WP 1

D1.2 – Fall Risk Modelling

Category: Deliverable

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Date: 20 October 2012

Status: Final version

Availability: Public

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1 Introduction

Deliverable 1.2 describes known and validated risk and risk factor assessments as tools that may help to identify patients at risk of fall that can benefit from further interventions. Information about these assessment tools and calculators has been gathered, similar to the production of Deliverable 1.1, from different scientific sources. The tools and calculators have been discussed within project partners, and will further be discussed with end-users throughout the duration of the project. There is indeed a distinction to be made between **fall risk modelling** and **fall risk factor modelling**, and similarly between **fall risk screening** and **fall risk assessment**.

The gradation of fall risk is usually taken to be linear, i.e., using either a discrete or continuous interval, typically represented by the boundaries 0% and 100%, and risk calculation is very often quite simple scorecard like calculation. Other gradation scale structures are possible, but are not considered for the purpose of this deliverable.

Apart from risk factors that have been properly and broadly studied, there are aspects of risk not yet being fully recognized or analyzed. Behaviour is good example which is difficult to quantify or assess. Nevertheless, a certain behaviour or attitude, which may be episodic or permanent, may appear as underestimation of risk and thereby have effect on increasing the outcome of certain risk factors. Underestimating the risk of falling means that an ageing person has more belief in the extend of his or her abilities to perform certain actions that what his or her ability really is. These persons may undertake tasks that include risk of falling. This kind of theory derives from Bandura´s Social Cognitive Theory[1]. There could a social coordinate in this risk factor because in many societies, elderly are considered frail and are seen as not active and there is a negative image of old age in general. People who are living in such societies do not wish to get stigmatized as old and present therefore a risky behaviour, by undertaking tasks that are too dangerous for them[2].

The overly belief in own self-efficacy is a factor that has not been sufficiently studied as a risk factor for falling since it is very difficult to determine. Psychological studies are targeting mostly the fear of falling and interventions aim at increasing the self-efficacy feeling[3].

As there are no clear evidence supporting and assessing these factors, they are also not included in well-known risk computations.

2 Risk Factors

In Deliverable 1.1 we presented a grouping of risk factors

- ✓ Socio-demographic factors
- ✓ Postural control
- ✓ Drugs
- ✓ Medical factors
- ✓ Psychological and cognitive factors

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[1] M. E. Tinetti, L. Powell, *Fear of falling and low self-efficacy: A cause of dependence in elderly persons*, J Gerontol **48** (1993), 35-38.

[2] WHO Global Report on Falls Prevention in Older Age, 2007, http://www.who.int/ageing/publications/Falls_prevention7March.pdf

[3] K. Delbaere, J. C. T. Close, H. Brodaty, P. Sachdev, S. R. Lord, *Determinants of disparities between perceived and physiological risk of falling among elderly people: cohort study*, BMJ **341** (2010), c4165.

- ✓ Environmental factors

and hierarchical list of risk factors based on that grouping. The hierarchical structure invites to identify risk factor granularity, and some of these aspects are briefly mentioned in discussions of particular tools and calculators.

Apart from epidemiological and environmental risk factors, the other risk factor groups relate quite specifically to discipline or professionality.

However, from risk computation point of view, when optimizing the (numerical) accuracy and/or (logical) correctness, it is far from clear that this grouping as a structure is sufficiently detailed for the purpose of developing the functional or logical models of the risk computation. Furthermore, there are no risk computations aiming at covering as many risk factors as possible. On the contrary, existing risk computations typically focus on smaller numbers of risk factors, and also lean on one or at most a few of the groups of risk factors, thereafter being quite selective about risk factors, and aiming at rather course granule data.

A further reason for being selective about risk factors are the living circumstances, and risk computations are frequently targeted to communicty or residential living. Further, fall risk estimation for patients staying at hospital wards is again different as compared to more independent living.

3 Definition of Fall

Researchers have sought to define fall since the 1980s. The adoption of a definition is an important requirement when studying falls as many studies fail to specify an operational definition, leaving room for interpretation to study participants. In the early 1990s, Lach et al observed that the research literature rarely provides operational definitions of falls, thereby preventing use of those data by others investigators[4]. Not surprisingly, researchers often provide definitions for falls that reflect the needs of particular studies. This results in many different interpretations of falls. Therefore, the operational definition of a fall is highly important. The definition of fall is very important to understand as the definition used in studies determines when observations for risk factors are registered and **how falls and non-falls are discriminated**.

Although there is still no universally accepted definition or consensus as to what a fall should be, some definitions are more popular than others. In 1987 the Kellogg International Working Group on the prevention of falls in the elderly defined a fall as “an unintentionally coming to the ground or some lower level as a consequence of sustaining a violent blow, loss of consciousness, sudden onset of paralysis as in stroke or an epileptic seizure”[5]. Since then, many researchers have used this or very similar definitions of a fall. Depending on the focus of study, however, some researchers have used a broader definition of falls to include those that occur as a result of dizziness and syncope. The Kellogg definition is appropriate for studies aimed at identifying factors that impair sensorimotor function and balance control, whereas the broader definition is appropriate for studies that also address cardiovascular causes of falls such as postural hypotension and transient ischaemic attacks. Nevitt et al added syncopal and unexplained falls

[4] Lach HW, Reed AT, Arfken CL, Miller JP, Paige GD, Birge SJ, Peck WA. Falls in the elderly: reliability of a classification system. J Am Geriatr Soc. 1991; 39(2):197-202.

