl. psycholeptics
                - N02AA79 codeine, combinations with psycholeptics
            - N02AC diphenylpropylamine derivatives
                - N02AC04 dextropropoxyphene
    - N05 psycholeptics
        - N05A antipsychotics
        - N05B anxiolytics
            - N05BA benzodiazepine derivatives
                - N05BA01 diazepam, long-acting drug for insomnia
        - N05C hypnotics and sedatives
            - N05CD benzodiazepine derivatives
                - N05CD02 nitrazepam, long-acting drug for insomnia
            - N05CF benzodiazepine related drugs
                - N05CF02 zolpidem, short-acting drug for insomnia
    - N06 psychoanaleptics
        - N06A antidepressants
            - N06AB selective serotonine reuptake inhibitors
- ✓ Multiple drug use

[Cardiovascular system]
Although cardiovascular drugs are the most commonly used drugs among elderly persons, very few studies reported results on the use of them, choosing instead to view them concurrently with other medications.

[Digoxin]
Digoxin, mostly used for atrial fibrillation, increases weakly the risk of experiencing a fall, although it is possible that its use is simply a marker of physical frailty rather than a cause of falls.

[Antihypertensives]
There has been little support for an association between antihypertensives and falls. While some studies have reported that the use of antihypertensives is associated with a moderately increased risk of falling, most studies have found a non-significant relationship for both older

community and long-term care residents. The only prospective, randomized controlled trial on hypertensive use found no difference in falls prevalence between subjects taking the medication and those taking a placebo[45]. However, persons taking more than 1 type of antihypertensive drug have an increased risk of falling compared with those taking just one[46].

[Diuretics]
Diuretics are the only type that appears to independently increase the risk of falling[47], although many studies have failed to report any significance of diuretic use in terms of falls risk.

[Nervous system]
Over 20% of community-dwelling older adults are at two- to threefold increased risk of falling from taking one or more psychoactive medications. Psychoactive medications can decrease alertness, affect judgment, compromise neuromuscular function or cause dizziness and syncope, increasing the falls risk. The use of multiple psychoactive medications also has an additive effect on falls risk: while the odds ratio of experiencing a fall for community-dwelling older people taking one psychoactive medication is 1.5, those taking two or more of these increase their odds ratio to 2.4[48].

[Opioids]
Opioids, or narcotic analgesics (e.g. codeine and propoxyphene) have been found to produce psychomotor impairment. However, no relationship has been reported between narcotic analgesics and falls. The fundamental limitation in clarifying whether narcotics are related to falls is simply that there are only small numbers of older people taking these medications in the samples studied.

[Antipsychotics]
Antipsychotic drugs as a group seem to be associated with an increased risk of falling among nursing home residents. This risk is linearly related to increasing dosage of antipsychotic drug The extrapyramidal adverse effects of antipsychotic drugs are one explanation for the increased risk of falls, but also the anticholinergic properties and effects on alpha-adrenergic receptors may contribute to the risk of falling. However, studies involving community or intermediate care samples have generally not found antipsychotic drugs to be a risk factor for falls. These findings can be interpreted in two ways: community-dwellers using antipsychotic drugs may not comprise sufficient numbers to detect a significant relationship; or the predisposing effects of antipsychotics on falls may be more pronounced in long-term care residents where the prevalence of frailty, cognitive impairment and immobility are higher.

[Hypnotics and anxiolytics]
Hypnotic and anxiolytic medications are prescribed for up to 15% of older adults to treat anxiety, insomnia, and seizure disorders and have negative effects on cognition, gait, and balance. The pharmacodynamic responses of these drugs tend to change with advancing age; the concentration that produces half of a full response (EC50) for sedation is reduced by 50% in elderly persons. Prospective studies have reported that hypnotics and anxiolytics carry a two- to

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[45] *Curb JD, Applegate WB, Vogt TM. Antihypertensive therapy and falls and fractures in the systolic hypertension in the elderly program. J Am Geriatr Soc 1993; 41: SA15.*

[46] *Lord SR, Ward JA, Williams P, Anstey KJ. An epidemiological study of falls in older community-dwelling women: the Randwick falls and fractures study. Aust J Public Health. 1993; 17: 240-245.*

[47] *Cameron KA. The role of medication modification in fall prevention. Falls Free: Promoting a National Falls Prevention Action Plan Research Review Papers. Washington 2005, National Council on Aging.*

[48] *Weiner DK, Hanlon JT, Studenski SA. Effects of central nervous system polypharmacy on falls liability in community-dwelling elderly. Gerontology 1998; 44: 217–21.*

fourfold increase in the risk of falling in institutionalized, and community-dwelling older people. However, the findings regarding the association between hypnotics and anxiolytics and falls are somewhat contradictory with different studies reporting no increased risk of falling for users of hypnotics and anxiolytics among older nursing home residents and community-dwellers. These apparently discrepant results may be explained by differences in drug dosage (subjects taking more than the recommended dose double the risk of hip fracture), the duration of use (greatest risk for falls injury within the first 15 days) and the class of drug (higher risk in long vs. short-acting benzodiazepines).

