Multi-Domain Model of Healthy Ageing: The Experience of the H2020 NESTORE Project

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Abstract Ageing is a complex multidimensional and multifactorial process associated with the decline in multiple physiological systems which can lead to frailties and disabilities over the lifespan. With the aim of supporting healthy older adults in order to sustain their wellbeing and capacity to live independently, the NESTORE project was recently funded by the EU Commission. In order to take into account the complex interactions among different aspects involved in the ageing processes, a model of healthy ageing was developed in NESTORE. This model included three core dimensions related to older people wellbeing (Physical/Physiological, Nutritional, Cognitive/Mental/Social). The NESTORE model was intended to provide a structured arrangement of the knowledge coming from such different domains in order to provide a simplified pool of information for: i) the characterization of the older adults, ii) the personalization of the coaching plans and iii) the implementation of an effective ICT system.

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1. Introduction

The European population aged 65 years and older is expected to increase from 17.4% to nearly 30% by 2060 [1] while the population of those aged 80 years and older is predicted to triple during the same period [2]. Ageing is associated with the decline in multiple physiological systems which can lead to frailties and disabilities over the lifespan [3]. Importantly to note, despite many age-related changes and preconceptions of marked declines, many older adults in the early later adult decades are cognitively healthy [4]. In order to plan policies with the main goal of mitigating the effects of the increasing ageing population on the socio-economical system, the European Commission has identified active and healthy ageing as a major societal challenge common to all European countries.

In this context, the NESTORE project (Novel Empowering Solutions and Technologies for Older people to Retain Everyday life activities), which was recently funded by EU commission within the H2020 programme, was designed and proposed [5].

NESTORE aims at supporting healthy older adults in order to sustain their well-being and capacity to live independently by promoting personalized pathways to wellbeing. NESTORE’s ambitious objective is to develop an innovative, multi-dimensional, cross-disciplinary and personalized coaching system that, leveraging ICT social connectivity, will support older adults by encouraging them to become co-producers of their wellness. NESTORE is a project that contemplates from early stages the end-user involvement to guarantee the reflection of real users’ needs and preferences.

Since ageing is a complex multidimensional and multifactorial process, within the NESTORE project, a model of healthy ageing was developed. This model included three core dimensions related to well-being (Physical/Physiological, Nutritional, Cognitive/Mental/Social).

The NESTORE model of healthy ageing is described in detail in the next paragraphs.

2. NESTORE Model of Healthy Ageing

The NESTORE Model of Healthy Ageing was aimed at providing a structured knowledge, built on the expertise of the NESTORE experts (exercise physiologists, nutritionists, lifespan psychologists, geriatricians), able to characterize the person in terms of both status and behaviour. In particular, the formalisation proposed in this paper is intended to provide organized information about healthy ageing-related
domains that can be useful to support reasoning, to manage the information flow and to facilitate the interoperability between devices and platforms used to monitor older adults’ status and behaviour. A similar descriptive model has been adopted in a previous European project aimed at counteracting obesity in young people [6], in order to provide structured information and ontological representation of physical/psychosocial/behavioural characteristics of the target user [7].

In NESTORE, the final user is an older adult (65 to 75) living an autonomous life and interested in maintaining or promoting her/his wellbeing and quality of life, without any clinically relevant impairment and/or pathology.

Based on this user definition, the model adopts a multi-domain classification, which includes: Physiological Status and Physical Activity Behaviour, Nutrition, Cognitive and Mental Status and Social Behaviour. For each domain, the model includes:

a) The definition of the domain variables that are useful for the characterization and monitoring of the person.

b) The relationships among the domain variables taking into account: 1) the direct causal relationships; 2) the indirect causal relationships; 3) the correlations between 2 variables; 4) the mathematical expressions for derived variables.

The development of a structured model was specifically thought to support the development of the NESTORE ontology and also for profiling activities and, consequently, for the personalization of coaching activities.

The characterization of a subject using such a holistic approach is aimed at improving the engagement of the users since it is helpful for a more effective implementation of the Selective Optimization with Compensation (SOC) [8] and Health Action Process Approach (HAPA) [9] models that will guide the NESTORE coaching system.