[5] Gibson MJ, Andres RO, Isaacs B, Radebaugh T, Worm-Petersen J. The prevention of falls in later life. A report of the Kellogg International Work Group on the prevention of falls by the elderly. Dan Med Bull 1987; 34 (Suppl 4): 1–24.

to the Kellogg definition in 1991[6]. WHO defines falls more broadly as ’an unexpected event in which the participant comes to rest on the ground, floor or lower level’, and indeed without excluding particular events as in Kellogg’s definition. The NICE (2004) definition is similar to WHO, defining fall as ’an event whereby an individual comes to rest on the ground or another lower level with or without loss of consciousness’.

Falls can occur from standing, sitting or horizontal position[7], with or without loss of consciousness[8] and with or without injury[9], excluding intentional change in position to rest in furniture, wall or other objects[10].

It can be added to this definition that fall incidents will usually involve a person moving about his or her environment or, when stationary, having his or her balance disrupted through movement of the surface on which they are standing, e.g., as might occur when standing on a moving bus or train. Other circumstances, such as the collapse of a person due to a medical condition, such as epilepsy or syncope, are not excluded from consideration, but should be represented as discrete categories of falling, with distinct causation. The same applies to an individual falling as a consequence of being struck by an object. A person losing his or her balance and falling as a result of being jostled in a moving crowd, for example, would appear to be of legitimate interest from a fall prevention perspective.

In summary, a fall could be defined as an unintentionally coming to the ground or some lower level from standing, sitting or horizontal position with or without loss of consciousness and with or without injury, excluding intentional change in position to rest in furniture, wall or other objects.

In the literature, a distinction is made between once-fallers and recurrent fallers. Falling refers to any fall and includes occasional falls. Occasional falls may be caused mainly by extrinsic factors, i.e., environmental factors that act upon the person, whereas recurrent falls are usually caused by intrinsic factors, i.e., physical, cognitive and behavioural factors within the person, like mobility limitations, accompanied by an environmental hazard. Recurrent falling has been defined as two or more falls within 6 months[11].

Falls and fall-related injuries are major health problems in the older adult population. Injurious fall refers to a fall resulting in a fracture or soft tissue damage that requires treatment[12]. Consequences of falls include fracture of the hip, spine, arm, pelvis, or wrist, and head concussions, bruises, and lacerations. Even when no injury occurs, falls can have psychological effects on the life of the individual. “Fear of falling” results not only in restricted activity, but increased dependency on others and a decrease in social interaction. Fall-related injuries not

[6] Nevitt MC, Cummings SR, Hudes ES. Risk factors for injurious falls: a prospective study. J Gerontol. 1991; 46(5): M164-70.
[7] Agostini JV, Baker DI, Bogardus ST. Prevention of falls in hospitalized and institutionalized older people. In: Markowitz AJ, Shojania KG, Duncan BW, McDonald KM, Watcher RM (Eds.) Making health safer: A critical analysis of patient safety practices. Agency for Health Care Research and Quality, U.S. Department of Health and Human Services. Rockville (MD) 2001, No. 43, pg. 281-299.
[8] American Geriatric Society, British Geriatrics Society and American Academy of Orthopaedic Surgeons Panel on Falls Prevention (2001) Guideline for the prevention of falls in older persons, Journal of the American Geriatric Society 2001; 49: 664-672.
[9] Public Health Agency of Canada. Report on Senior’s Falls in Canada. Ottawa, ON: Government of Canada, 2005.
[10] WHO global report on falls prevention in older age. World Health Organization, 2007
[11] Stel VS, Pluijm SM, Deeg DJ, Smit JH, Bouter LM, Lips P. A classification tree for predicting recurrent falling in community-dwelling older persons. J Am Geriatr Soc 2003; 51(10): 1356–64.
[12] National Collaborating Centre for Nursing and Supportive Care. Clinical practice guideline for the assessment and prevention of falls in older people. Royal College of Nursing, London 2004.

only bring suffering to the individuals who experience them; they also represent a huge cost to the society.

It is also important to point out the distinction between **fall** and **consequence of fall**. This distinction separates falls from injuries caused by falls, so that selections of data records for more general-purpose analysis is done based on well-founded definitions of falls without too specific relations to injuries resulting from falls. As an example, injury types related to drop attacks are expected to be different from injury types caused by fall due to dysequilibrium.

As the definition of fall is hard to provide, the definition of previous falls is even harder, as these data are usually collected from different sources like medical records, various care providers, or from patients themselves and family members. The definition of falls among these sources is obviously not unique, and e.g. the number of previous falls is often really hard to estimate.

4 Formal Ontology, Logic and Typing of Fall Risk Computation

The literature on fall risk estimation is unclear about the distinction between computations being e.g. **estimators**, **predictors** or **assessments**. Estimators are most typical, and the computation scheme is usually just plain arithmetic, where possible overlaps between risk factors may not necessarily have been properly considered. Overlap may be statistically captured e.g. by correlations or probabilistically by conditionalities. Logically it would be modelled by appropriate selection of logical operators and their parameters. Logical computations are, however, very rare in particular in evidence-based medicine. This is sometimes a dilemma as computations and assessments are statistic whereas guidelines are more logical in nature. There is an apparent giant leap between, on the one hand, statistics and probability theory, and, on the other hand, logic and epistemology, where evidence-based findings do not *per se* carry over to be formulated from logic and knowledge-base point of view,

It is further important to be clearly aware of the disctinction between **risk computation** and **risk factor computation**. For instance, Downton's Fall Risk Index is clearly a risk computation, whereas e.g. Berg's Balance Scale is a risk factor computation with specific factors residing in the group of postural control related risk factors. An amalgamated approach where an overall risk computation would be based on well-known risk factor computations is also not immediate as the form and format of risk factor elements are often quite different in respective risk factor computations. The ontology of risk factors is mostly missing and an amalgamated overall assessment of computations is difficult to achieve.