[Antidepressants]
Antidepressants include the drug groupings of selective serotonin re-uptake inhibitors (SSRIs), tetracyclics, monamine oxidase inhibitors, and tricyclic antidepressants (TCA). Evidence for the association between antidepressant use and falls risk seems to be divided with results both for and against. Overall, prospective designs have tended to report a significant association, whereas retrospective studies have not. The relationship between antidepressants and falls has been frequently observed even when controlling for variables such as medical conditions, dementia, functional status, age and body mass. Specific classes of antidepressants and their effect on falls have also been investigated. Current users of TCA and SSRI, seem to be associated with a high risk for falling[49]. Whether antidepressants that inhibit both serotonin and noradrenalin reuptake are safer than TCA or SSRI has yet to be studied.

[Multiple drug use]
Several studies also showed a strong relationship between the use of three or more medications and the risk for falls. The reason for this might not be just the number but also the type of preparations included in the medication. After adjustment for comorbid conditions, polypharmacy remained a risk factor for falls only when the medication included at least one drug known to pose a risk for falling[50].

<u>Medical factors</u>:

It has long been recognized that frail, older people with multiple chronic illnesses experience higher rates of falls than active, healthy older people. This observation suggests that rather than being a nonspecific accompaniment of ageing, many falls may occur as a result of clinically identifiable causes. Thus, differentiating the relative contribution of pre-existing disease to risk of falling is an important component of a falls prevention programme, as it enables clinicians involved in the management of older people to determine when it is appropriate to intervene medically.

- ✓ Vision
    - Glaucoma
    - Cataracts
    - Macular degeneration
- ✓ Neurological problems
    - Stroke
    - Parkinson’s disease
    - Vestibular pathology
        - Peripheral vestibular problem

[49] *Hartikainen S, Eija Lönnroos E, Louhivuori K. Medication as a Risk Factor for Falls: Critical Systematic Review. J Gerontol A Biol Sci Med Sci 2007; 62 (10): 1172–1181*

[50] *Ziere G, Dieleman JP, Hofman A, Pols HA, van de Cammen TJ, Stricker BH. Polypharmacy and falls in the middle-aged and elderly population. Br J Clin Pharmacol. 2005; 61: 218–223.*

            - BPPV (Benign Paroxysmal Positional Vertigo)
                - Episodic
            - Menières disease
            - Vestibular neuronitis
            - Chronic suppurative otitis media
        - Central vestibular problems
            - Acoustic neuroma
            - Chronic suppurative otitis media
    - Peripheral neuropathy
    - Myelopathy
    - Neural failure of postural control
        - Syncope
            - Cardiovascular
                - Cardiac arrhythmias
                    - e.g. ventricular tachycardia
                - Orthostatic hypotension
                - Transient ischaemic attack (TIA)
            - Central nervous system disorders
                - Epilepsy
        - Dysequilibrium
            - Somatosensory problems
            - Drug intoxination
        - Drop attack
- ✓ Lower extrimity problems
    - Osteoarthritis
    - Foot problems
- ✓ Urinary incontinence
- ✓ Functional status
    - Functional impairment
    - Walking aids
- ✓ Multiple chronic diseases

[Vision]
With ageing, the eye undergoes numerous physiological changes associated with a decline in visual acuity. Age-related visual system problems include poor lens elasticity, lack of lens transparency, decreased peripheral field view, reduced acuity in near vision, decreased contrast sensitivity, and decreased accommodation during lighting changes. Other age-related pathologies known to affect visual function include cataracts, macular degeneration, and glaucoma, and other factors related to visual functioning associated with falls include using bifocal and multifocal lenses, wearing ill-fitting glasses, or relying on an out-of-date lens prescription. In the absence of accurate visual information, spatial awareness is impaired, leading to an increased likelihood of misjudging obstacles such as steps or cracks in the footpath. Not surprisingly, older adults with visual deficits are 2.5 times more likely to sustain a fall than those without visual deficits[51]. An increase in sway during standing when visual input is

[51] *American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Falls Prevention. Guideline for the prevention of falls in older persons. J Am Geriatr Soc. 2001; 49: 664-672.*

altered or removed may account for this increased risk[52]. Contrast sensitivity (deficits often seen in older adults with cataracts)[53] and visual acuity (worse than 20/30)[54] are each associated with 2 or more falls.

[Glaucoma]
Glaucoma is a common cause of blindness in older people and affects approximately 3% of people over the age of 65. The presence of glaucoma has been reported to be associated with an increased risk of falling in both retrospective and prospective investigations.

[Cataracts]
Cataracts affect approximately 16% of people over the age of 65, and are a common cause of impaired vision in older people. Results from different studies indicate that cataracts are independently associated with an increased risk of falling in older people.

[Macular degeneration]
Several disorders can lead to degenerative lesions of the macular region of the retina, being age-related macular degeneration the most common and serious form, affecting approximately 9% of older people aged over 65 years, and up to 19% of people over 85 years of age. Despite the recognition of macular degeneration as a common and serious eye disease, few studies have assessed the role of macular degeneration as a risk factor for falls. Further studies need to be undertaken in large samples of older people with macular degeneration to determine its contribution to falls risk.