A typical situation of **assessment within assessment** appears in Downton's Fall Risk Index, where MMSE may be used to assess cognitive impaiment. MMSE is obviously not seen as a fall risk assessment scale, and primarily it isn't. However, it does provide an assessment of cognitive factors, and the MMSE[13] index is at least loosely correlated with severity of `Dementia`, so it qualifies as a candidate assessment method for risk factor `Cognitive impairment` residing under the group `Psychological and cognitive factors`. This qualification can be compared with the qualification of Berg Balance scale for `Impaired postural stability` and `Gait pattern of limb movement and gait characteristics` under the group `Postural control`. An MMSE value below 24 may be seen as `Cognitive impairment = Yes (1 point)` in Downton's Fall Risk Index, and this is then *assessment within assessment*, where the logical justification is usually not discussed at all.

[13] 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.

The potential ontological structure of the risk factors in D1.1 is yet to be developed more formally (outside the scope of AiB), but since we have mentioned ”measurement and observations” we also need to connect this to ”symbolic and numeric values”, and more specifically, what **type of data** we are using in respective calculations. These aspects will need attention in specifications that underpin software solutions.

An interesting aspect concerning the bridge between statistics and logic, i.e., assessment and guidelines, is the need for flowcharts to support assessment. Flowcharts are not rules *per se*, but are intuitively presented as logical rules. A clear history of falls without other signs of illness points at environmental and psychological factors, whereas risk assessment in presence of acute illness turns the focus to medical conditions and drugs. Such flowcharts are typically not reflected in the risk calculations so that the statistics and logics of fall are basically independent.

5 Risk assessment methods and tools for fall risk calculation

The selection of screening and assessment tools is a trade-off between accuracy and ease administration within the particular care context where it is used, varying from community-based to particular clinical domains.

In the following we list some of the well-known and most frequently used assessment and screening tools. Short backgrounds with main references are given for all tools, and for some of the tools we provide a more detailed discussion on how underlying risk factors related to the risk factor structure in Deliverable 1.1, and also how risk factors possibly related to international standards for information in different domains.

5.1 Fall Risk Assessment and Screening Tools

a. Downton Fall Risk Index

The Downton fall risk index includes well-documented risk factors for falls and therefore offers satisfactory content validity and also seems to be very easy to administer[14]. It showed a moderate association between index score and number of patients with falls during the previous year in a sample of 28 patients Sensitivity was very high (100%) but specificity very low (9%). Although the Downton index was develop for elderly people in continuing care wards, it has been validated externally only among stroke patient in geriatric rehabilitation[15], in which a moderately high correlation was found between predicted risk of falls and observed falls, and in residential care facilities[16].

The Downton fall risk index includes 11 risk items which are scored one point each. Scores are summed to a total index score, range 0-11. A score of 3 or more is taken to indicate a high risk of falls.

[14] Downton JH. Falls in the elderly. London: Edward Arnold, 1993: 128-130.
[15] Nyberg L, Gustafson Y. Using the Downton Index to predict those prone to falls in stroke rehabilitation. Stroke 1996; 27(10): 1821–4.
[16] Rosendahl E, Lundin-Olsson L, Kallin K, Jensen J, Gustafson Y,Nyberg L. Prediction of falls among older people in residential care facilities by the Downton Index. Aging 2003; 15(2): 142–7.

The Downton fall risk index

Item	Score
Known previous falls	
No	0
Yes	1
Medications	
None	0
Tranquilizers/sedatives	1
Diuretics	1
Antihypertensives (other than diuretics)	1
Antiparkinsonian drugs	1
Antidepressants	1
Other medications	0
Sensory deficits	
None	0
Visual impairment	1
Hearing impairment	1
Limb impairment	1
Mental state	
Orientated	0
Cognitively impaired	1
Gait	
Normal (safe without walking aids)	0
Safe with walking aids	0
Unsafe (with or without walking aids)	1
Unable	1

No explicit operational definitions are provided with this index, although Rosendahl et al[3]. specified them in their study as follows. History of falls was obtained from medical records, the participants themselves or family members or caregivers. Medications were grouped according the index categories. Visual impairment was noted if the participant, with or without glasses, was not able to read a word in 5-mm block letters at reading distance. Hearing impairment was noted if the participant, without a hearing aid, was not able to perceive a conversation in a normal voice at a distance of 1 meter. Limb impairment was assessed by a physiotherapist and defined as the presence of amputated limb, signs of extremity paresis, muscle weakness or sensitivity impairment. MMSE cut-off score of ≤23/30 points was used as diagnostic criterion indicating cognitively impaired. Participants' ability to walk safely was rated according to the following categories: normal (safe without walking aids), safe with walking aids, unsafe and unable. Safe gait was scored when the participant was able to move easily and safely when, for example, opening and closing doors, meeting people in the hallway and approaching a chair to sit down. Unsafe gait indicated that the participant moved in an uncontrolled way, staggered or stumbled.

The magnitude of risk is not detailed any further, nor are time windows included. It is kind of assumed, that if nothing else happens concerning condition and intervention, the fall risk remains constant over time.

The tool does not explicitly point and interventions or pathways that will reduce the risk of fall as calculated by this particular tool.

Concerning granularity of risk factors, "multiple drugs" is itself not a risk factor to be registered, but is rather the name of the subset of drug related risk factors, each of which provide one point for scoring if the patient is presently using a drug within that drug risk factor. Given that use of sedatives, diuretics and antihypertensives suffices to score 3 points, Downton's index leans quite heavily of drug related risk factors, even if the index is seen as general fall risk calculator. Note also how Downton's index registers diuretics (C03) on anatomic level in the ATC encoding, but not specifically thiazide diuretics (therapeutic) or e.g. bendroflumethiazide (chemical).