[Stroke]
Cerebrovascular accidents are common in older people, and have been associated with a two to sixfold increased risk of falling by a number of prospective investigations. Following a stroke, many people have an inability to generate sufficient amounts of force in lower limb musculature, or to coordinate the actions of different muscle groups. This may result in a decreased ability to maintain the leg extended during the stance phase of walking and decreased foot clearance during the swing phase which may result in tripping. People with impaired gait following a stroke may also have difficulty adapting to challenging environments. In addition, brainstem and cerebellar strokes may cause damage to areas in the brain closely associated with balance, while sensory and visual inattention when recovering from a stroke may produce a tendency to bump into environmental hazards. Parietal lobe damage may impair the planning and execution of locomotor activities, and in cases where the frontal lobes are damaged, there is the possibility that judgement may be affected, causing the older person to take risks when navigating obstacles in the environment.

[Parkinson’s disease]
Parkinson’s disease is characterized by postural instability, bradykinesia, tremor and muscular rigidity, and is known to affect approximately 2% of people over the age of 65 years. The characteristic gait of the parkinsonian patient exhibits short, shuffling steps, lack of arm swing, loss of trunk movements, decreased foot clearance, and festination (fast, short steps). These changes are associated with impaired responses to external perturbations, and increased variability in stride length when walking. Due to their rigid posture, gait, and impaired ability to respond to external perturbations, many older people with Parkinson’s disease suffer from

[52] *Woollacott MH, Shumway-Cook A, Nashner LM. Aging and posture control:changes in sensory organization and muscular coordination. Int J Aging HumDev. 1986; 23: 97-114.*

[53] *Abrahamsson M, Sjostrand J. Impairment of contrast sensitivity function (CSF) as a measure of disability glare. Invest Ophthalmol Vis Sci. 1986; 27: 1131-1136.*

[54] *Ivers RQ, Cumming RG, Mitchell P, Attebo K. Visual impairment and falls in older adults: the Blue Mountains Eye Study. J Am Geriatr Soc. 1998; 46:58-64.*

frequent falls. Parkinson's disease has been found to be a strong independent risk factor for falling in epidemiological studies, in both institutionalized and community-dwelling older people.

[Vestibular pathology]
The vestibular system provides information about position in space and head movement with respect to gravity and inertial forces. Age affects the vestibular system such that there is an increase in lipofuscin content, a 40% reduction in hair cells for those older than 70 years, a progressive loss of nerve fibers in the peripheral vestibular system, and an overall decline in vestibular system function, which contribute to unsteadiness, dizziness, and lightheadedness. Vestibular pathology is one of the most common causes of persistent and recurrent symptoms of dizziness in older people, and is classically characterized by marked postural instability when standing and a broad-based, staggering gait pattern with unsteady turns, placing the older person at an increased risk of recurrent falls. No studies have found tests of vestibular function to be strong predictors of falls in older people. This may be due to the insensitivity of the tests used for this purpose, being unable to detect subtle yet significant impairments in vestibular function. Vestibular function is less amenable to measurement or intervention than vision or peripheral sensation, and further research is required to elucidate the significance of vestibular input.

[Peripheral neuropathy]
Sensory input from the extremities provides the central nervous system with important information regarding the position and movement of the limbs. Advancing age is associated with decreased vibration, tactile and joint position sense, and subsequently the ability to detect and control the movement of the legs when standing and walking is impaired. In addition to normal ageing, peripheral neuropathy can result from a wide range of causes, including diabetes mellitus as the most common cause. Peripheral nerve damage occurs in up to 25% of patients with diabetes mellitus after 10 years of being diagnosed with the disease, and in up to 50% of patients after 20 years disease duration. People with diabetic neuropathy have impaired standing stability compared with age-matched controls and perform worse in tests of foot position sense. The presence of diabetic neuropathy has also been found to increase the risk of fall-related injury by up to 15 times[55,56,57]. The available evidence therefore suggests that peripheral neuropathy, by affecting the ability of an older person to perceive the orientation and movements of the limbs, is a significant risk factor for falls and fall-related injuries.

[Syncope]
Different cardiac, haemodynamic, metabolic and psychiatric factors may cause a loss of consciousness, and invariably this will cause the older person to fall. Syncope can be defined as a temporary loss of consciousness with spontaneous recovery, and occurs when there is a transient decrease in cerebral blood flow. The significance of syncope in elderly falls, however, is very difficult to determine, as loss of consciousness is often associated with amnesia, making retrospective assessments difficult. In addition, many studies consider falls and syncope to be two separate diagnoses with two separate sets of aetiologies, rather than viewing syncope as a precursor of falling. This may explain why syncope has been reported as the cause of only 3% of falls in both nursing home and community-dwelling populations. However, there is some evidence that falls caused by syncope may be more likely to cause serious injury than falls without a loss of consciousness, presumably because the older person is unable to make any postural adjustments to minimize the impact of the fall. The major limitation of the literature on

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[55] *Cavanagh P, Derr J, Ulbrecht J, Maser R, Orchard T. Problems with gait and posture in neuropathic patients with insulin-dependent diabetes mellitus. Diabet Med 1992;9: 469–474.*

[56] *Richardson JK, Ching C, Hurvitz EA. The relationship between electromyographically documented peripheral neuropathy and falls. J Am Geriatr Soc 1992; 40: 1008–1012.*

[57] *Richardson JK, Hurvitz EA. Peripheral neuropathy: a true risk factor for falls. J Gerontology 1995; 50: M211–215.*

syncope and falls, however, is the confusion caused by the interchangeable use of the terms syncope and drop attack, in addition to their 'shared' suspected aetiologies (orthostatic hypotension, postprandial hypotension, carotid sinus hypersensitivity, etc.). This confusing use of terminology and complex causal inter-relationships may be primarily responsible for the limited understanding of the significance of syncope in falls in older people.