Sedatives (N05C) and antidepressants (N06A) are on therapeutical level, and e.g. for sedatives no distinction is made between short-acting and long-acting benzodiazepines (chemical). Antiparkinsonian drugs (N04) are also on anatomic level.

For MMSE, going under 24 gives one point, and no considerations are made where in the MMSE scale points were lost, e.g. if points were lost mostly with respect to orientation or memory. Clearly, the original intention and purpose of Downton's index was not to be more specific on MMSE content. However, it is interesting to note that making no distinction at that point means that the cognition risk factor in Downton's index cannot be related e.g. to ICF encoded memory factors (b144) under mental functions (b1). This obviously raises the question about the various ways a patient can loose more than 6 MMSE points in order to score one point for Downton's index, or is the actually performance of a MMSE test a requirement for making "MMSE < 24" become true, and consequently increment one point to the index. Specific care units must clearly agree one way or the other, but we should also note that different care units may adopt different principles in these respects. Similar remarks can be made for seeing (ICF b210) and hearing (ICF b230), where ICF is quire specific about types of problems e.g. related to seeing, but Downton's index use a very coarse granular risk factor registration about seeing.

SNOMED as a standard nomenclature is frequently mentioned, and in the context of drugs as appearing in and used by Downton's index, we see e.g. that *dependence of sedatives*, *symptoms and syndromes caused by the use of sedatives*, and *side-effect of benzodiazepines* are terms in SNOMED, and this then may be seen as fairly close to qualify the use of SNOMED for encoding part of the risk factors appearing in Downton's index.

From information quality and management point of view these questions cannot be neglected in particular if we want to compare outcomes, or even aim at common observatories of data for the purpose of fall risk analytics.

b. Falls Risk for Older People in the Community (FROP-COM)

The Falls Risk for Older People in the Community (FROP-com)[17] developed by the National Ageing Research Institute (NARI) in Australia, incorporate information from multiple domains into a single falls risk score, being perhaps the most comprehensive instrument, as it purports to assess simultaneously 13 risk factors via a 28-item survey. While this instrument appears to be reliable and predictive of falls, the items rely on self-report and/or subjective appraisal of the tester. This may explain the no greater than moderate predictive validity of the instrument (sensitivity = 71% and specificity < 56%) with a good inter-rater and test-retest reliabilities (ICC = 0.93 and 0.91, respectively). It takes 40 to 50 minutes to apply and requires an extensive training.

The tool is interesting from the viewpoint that it contains not only the risk calculator, but also provides recommendations for interventions with respect to the risk factors registered.

Risk factors included falls history, ADL status and balance, each scoring a maximum of 3 points. The falls history question is based on WHO's definition of a fall. The falls history score is *n* if there are *n* falls in the past 12 months, and in the case of *n*=3, it's '3 or more falls', so that the maximum of *n* is 3. The ADL status is in fact a IADL status, and it the question can be seen as a subset of Lawton's IADL assessment tool. The balance question is also more shallow as compared to specific balance assessment scales.

[17] Russell MA, Hill KD, Blackberry I, Day LM, Dharmage SC. The reliability and predictive accuracy of the falls risk for older people in the community assessment (FROP-Com) tool. Age Ageing 2008; 37: 634-639.

The options for interventions included in FROP-Com are very general, and do not include specific intervention programmes. In the case of 1-3 points given by fall history the ”intervention” is ’inform the GP and address individual risk factors’.

c. Falls Risk Assessment Tool (FRAT)

FRAT[18] has three sections including falls risk status, risk factor checklist, and action plan. The first section can be used as a falls risk screening tool. This first section scores a maximum of 20 points for recent falls (8 points), medications (4 points), psychological (4 points), and cognitive status (4 points). The content and granularity of medication data is almost as in Downton’s index. Cognitive factors build upon Hodkinson’s Abbreviated Mental Test Score (AMTS).

The second section is a risk factor check list, where risk factors more broadly, and in fact quite like a subset of Deliverable 1.1 risk factors, are listed but not attached with quantification to be used in a scoring calculation.

Is a easy tool for use routinely by clinical and nonclinical care professionals. It has a high specificity (0.92, 95 per cent CI 0.88–0.94) and a positive predictive value of 0.57 (0.43–0.69); low sensitivity (0.42, 95 per cent CI 0.32–0.54) and negative predictive value (0.86, 0.83–0.89)
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d. Geriatric Postal Screening Survey (GPSS)

GPSS[19] developed to identify older persons in need of outpatient geriatric assessment and follow-up services screens for common geriatric conditions like depression, cognitive impairment, urinary incontinence, falls, and functional status impairment.

e. Elderly Fall Screening (EFST)

EFST[20] is a five-item screening test, focusing on history of falls and gait patterns. EFST aims to differentiate functionally independent community-dwelling elderly people into low and high risk groups in order to support targeted preventive interventions. With a short training It is easy to be administered by even non-medical personnel.

The EFST shows a high sensitivity (83%) to differentiates those at high risk of falls, *lower* specificity level (69%) and good positive predictive value (66.7%) so it can be considered useful to predict falls.

f. Fall Assessment Questionnaire (FAQ)

FAQ[21] focuses on known risk factors for falls in an inpatient setting.

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[18] S. Nandy, S. Parsons, C. Cryer, M. Underwood, E. Rashbrook, Y. Carter, S. Eldridge, J. Close, D. Skelton, S. Taylor, G. Feder, *Development and preliminary examination of the predictive validity of the Falls Risk Assessment Tool (FRAT) for use in primary care*, J Public Health (Oxf) **26** (2004), 138-143.

[19] C. A. Alessi, K. R. Josephson, J. O. Harker, F. M. Pietruszka, M. T. Hoyl, L. Z. Rubenstein, The yield, reliability, and validity of a postal survey for screening community-dwelling older people, J Am Geriatr **51** (2003), 194-202.

[20] J. G. Cwikelt, A. V. Fried, A. Biderman, D. Galinsky, *Validation of a fall-risk screening test, the Elderly Fall Screening Test (EFST), for community-dwelling elderly*, Disability and Rehabilitation, 20 (1998), 161-167.

[21] L. J. Rapport, J. S. Webster, K. L. Flemming, J. W. Lindberg, M. C. Godlewski, J. E. Brees, P. S. Abadee, *Predictors of falls among right-hemisphere stroke patients in the rehabilitation setting*, Arch Phys Med Rehabil **74** (1993), 621-626.

5.2 Fall Risk Factor Assessment and Screening Tools

g. Timed Up-and-Go test (TUGT)

The TUGT[22] test begins with the subject sitting correctly in a chair with arms. A piece of tape or other marker is placed on the floor 3 meters away from the chair. The subject then receives the following instructions: "On the word GO you will stand up, walk to the line on the floor, turn around and walk back to the chair and sit down. Walk at your regular pace." The person wears regular footwear and customary walking aid.

Timing starts on the word "GO", and stops when the subject is seated again correctly in the chair with their back resting on the back of the chair.

Normal healthy elderly usually complete the task in ten seconds or less. Very frail or weak elderly with poor mobility may take 2 minutes or more.

Results correlate with gait speed, balance, functional level, and the ability to go out. Completion in less than 20 seconds still implies good mobility, ability to go out alone, and being mobile without a gait aid, whereas durations over 20 seconds indicate problems in these respects.

This test is a sensitive and specific measure for identifying community-dwelling adults who are at risk for falls[23]. TUG is very simple to perform so is frequently used as general screening method to determine whether an in-depth mobility assessment and early intervention is necessary[24].

h. Performance Oriented Balance and Mobility Assessment (POMA)

Tinetti's fall risk index POMA[25,26,27] is a simple, easily administered test that measures a patient's gait and balance. The test is scored on the patient's ability to perform specific tasks. It takes 10 to 15 minutes including time to complete and scoring the test. Every item is scored in a range of 0-2 points: from the bigger impairment till the complete independence.

The individual scores are then combined to form three measures; an overall gait assessment score (12 points), an overall balance assessment score (16 points), and a gait and balance score (28 points). Patients who score below 19 are at a high risk for falls. Patients who score in the range of 19-24 indicate that the patient has a risk for falls. A score at 24 or more indicates low fall risk.

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[22] D. Podsiadlo, S. Richardson, *The Time "Up & Go": A test of basic functional mobility for frail elderly persons*, J. Amer. Geriatr. Soc. **39** (1991), 142-148.

[23] Anne Shumway-Cook, Sandy Brauer and Marjorie Woollacott *Predicting the Probability for Falls in Community-Dwelling Older Adults Using the Timed Up & Go Test*
Community-Dwelling Older Adults Using the Timed Up & Go Test Physical Therapy September 2000 vol. 80 no. 9 896-903

[24] Heike A. Bischoff, Hannes B. Sta¨ Helin , Andreas U. Monsch, Maura D. Iversen, Antje Weyh, Margot Von Dechend, Regula Akos, Martin Conzelmann, Walter Dick, Robert Theiler *Identifying a cut-off point for normal mobility: a comparison of the timed 'up and go' test in community-dwelling and institutionalised elderly women* Age and Ageing 2003; 32: 315–320

[25] M. E. Tinetti, *Performance-oriented assessment of mobility problems in elderly patients*, J. Amer. Geriatric Soc. **34** (1986), 119–126.

[26] 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.

[27] Lewis C. Balance, Gait Test Proves Simple Yet useful. P.T. Bulletin 1993; 2/10:9 & 40.

i. Berg Balance Scale (BBS)

BBS[28] has the following 14 items:

- ✓ sitting to standing
- ✓ standing unsupported
- ✓ sitting unsupported
- ✓ standing to sitting
- ✓ transfers
- ✓ standing with eyes closed
- ✓ standing with feet together
- ✓ reaching forward with outstretched arm
- ✓ retrieving object from floor
- ✓ turning to look behind
- ✓ turning 360 degrees
- ✓ placing alternate foot on stool
- ✓ standing with one foot in front
- ✓ standing on one foot

Each item scores a maximum of 4 points so that the BBS maximum score is 56. A score in the range 41-56 indicates low fall risk, 21-40 medium fall risk, and 0-20 high fall risk.

Each item comes with instructions, and rules concerning the score. As an example ’Sitting to standing’ is performed given the instruction ”Please stand up. Try not to use your hand for support.” A person able to stand without using hands and stabilize independently obtains 4 points, ability to stand independently using hands gives 3 points, ability to stand using hands after several tries gives 2 points, a need of minimal aid to stand or stabilize scores one point, and needing moderate or maximal assist to stand scores zero points.

All 14 items clearly relate to risk factor group ’postural control’, and they relate more to postural stability than gait characteristics. Some items are more directly related to risk factors, like ’placing alternate foot on stool’ is related to ’stepping over and obstacle avoiding’. Further, a few items, e.g. like 'standing with eyes closed' and 'standing with feet together' correlate with risk factor ’perturbation and its control’.