[Orthostatic hypotension]
Orthostatic hypotension, also known as *postural hypotension*, refers to the drop in blood pressure which occurs when transferring from a supine to a standing position. The reported prevalence of orthostatic hypotension in community-dwelling older people is approximately 6% and tends to be associated with pre-existing disease or use of medications which have antihypertensive effects. The most common cause of orthostatic hypotension is the failure of the autonomic nervous system to react to the body's change in posture. However, numerous diseases have also been found to be associated with an increased risk of developing orthostatic hypotension, including heart failure, diabetes mellitus, Parkinson's disease, stroke, dementia and depression. Drugs known to induce orthostatic hypotension include antihypertensives, anti-Parkinsonian drugs, antidepressants, antipsychotics and diuretics. Numerous retrospective studies have provided evidence to support a relationship between orthostatic hypotension and falls. The validity of the results of these studies is limited by the retrospective design employed, and no prospective investigations have reported orthostatic hypotension as a strong risk factor for falls.

[Drop attacks]
The term 'drop attack' refers to a sudden, unexpected fall to the ground without experiencing any loss of consciousness; however, there is often a transient loss of strength in the legs and trunk. The causative mechanism of a drop attack is still poorly understood, and indeed in many cases no cause can be identified. Recent studies have implicated vertebral–basilar artery insufficiency, structural lesions of the cervical spine, and carotid sinus hypersensitivity. Drop attacks have been reported as the cause of between 2% and 25 % of falls, but the definition of a drop attack and the population studied varies considerably in the literature. It would appear that drop attacks may be responsible for a number of falls that cannot to be explained by multiple sensory and motor risk factor assessments. However, the evidence for drop attacks as a cause of falls is primarily retrospective, and is marred by the use of inconsistent definitions across the literature.

[Osteoarthritis]
Osteoarthritis is the commonest cause of musculoskeletal disability among older people affecting the major weight-bearing joints of the lower limb, leading to structural deformity, decreased range of motion, and pain. Older people with osteoarthritis often suffer wasting of associated muscle groups and have difficulty rising from a chair and performing daily tasks, and tend to walk more slowly than older people without the condition. There is also evidence to suggest that the presence of osteoarthritis impairs standing balance and joint position sense. Thus it is clear that osteoarthritis, by reducing joint range of motion, reducing muscle strength and causing pain in lower limb joints, will have a detrimental effect on postural stability in older people. A medical history of osteoarthritis has been found to be a significant risk factor for falling by several prospective investigations[58,59,60], while self-reported symptoms commonly associated

[58] *Campbell AJ, Borrie MJ, Spears GF. Risk factors for falls in a community-based prospective study of people 70 years and older. J Gerontol 1989; 44: M112–117.*

[59] *Robbins AS, Rubenstein LZ, Josephson KR, Schulman BL, Osterweil D, Fine G. Predictors of falls among elderly people – results of two population-based studies. Arch Intern Med 1989; 149: 1628–1633.*

[60] *Blake A, Morgan K, Bendall M, et al. Falls by elderly people at home – prevalence and associated factors. Age Ageing 1988; 17: 365–372.*

with the condition, such as pain or reduced range of motion in the knees and hips, are also associated with increased falls risk[61].

[Foot problems]
Foot problems affect at least one in three community-dwelling people over the age of 65 years, and up to 85% of older people in long-term care facilities. Foot problems may result from osteoarthritic decreases in joint range of motion, dermatological conditions, detrimental effects of footwear, and systemic diseases such as peripheral vascular disease, diabetes mellitus and osteoarthritis. Foot problems are well recognized as a contributing factor to mobility impairment in older people. Older people with foot pain walk more slowly than those without, and have more difficulty performing daily household tasks. As the foot provides the structural foundation for both static support and progression of the body during locomotion, it is plausible that foot problems could increase the risk of falling. However, few studies have directly investigated the role of foot problems in postural stability and falls. Retrospective studies suggest that undefined foot problems are more common in older people who fall[62,63], whereas prospective studies find foot problems to only moderately increase risk of falling[64,65]. One of the limitations with the available evidence is that foot problems are generally poorly defined in epidemiological falls studies.

[Urinary incontinence]
Incontinence is an extremely common problem in older people, particularly older women. In industrialized societies, up to 34% of older men and 55% of older women suffer from an inability to control urinary functions. Both retrospective and prospective falls investigations have consistently reported urinary incontinence to be a strong risk factor for falls in community-dwelling and institutionalized older people[66,67]. Falls related to incontinence are generally thought to result from loss of balance when rushing to the toilet or an increased likelihood of slipping on urine. However, there is some question as to whether incontinence is a primary cause of falls, or whether it is simply a marker of generalized physical frailty. While numerous falls in long-term care facilities occur when going to, or returning from the toilet, few falls in community-dwelling older people involve toileting.