Note also how perturbations can be observed both by force plates and optical motion capture, which opens up questions about how far sensors and devices can be used to capture data into the BBS variables.

j. Alternate Step Test (AST)

The AST is a modified version of the BBS ’placing alternate foot on stool’ item.

k. Sit-to-Stand test with five repetitions (STS5)

STS5 can also be seen as a modified version of a BBS item, namely, the ’sitting to standing’ item, but STS5 is additionally used to measure lower limb strength in older people; however, performance is also influenced by other physiological and psychological factors related to

[28] K. Berg, S. Wood-Dauphinée, J. I. Williams, D. Gayton, *Measuring balance in the elderly: preliminary development of an instrument*, Physiotherapy Canada **41** (1989), 304–311.

balance and mobility and represents a particular transfer skill, rather than a proxy measure of lower limb strength[29].

This test can more clearly be automized e.g. by a force plate.

l. Functional Reach Test

The Functional Reach Test[30] measures the "margin of stability" and the ability to maintain balance while performing a functional task. The test is predictive of falls in older adults.
Functional reach is defined as ”the maximal distance one can reach forward beyond arm's length, while maintaining a fixed base of support in the standing position" (Duncan et al., 1990).
This test also involves perturbation where suitable devices can provide quite accurate values and distribution functions for the "margin of stability".

m. Physiological Profile Assessment (PPA)

The Falls and Balance Research Group[31] (FBRG) within NeuRA (Neuroscience Research Australia, Sydney) has developed the FallScreen©[32] falls risk calculator, which has a short and a long form. The short form contains five items: a single assessment of vision, peripheral sensation, lower limb strength, reaction time and body sway. The long form contains 15 items: three assessments of vision (high and low contrast visual acuity and edge contrast sensitivity), three assessments of peripheral sensation (tactile sensitivity, vibration sense and proprioception), assessments of three lower limb muscle groups (knee extensors, knee flexors and ankle dorsiflexors), assessments of both hand and foot reaction time and four assessments of body sway (sway on floor and foam with eyes open and closed). The underlying methodology is based on Stephen Lord's Physiological Profile Assessment[33] (PPA).

FallScreen© covers mostly gait and balance issues for risk assessments, and not explicitly other risk factors like medical, psychological or pharmacological.

PPA and FallScreen© is used within Australia and across the world, including Belgium, Canada, China, Denmark, Finland[34], Korea, Malta, New Zealand, Norway, Poland, Singapore, Sweden, Switzerland, Taiwan, USA and UK.

The PPA QuickScreen© is also frequently used.

n. Drugs

The effect of drugs of falls, and in a multifactorial setting, have been extensively studied e.g. at the University of Turku[35] in Southwest Finland.

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[29] Lord SR, Murray SM, Chapman K, Munro B, Tiedemann *A. Sit-to-stand performance depends on sensation, speed, balance, and psychological status in addition to strength in older people* J Gerontol A Biol Sci Med Sci. 2002 Aug;57(8):M539-43.
[30] P. W. Duncan, D. K. Weiner, J. Chandler, S. Studenski, *Functional reach: a new clinical measure of balance*, J Gerontol. **45** (1990), 192-197.
[31] http://www.neura.edu.au/research/facilities/falls-and-balance-research-group
[32] http://www.neura.edu.au/fbrg
[33] S. Lord, C. Sherrington, H. Menz, J. Close, *loc. sit*.
[34] Recommended in THL’s IKINÄ report.
[35] Sirkka-Liisa Kivelä and her group in Turku has produced a wide range of results in this area, and a recent thesis by Maritta Salonoja can also be mentioned. Salonoja is presently active in the City of Pori in region Satakunta. Fall risk analyses was performed in Pori e.g. during the years 2003-2005, with over 600 falls in the data set.

Psychotropics, opiates and potent anticholinergics were seen as fall-risk-increasing drugs (FRIDs) in a sub-analysis[36] of a randomized, controlled multifactorial fall prevention study. Falls were recorded from medical records, and the 12-month study consisted in the end of 528 community-dwelling subjects selected from a set of 591 volunteers (in the town of Pori, Finland) satisfying the following criteria:

- ✓ one or more self-reported falls in the previous 12 months
- ✓ ability to walk independently at least 10 m with or without walking aids
- ✓ normal cognitive functioning or only mild dementia (defined as being MMSE at 17 or more)
- ✓ age at least 65 years
- ✓ living at home or in an assisted living facility

This selection obviously provides a boundary concerning postural control and cognitive impairment oriented problems, so that the focus really comes mostly on drugs.

Subjects were divided into three groups according to the use of any FRID, any psychotropic drug, and use of benzodiazepine derivatives (BZD; N05BA, N05CD) or benzodiazepine related drugs (BZDRD; N05CF). Withdrawal (as an intervention!) of psychotropics, especially BZDs and BZDRDs, appeared to play an important role by lowering the risk of falls during the year after the 12-month multifactorial intervention.

This study was very detailed about use of particular FRIDs. The psychotropics included were antidepressives (N06A, N06CA01), antipsychotics (N05A), BZDs/BZDRDs (A03CA, N03AE01, N05BA, N05CD, N05CF, N06CA01, R06AE53, M09AA72) and others (N05BE01). Opioids (N02A) and potent anticholinergic drugs (A03CA02, A03CA05, C01BA01, G04BD04, G04BD07 G04BD08, G04BD09, M03BC51, N04AA02, N05BB01, R01BA52) were additionally seen as possible FRIDs.

From fall risk factor granularity point of view this study shows clearly that the drug factor subgroup is ”very ontological” as the ATC encoding strongly supports information management in ICT solutions.

o. Activities-specific Balance Confidence (ABC)

ABC[37] is a ’fear of falls’ test, and is predicitive of future falls. For certain activities, a level of self-confidence is indicated by choosing a percentage in the range 0-100%, i.e. from 'no confidence' to 'completely confident'. There are 16 activities, and an average self-confidence level is computed. An average level of less than 67% is seen to be an older adults at risk for falling.

p. Survey of Activities and Fear of Falling in the Elderly (SAFE)

SAFE[38] (Lachman et al., 1998) is a 22-item measure of the fear of falling, including types of physical activity, and worry about falling, BADL, IADL, mobility, and social activity. The score is again an unweighted sum of these 22 items, with a scale range of 0–66.