[Functional status]
Functional outcomes that are of particular relevance in the falls literature include competency with basic and instrumental activities of daily living (BADL and IADL, respectively).

[Functional impairment]
Functional impairment, usually indicated by the inability to perform basic activities of daily living (BADL) (such as feeding oneself, dressing, bathing, getting out of bed, toileting, walking, and

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[61] *Nevitt MC, Cummings SR, Kidd S, Black D. Risk factors for recurrent nonsyncopal falls. A prospective study. JAMA 1989; 261: 2663–2668.*

[62] *Gabell A, Simons MA, Nayak USL. Falls in the healthy elderly: predisposing causes. Ergonomics 1985; 28: 965–75.*

[63] *Wild D, Nayak U, Isaacs B. Characteristics of old people who fell at home. J Clin Exp Gerontol 1980; 2: 271–87.*

[64] *Koski K, Luukinen H, Laippala P, Kivela S-L. Risk factors for major injurious falls among the home-dwelling elderly by functional abilities. Gerontology 1998; 44: 232–238.*

[65] *Koski K, Luukinen H, Laippala P, Kivela SL. Physiological factors and medications as predictors of injurious falls by elderly people: a prospective population-based study. Age Ageing 1996; 25:29–38.*

[66] *Robbins AS, Rubenstein LZ, Josephson KR, Schulman BL, Osterweil D, Fine G. Predictors of falls among elderly people – results of two population-based studies. Arch Intern Med 1989; 149: 1628–33.*

[67] *Tinetti ME, Speechley M, Ginter SF. Risk factors for falls among elderly persons living in the community. N Engl J Med 1988; 319: 1701–1707.*

climbing steps and stairs), is associated with an increased falls risk[68,69]. In the community, ADL impairment affects 20% of persons who are older than age 70. In the nursing home setting, the prevalence of functional impairment is much higher; 96% of nursing home residents require assistance with bathing and 45% require assistance with eating. Difficulty with IADLs (such as grocery shopping, performing housework, gardening, preparing meals, or using a telephone), a higher level of functional impairment, is associated with a loss of balance[70].

[Walking aids]
In general, the use of assistive devices is indicative of a high risk for falls (RR = 2.6)[71]. The extent to which the use of assistive devices contributes to falls risk is not entirely clear; however, walking without a mobility aid when one is prescribed, and/or an otherwise inappropriate use of such a device can be harmful. Used correctly and appropriately, however, assistive devices such as walkers, canes, scooters, and wheelchairs may reduce the risk of falling by allowing safe mobility while increasing independence and activity levels. Thus, there is a present gap in the literature regarding the nature of the relationship between the use of assistive devices and increased falls risk.

<u>Psychological and cognitive factors</u>:

- ✓ Cognitive impairment
  - Dementia
    - Alzheimer’s disease
    - Vascular dementia
- ✓ Depression
- ✓ Attentional limitations
  - Reduced dual tasking ability
  - Impaired selective attention
  - Reaction time
- ✓ Fear of falling
  - Previous falls
  - Functional decline
  - Frailty

[Cognitive impairment]
Cognitive impairment affects between 5% and 15% of persons who are older than age 65, and the prevalence increases with age and among institutionalized populations. Cognitive impairment associated with dementia and acute confusional states may increase risk of falling by directly influencing the older person’s ability to deal appropriately with environmental hazards, impairing judgment, visuospatial perception, and orientation ability, increasing the tendency of an older person to wander, , attempt to get out of wheelchairs, or climb over bed

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[68] *Jefferson AL, Byerly LK, Vanderhill S, et al. Characterization of activities of daily living in individuals with mild cognitive impairment. Am J Geriatr Psychiatry 2008; 16: 375-383.*

[69] *Lawton MP, Brody EM. Assessment of older people: self-maintaining and instrumental activities of daily living. Gerontologist 1969; 9: 179-186.*

[70] *Judge JO, King MB, Whipple R, Clive J, Wolfson LI. Dynamic balance in older persons: effects of reduced visual and proprioceptive input. J Gerontol A Biol Sci Med Sci 1995; 50: M263-M270.*

[71] *American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Falls Prevention. Guideline for the prevention of falls in older persons. J Am Geriatr Soc 2001; 49: 664-672.*

side rails, and altering gait patterns. Cognitive impairment almost doubles the risk for falling[72]. One study found that five or more errors on the Short Portable Mental Status Questionnaire were associated with one or more falls[73].

[Depression]
Numerous studies have reported an association between the presence of depression and falls with an odds ratio of up to 7.5 for experiencing a fall[74,75]. Although the mechanisms underlying depressive symptoms and falls risk have not been fully assessed, it has been suggested that older people who suffer from depression are less likely to be involved in physical activity, and are therefore at greater risk of falls due to reduced muscle strength, coordination and balance.

[Fear of falling]
Experience of previous falls is significantly associated with fear of falling. As a reaction to a previous fall, the fear of falling again can lead to avoidance of performing chores or participating in various forms of physical activity. The consequential degeneration of postural control, reduced stride length, reduced speed and increased double support time places the older adult at an increased risk of future falls. Furthermore, fear of falling is an independent risk factor for decreased mobility and loss of quality of life that may affect social interaction and possibly health-related quality of life. The marked deficits in strength and health status observed among independent community-dwelling older adults who report a fear of falling underscore the importance of fear as a falls risk factor and makes it difficult to establish such a cause and effect relationship.