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[36] M. Salonoja, M. Salminen, T. Vahlberg, P. Aarnio, S.-L. Kivelä, Withdrawal of psychotropic drugs decreases the risk of falls requiring treatment, Arch Gerontol Geriatr 54 (2012), 160-167.
[37] L. E. Powell, A. M. Myers, *The Activities-specific Balance Confidence (ABC) Scale*, J Gerontol Med Sci 50 (1995), 28-34.
[38] M. E. Lachman, J. Howland, S. Tennstedt, A. Jette, S. Assmann, E. W. Peterson, *Fear of falling and activity restriction: The Survey of Activity and Fear of Falling in the Elderly (SAFFE)*, Journal of Gerontology: Psychological Sciences, 53 (1998), P43–P50.

q. The Falls Efficacy Scale-International (FES-I)

FES[39] is a 10-item questionnaire that was designed to measure falls efficacy, and measures confidence for performing 10 daily activities without falling on a scale 0–10. It is yet another fear of falling test, involving confidence related to performance of BADL like activities.

r. Mini-Mental State Examination (MMSE)

MMSE[40] is the most frequently used scale to assess cognitive decline. The maximum score is 30. MMSE values appear e.g. in Downton’s index.

s. Geriatric Depression Scale (GDS)

There are numerous assessment scales[41] for Depression, GDS[42] being of them. Furthermore, the full scale GDS-30 does not always have to be used, as the sensitivity and specificity for the optimum cutoff scores of the GDS-15, GDS-10 and GDS-4 are surprisingly good. Clearly, GDS-30 requires more time, and some questions are more ambiguous, whereas the GDS-4 value can be provided almost instantly in particular if the care provider/receiver relation is well established and long-term.

For diagnosing major depressive episode according to the DSM-IV[43] diagnostic criteria, cutoff at 2/3 shows a sensitivity rate at 80.5% and specificity at 78.3%[44].

The relation between depression and fear of fall has been established e.g. by investigating the relation between GDS-15, FES and SAGE[45], and there are also other studies on the correlation between depression and fall, as we pointed out in Deliverable 1.1.

The GDS-4 questionnaire is the following:

1. *Are you basically satisfied with your life?* (NO/yes)
2. *Do you feel that your life is empty?* (no/YES)
3. *Are you afraid that something bad is going to happen to you?* (no/YES)
4. *Do you feel happy most of the time?* (NO/yes)

A capital letter answer gives one point, and points are simply added to score a maximum of four points, so the cutoff 2/3 means scoring at least two points.

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[39] M. Tinetti, D. Richman, L. Powell, *Falls Efficacy as a Measure of Fear of Falling*, Journal of Gerontology. **45** (1990), 239.
[40] 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.
[41] A. Burns, B. Lawlor, S. Craig, *Assessment Scales in Old Age Psychiatry* (2nd edition), Informa Healthcare, 2009.
[42] J. Yesavage, *Development and Validation of Geriatric Depression Screening Scale: A preliminary report*, Journal of Psychiatry 17 (1983), 37-49.
[43] American Psychiatric Association, *Diagnostic and statistical manual of mental disorders*, Fourth Edition (DSM-IV-TR®), Text Revisions, American Psychiatric Association, 2000.
[44] O. P. Almeida, S. A. Almeida, Short versions of the geriatric depression scale: A study of their validity for the diagnosis of a major depressive episode according to the ICD-10 and DSM-IV.
[45] K.-L. Chou, F. K. C. Yeung, E. C. H. Wong, *Fear of falling and depressive symptoms in Chinese elderly living in nursing homes: Fall efficacy and activity level as mediator or moderator?*, Aging & Mental Health 9 (2005), 255–261.

t. Environmental checklists

There is a number of environmental checklist for identification of environmental hazards related to environmental risk factors mentioned in Deliverable 1.1. THL's IKINÄ appendix contains such a checklist, and there are several checklists used.

u. AUDIT

For alcohol consumption screening, AUDIT[46] and AUDIT-C[47] are frequently used.

6 Interventions and Preventions

Generally on interventions it is interesting not just to look at specific interventions targeting specific risk factors, but also more broadly on intervention processes targeting a wider scope of risk factors.

For preventions it also important to note the different use of assessment of fall risk factor and assessment of fall risk. Assessments related to particular risk factors target specific factors and thus prevents fall only implicitly, unless integrating these assessments into an overall risk assessment.

The overall discussion on interventions and preventions appears more in future AiB deliverables. Roughly, interventions ca be seen as representing (at least) the following types:

- ✓ physiological and physiotherapeutical interventions related to postural control
- ✓ pharmacological interventions and withdrawals of drugs
- ✓ medical interventions focusing on medical factors
- ✓ interventions focusing on psychological and cognitive factors
- ✓ interventions focusing on environmental factors
- ✓ intervention processes targeting a wider scope of risk factors

7 Technology and Sensors

Sensors provide means for an objective falls risk assessment. Besides used solely, they can be seen as an addition or extension to the usually somewhat subjective standard falls risk assessment scales. Especially wearable movement monitors, such as accelerometers, can broaden the falls risk screening beyond the clinical arena to the unsupervised environment, although entailing the challenges of design considerations, implementation protocols and signal analysis[48]. Sensors typically used for balance and gait assessment are force plates, optical

[46] K. A. Bradley, K. R. Bush, A. J. Epler, D. J. Dobie, T. M. Davis, J. L. Sporleder, C. Maynard, M. L. Burman, D. R. Kivlahan, *Two brief alcohol-screening tests From the Alcohol Use Disorders Identification Test (AUDIT): validation in a female Veterans Affairs patient population*, Arch Intern Med. **14** (2003), 821-829.