Significant levels of depression and comorbid anxiety is expected to result in lack of confidence in mobility and thereby in fear of falling. There is a disctinction between anxiety related to activity and anxiety reducing or even preventing activity. Further, there is a disctinction between fear immediately following a fall and anxiety persisting well after the time of the fall[76]. Disparities between perceived and physiological risk of falling are also very important[77].

Influence of pain and depression on fear of falling has been shown in many studies, e.g. for depression as measured and assessed using the GDS assessment scale for depression[78] [79].

[72] *Van Doorn C, Gruber-Baldini AL, Zimmerman S, Hebel JR, Port CL, Baumgarten M, Quinn CC, Taler G, May C, Magaziner J. Dementia as a risk factor for falls and fall injuries among nursing home residents. J Am Geriatr Soc 2003; 51: 1213–1218.*

[73] *Tinetti ME, Speechley M, Ginter SF. Risk factors for falls among elderly persons living in the community. N Engl J Med. 1988; 319: 1701-1707.*

[74] *Myers AH, Baker SP, Van Natta ML, Abbey H, Robinson EG. Risk factors associated with falls and injuries among elderly institutionalized persons. Am J Epidemiol 1991; 133: 1179–1190.*

[75] *Whooley MA, Kip KE, Cauley JA, Ensrud KE, Nevitt MC, Browner WS. Depression, falls, and risk of fracture in older women. Arch Intern Med 1999; 158 :484–490.*

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Environmental factors[80]:

Environmental hazards at home and in the community create opportunities for falls among community-dwelling older adults who may already have multiple intrinsic falls risk factors. The majority of studies have not found that the presence of environmental home hazards is a major risk factor for falls in older people; however, this does not mean that environmental factors are not commonly involved in falls when they occur. Around 45% of community-dwelling fallers report that their falls involved an environmental factor. Some authors suggest that the role of the environment is less important among frailer people, who are weaker, have poorer balance and are more likely to fall regardless of environmental factors. In contrast, particular hazards are required for more vigorous people to fall. Others describe a model of the interaction between an older person's competence and the demands of the environment. A person must have a high competence level to cope effectively in an environment with high demands, while a person with a low competence level will be able to cope with an environment with low demands.

A majority (55%) of injuries that occurred from falls take place inside of the home, and over 20% of additional fall-related injuries occurred outside, but near the home. The highest risk for falling in the home is among community-dwelling older adults who were mobile, but unsteady on their feet. The most common cause of falls is tripping or slipping while forward walking followed by falling during transfers from one position (chair to bed) to another or while negotiating stairs or steps. Thus, falls can occur while performing routine activities in the home like dressing, bathing, toileting, or walking along a familiar route.

It is estimated that 80% of homes have at least 1 hazard and that nearly 40% have 5 or more hazards that are associated with falls such as excessive clutter, electrical cords in walkways, throw rugs and loose carpets, inadequate lighting, floor surface transitions or slippery surfaces, lack of stair handrails, inappropriate chair or cabinet heights, and pets and pet-related objects. Within the house, the bathroom was identified as the most hazardous room, with 66% of bathrooms having at least one hazard. In addition, many homes present obstacles or barriers for safely executing activities of daily living such as negotiating outside steps or indoor stairs and using unsafe bathrooms. With respect to community hazards, poor sidewalk and pavement maintenance such as pavement cracks, tree roots, inadequate street markings, slippery footing, and obstacles in walkways (bike racks, flower boxes, and garbage cans) are other common causes of falls for older adults.

Individual health, mobility, and environmental factors have been linked, in some way, to risk of falls in the older adult population. However, few studies have tried to understand the effect of behavioural factors (e.g., risk taking) in individuals' risk for falls. Some authors found that there was a dynamic interaction between environmental conditions and behavior involving use of the environment and argued that most environmental falls can be attributed to poor judgment and not to environmental characteristics. Behaviors that increase an older adult's risk for falling include frequent changing of shoe styles or wearing inappropriate footwear, alcohol consumption, and attempting to perform activities or chores beyond one's physical ability. Inattention to one's surroundings also might increase the chance of falling particularly in a new environment or transition area such as a doorway entrance or an elevation change.

- ✓ General
  - Slippery floor surfaces
  - Loose rugs
  - Upended carpet edges
  - Raised door sills

[80] S. Lord, C. Sherrington, H. Menz, J. Close, *op. sit*., p. 152.

- Obstructed walkways
- Cord across walkways
- Shelves or cupboards too high or too low
- Spilt liquids
- Pets

✓ Furniture
- Low chairs
- Low or elevated bed height
- Unstable furniture
- Use of ladders and step ladders

✓ Bathroom/toilet/laundry
- Lack of grab rails shower/ bathtub/ toilet
- Hob on shower recess
- Low toilet seat
- Outdoor toilet
- Slippery surfaces
- Use of bath oils

✓ Stairs
- No or inadequate handrails
- Noncontrasting steps
- Stairs too steep, tread too narrow
- Distracting surroundings
- Unmodifiable stairs or individual unable to manage stairs

✓ Outdoors
- Sloping, slippery, obstructed or uneven pathways, ramps and stairways
- Brief cycles in traffic lights
- Crowds
- Certain weather conditions (leaves, snow, ice, rain)
- Lack of places to rest
- Unsafe garbage bin use

Poor footwear and inappropriate spectacles are risk factors for falls. Note also how poor footwear and slippery floor surfaces are synthetical risk factors, so that providing appropriate footwear and non-slippery floor surfaces is intervention. Hazard reduction is a further obvious intervention.

4 Performance assessment and risk calculators

4.1 Concepts, ontology and logic

’Assessment’ has multiple and multi-modal meanings. Assessment involves the gathering and ’recording’ of information, and is more broadly an event or process as compared to a ’measurement’, which typically provides a specific value and is of a specific numeric type. One could even a bit naively say that measurement id assessment in a very narrow sense, and assessment is measurement in a very broad sense. Assessment tools are indeed frequently called ’instruments’, where MMSE and GDS are typical such instruments used in assessment of various conditions or capabilitites. In fact, ’assessment scale’ and ’(assessment) instrument’ is seen as one and the same thing.

The **distinction between measurement and assessment** is important, as is the **distinction between examination and assessment**. A measurement is perceived either by a human or by a device or sensor. Recording orientation characteristics e.g. as appearing in the MMSE ’assessment scale’ is done either in an interview situation or directly as an observation by a carer, whereas a glucose value is obtained by a glucometer. Here it is not always recognized that the typing of the orientation characteristics is as important as the typing of a glucose value.

Thus, **measurement appear as part of assessments, and assessments appear as part of examinations**. The role of human observations as measurements is the well understood, and the use of devices is thereby also well-defined as e.g. electromechanical devices produce measurements.

Risk factors must be measurable, by humans and/or devices, and **risk is either assessed** (statistics) **or examined** (logic).

In general, values of attributes may be numeric or symbolic, and they may appear as probability values or truth values. Statistics and logic are two entirely different worlds of calculation principles, and therefore also assessments must be identified as being statistic or logical in nature. Roughly speaking, the more an assessment involves concepts and ontologies, the more it becomes logical, and the less it involves typed concepts, the more it becomes statistics in the sense of being based on frequences and ”counting occurences”. ’Calculation’ is then more related to ’numerical computations’, with results analyzed statistically, whereas ’deduction’ is related to ’logical inference’, with underlying knowledge being structured logically. Turning probability values into truth values is not advisable without very careful integration of typing and ontology. Therefore the paradigm shift from statistics of measurement and assessment to logic of assessment and examination is quite a giant leap that requires much attention with respect to typing and ontology. This is still rather poorly understood by the social and health care communities and professional organizations.

The purpose of this subsection is not to say that AiB will lean more on statistics or logic, but this subsection shows clearly how and when certain approaches to assessment scales become more statistical and when they become more logical. As guidelines and guidelines related examination is more logical, we may roughly conclude that assessment scales are more statistic in nature, whereas examinations and arriving at classification of conditions is necessarily more logical. Concerning risk estimation we then have to make a clear **distinction between risk assessment and risk examination**. The AiB risk modelling to be presented in detail in D1.2 will include both aspects. In this deliverable we briefly outline the state-of-the-art concerning assessment tools including risk assessment as based on the statistic paradigm, i.e. as mostly being ”non-ontological” and non-logical.

A ’clinical assessment’ is typically seen more as an investigation, and indeed as steps in an investigation (process), aiming to provide or enhance an anamnesis (medical history) and eventually lead to a diagnosis, whereas a ’nursing assessment’ is more seen as the gathering of information, often for holistic reasons than always being triggered by certain specific reasons.

Screening is often seen as a particular type of assessment, so that screening involves a population whereas assessment involves individuals.

4.2 General assessment scales and measurement of performance

The **OAD general framework for assessment scales**[81] will be used and enriched, and scales specific to fall and fall prevention must be in focus. This is part of general and comprehensive geriatric assessment.

A minimal set of assessment scales usually comprises of some ADL (Activities of Daily Living) scales combined with suitable cognitive scales like MMSE[82]. Combination scales, like the CDR[83] (Clinical Dementia Rating) for ADL/DEMENTIA, are also widely used in particular in connection with assessments related to dementia syndromes. Non-cognitive signs are captured e.g. by NPI[84] (Neuropsychiatric Inventory), CMAI[85] (Cohen-Mansfield Agitation Inventory) and BEHAVE-AD[86]. NPI is particularly useful in home care[87]. Depression is usually captured in its own right as a non-cognitive aspect of dementia, where e.g GDS[88] (Geriatric Depression Scale) is widely used in home care. Depression is known to correlate with fear of fall, and depression also accelerates cognitive decline. Nutrition scales are important, as are the scales for social conditions, and so on and so forth.

5 Technology

5.1 Sensors

Technology and physical measurement typically involve sensors and as adapted for remote monitoring. For falls, sensors contribute mostly to movement monitoring and classification, i.e. contribute explicitly to gait and implicitely to balance and sway. Sensors clearly do not connect directly with underlying causes as given by medical, psychological or pharmacological risk factors.