[47] K. Bush, D. R. Kivlahan, M. B. McDonell, S. D. Fihn, K. A. Bradley, *The AUDIT Alcohol Consumption Questions (AUDIT-C): An Effective Brief Screening Test for Problem Drinking*, Arch Intern Med **158** (1998), 1789-1795.

[48] 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.

motion capture systems, gait walkways, gait mats, insoles and wearable sensors, such as accelerometers, gyroscopes and magnetometers[49].

7.1 Wearable ambulatory sensors

Technology involving microelectromechanical systems (MEMS) enables production of cheap, small-sized and wearable sensors, such as accelerometers and gyroscopes, which (attached to the human body) are used for measuring movement of the human body. Accelerometers consist of a mass reacting to the movement or gravitation proportionally to the acceleration. By placing three accelerometers orthogonally to one another the movement can be monitored in three dimensions. Gravitational accelerations can be used for defining the postural orientation of the body it is attached to or sway for instance. The output voltage given by the accelerometer can be converted into m/s^2 values based on calibration. Gyroscopes on the other hand have a vibrating mass within the sensor, which displacement during the rotation of the sensor is proportional to the angle of the rotation. The rotation over time gives angular velocity of the sensor.

The raw sensor data itself isn't much of a use. There are a lot of data analysis methods and algorithms developed for e.g. activity recognition[50], falls detection[51], gait analysis[52] and falls risk estimation[53]. Usually calculated features include temporal parameters (e.g. step/stride times) and their variability, signal magnitude variables (e.g. maximum amplitudes) and frequency domain parameters (e.g. power spectrum). A vast amount of studies have investigated which parameters derived from sensor data can distinguish fallers from non-fallers or persons with high fall risk and low fall risk[54]. Usually the reference measure is a standard falls risk assessment scale such as Berg Balance Scale (BBS) or Physiological Profile Assessment (PPA). However, some studies suggest that body-worn kinematic sensors offer even improvement to the to the standard falls risk measures, such as BBS and Timed-Up-and-Go (TUG)[55] and five-times-sit-to-stand (STS5)[56].

With the combination of accelerometers, gyroscopes and magnetometers, which measure the sensor orientation in relation to the earth's magnetic north, the trajectory of the sensor movement (and body segment the sensor is attached to) can be calculated quite accurately[57].

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[49] 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.

[50] J. Pärkkä, M. Ermes, P. Korpipää, J. Mäntyjärvi, J. Peltola, I. Korhonen, *Activity Classification Using Realistic Data from Wearable Sensors*, IEEE Transactions on Technology in Biomedicine, Vol. 10, Issue 1, 2006, 119-128

[51] P. van de Ven, A. Bourke, C. Tavares, R. Feld, J. Nelson, A. Rocha, G.O. Laighin, *Integration of a suite of sensors in a wireless health sensor platform*, Proceedings of IEEE Sensors Conference, 2009, 1678-1683

[52] R. Moe-Nilssen, J.L. Helbostad, *Estimation of gait cycle characteristics by trunk accelerometry*, Journal of Biomechanics 37 (2004) 121-126

[53] J. Merilahti , T. Petäkoski-Hult , M. Ermes , H. Lahti , A. Ylinen , L. Autio , E. Hyvrinen , J. Hyttinen and M. van Gils, *Evaluation of new concept for balance and gait analysis: Patients with neurological disease, elderly people and young adults*, Proc. 6th Conf. Int. Soc. Gerontechnol., 2008

[54] 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.

[55] B.R. Greene, A. O'Donovan,R. Romero-Ortuno, L. Cogan, C.N. Scanaill, R.A. Kenny, *Quantitative Falls Risk Assessment Using the Timed Up and Go Test*, IEEE Transactions on Biomedical Engineering, Vol. 57, NO.12, December 2010

[56] E.P. Doheny, C.W. Fan, T. Foran, B.R. Greene, C. Cunningham, R.A. Kenny, *An instrumented sit-to-stand test used to examine differences between older fallers and non-fallers*, IEEE EMBS, Boston, 2011

[57] D. Roetenberg, *Inertial and Magnetic Sensing on Human Movement*, PhD. Thesis, University of Twente, 2006, http://doc.utwente.nl/56176/

In addition to the above mentioned sensors, goniometers can be used to determine range of motion of human body joints, pedometers detect steps taken and counts them (although nowadays pedometers usually incorporate accelerometers), sole pressure sensors measure pressure distribution across the plantar of the foot and actometers measure mechanically produced movements of human motion in order to estimate total energy expenditure.

7.2 Stationary monitoring systems

Stationary monitoring systems, such as force plates, optical motion capture systems and gait walkways provide accurate information about the human movement, but they are costly and thus often used only in clinical settings. Force plates measure ground reaction forces in three dimensions generated by a body standing or moving on them. Although they are not completely stationary, since there are also light-weight versions available[58], they are considered to be used in detailed balance evaluation and research environments rather than by all[59]. In addition to force plates, optical motion capture systems are considered as “gold standard” methods for human gait analysis. The cameras of the optical motion capture units track markers attached on the body to compute the motion of the body segments during movement. The system requires a stationary laboratory environment with fixed camera positions, which are not easily movable. Static and dynamic pressure distribution under feet during walking can be detected with gait walkways or gait mats, often used in falls clinics. With these equipment postural sway, side differences, timing and variability of certain parts of movements, etc. are measured to give indication of a person’s balance and falls risk.

[58] http://www.hurlabs.com/index.php?id=109

[59] 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.