Sensors are basically *detecting* balance related aspects, regardless of underlying reasons for imbalance. Sensors observe deviations in balance behaviour, but they should not be seen as replacing concepts and methods for *explaining and predicting* balance abnormalities.

Sensor values should mainly be used as connected with and transformed to attribute values as typically appearing e.g. in PPA and the FallScreen© falls risk calculator.

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[81] P. Eklund, *Assessment scales and consensus guidelines encoded in formal logic*, Journal of Nutrition, Health and Aging, Journal of Nutrition, Health & Aging **13** Suppl 1, S558-S559. (19th IAGG World Congress of Gerontology and Geriatrics, Paris, 2009)

[82] M. Folstein, S. Folstein, P. McHugh, “Mini Mental State”, A practical method for grading the cognitive state on patients for the clinician, Journal of Psychiatry Research **12** (1975), 189-198.

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[88] J. Yesavage, *Development and Validation of Geriatric Depression Screening Scale: A preliminary report*, Journal of Psychiatry 17 (1983), 37-49.

Sensors typically used for balance and gait assessment are force plates, optical motion capture systems, gait walkways, gait mats, insoles and wearable sensors, such as accelerometers, gyroscopes and magnetometers.[89]

Sensors like actometers and pedometers, respectively, measure the magnitude of mechanically produced movements and human motion as being translated into counting steps. The latter typically integrate microelectromechanical systems (MEMS) like accelerometers. Pressure sensors assess pressure distribution with respect to net ground reaction force. Further MEMS integrations include vibrating gyroscopes, and additional sensors can be provided e.g. by magnetometers and goniometers. Accelerometers and gyroscopes appear frequently in so called wearable ambulatory monitors (WAM).

As smaller and cheaper sensors, operating in a wireless manner, become available[90], it is expected that sensors can be utilized more broadly, and indeed in particular for aspects concerning and covering posture identification and gait analysis.

Although force-plates and/or optical motion capture systems are considered as a “gold standard” methods for human gait analysis[91], several studies aim at broadening the falls-risk screening beyond the clinical arena utilizing mainly accelerometry in unsupervised environment. E.g. Narayanan et al[92] measured directed routine of unsupervised physical tasks with waist-mounted accelerometer and mapped the fall-related features derived from accelerometry signals to clinically validated measure of falls risk. Gait and stability as characterized by head and pelvis levels, and measured using accelerometry, has been analyzed with respect to PPA in order to identify gait parameters on smooth and irregular surfaces[93]. Optimal cutoff point to provide for independent risk classification are, however, not easy to determine[94].

5.2 Technologies for health behaviour change

Interactive information technology designed for changing users’ attitudes or behaviour is known as persuasive technology [95]. In the design of fall prevention technology it can be applied in many ways. As an example, fear of falling can be reduced, care givers can be persuaded to conduct fall risk evaluations, and people can be persuaded to strengthen their muscle tone by exercising.

The development of persuasive systems consists of three steps[96]:

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[89] C. N. Scanail, C. Garattini, B. R. Greene, M. J. McGrath, *Technology innovation enabling falls risk assessment in a community setting,* Ageing Int **36** (2011), 217-231.

[90] T. Shany, S. J. Redmond, M. R. Narayanan, N. H. Lovell, *Sensors-Based Wearable Systems for Monitoring of Human Movement and Falls*, IEEE Sensors Journal **12** (2012), 658-670.

[91] C. N. Scanail, C. Garattini, B. R. Greene, M. J. McGrath, *Technology Innovation Enabling Falls Risk Assessment in a Community Setting, Ageing Int (2011) 36:217-231*

[92] M. R. Narayanan, S. J. Redmond, M. E. Scalzi, S. R. Lord, R. G. Celler, N. H. Lovell, *Longitudinal Falls-Risk Estimation Using Triaxial Accelerometry,* IEEE Transactions on Biomedical Engineering, Vol. 57, NO. 3, March 2010

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[96] Oinas-kukkonen, H. & Harjumaa, M., 2009. Communications of the Association for Information Systems Persuasive Systems Design : Key Issues , Process Model , and System Features Persuasive Systems Design : Key Issues , Process Model , and System Features. *Design*, 24(Article 28), p.485-500.

- ✓ Understanding key issues behind persuasive systems.
- ✓ Analysing the persuasion context: who persuades, what kind of change, what is use context, what is user context, what is technology context, and what is suggested message route.
- ✓ Design of system features.

It has been suggested that a set of persuasion principles could be used in the design of persuasive system features[97]. These principles include: reduction, tunnelling, tailoring, personalization, self-monitoring, simulation, rehearsal, praise, rewards, reminders, suggestion, similarity, liking, social role, trustworthiness, expertise, surface credibility, real-world feel, authority, third-party endorsements, variability, social learning, social comparison, normative influence, social facilitation, cooperation, competition, and recognition.

The objective of technologies for health behaviour change is that the users are supported in their health behaviour change process. As an example, they are supported 1) to recognise their personal needs and objectives, 2) to set goals and 3) to follow their progress with regards to their goals.

[97] Oinas-kukkonen, H. & Harjumaa, M., 2009. Communications of the Association for Information Systems Persuasive Systems Design : Key Issues , Process Model , and System Features Persuasive Systems Design : Key Issues , Process Model , and System Features. *Design*, 24(Article 28), p.485-500.