3. Physiological Status and Physical Activity Behaviour

With advancing age, structural and functional decline occurs in most physiological systems, even in the absence of evident disease. These age-related physiological changes involve a broad range of tissues, organ systems, and functions, which, cumulatively, can affect activities of daily living and the preservation of physical independence in older adults [10].

In NESTORE, the characterization of the physiological status of the subjects was structured in four subdomains: 1) Anthropometric Characteristics containing the main anthropometric variables describing body dimensions; 2) Cardiovascular System, which contains the main physiological variables that influence transport of nutrients, oxygen, carbon dioxide, hormones, and blood cells from the lungs to peripheral tissue and vice versa; 3) Respiratory System, containing the main physiological variables related to structure and function of the organs designated to exchange blood gases between ambient air and blood cells; 4) Musculoskeletal
System, which contains the key physiological variables related to the ability of skeletal muscle to generate force and power.

Moreover, a description of the variables describing the ability of a subject to perform exercise limited from the cardiorespiratory system (Cardiorespiratory Exercise Capacity) or musculoskeletal system (Strength-Balance-Flexibility Exercise Capacity) as well as the usual behaviour of a subject during everyday life (Physical activity Behaviour) was also included in the model. Finally, a description of the main factors related to sleep (Sleep Quality) was also included in this specific domain.

An example of a list of variables, included in the Physical Activity Behaviour subdomain, is reported in Table 1, whereas the block-diagram representing the relationships among variables, within the same subdomain, is shown in Fig. 1.

Table 1. List of variables included in Physical Activity Behaviour subdomain which is part of the Physiological Status and Physical Activity Behaviour domain.

| Subdomain                  | Physical Activity Behaviour                                                                 |
|----------------------------|---------------------------------------------------------------------------------------------|
| Variables                  | Distance, Exercise Duration, Exercise Intensity, Exercise Type (Cardiorespiratory, Muscle Strengthening, Balance, Flexibility), Exercise Frequency, Fatigue Accumulation, Grade, Activity Energy Expenditure, Rate of Perceived Exertion, Sedentariness, Speed, Steps (Number of Steps, Stride), Upper Limb Movements |

![Block-diagram of relationships among variables]
Fig. 1. Relationships among variables in the Physical Behaviour Subdomain.

4. Nutrition

Nutrition is an important element of health among older adults since it affects the whole process of ageing. The prevalence of malnutrition increases in older adults and it is associated with a decline in functional status, impaired muscle function, decreased bone mass, immune dysfunction, anaemia, reduced cognitive function and mortality [11]. Moreover, there are notable alterations related to ageing, such as body composition remodelling and metabolic dysregulation, which could be nutritionally managed.

In NESTORE, the nutrition domain was organized into four subdomains: 1) Anthropometric Characteristics, which is in common with the Physiological domain; 2) Blood Parameters which contain 3 crucial metabolic risk factors (glucose, cholesterol and triglycerides) for highly prevalent pathologies in aged adults like diabetes and cardiovascular disease; 3) Energy Balance which describes the components implicated in human energetic balance, a key factor for the regulation of body weight, mainly energy expenditure and energy intake; 4) Nutrition Habits which describes variables directly related to the study of a subject's dietary habits, including nutrient intakes.

An example of a list of variables, included in the Anthropometric Characteristics subdomain, is reported in Table 2, whereas the block-diagram representing the relationships among variables, within the same subdomain, is shown in Fig. 2.

Table 2. List of Variables included in the Anthropometric Characteristics subdomain which is part of the Nutrition Domain.

| Subdomain          | Anthropometric Characteristics                                      |
|--------------------|---------------------------------------------------------------------|
| Variables          | Body Height, Body Weight, Body Mass Index, Fat Mass, Fat-Free Mass,  |
|                    | Hip Circumference, Waist Circumference, Waist to Hip Ratio, Waist to |
|                    | Height Ratio                                                       |
5. Cognitive and Mental Status and Social Behaviour

Ageing is often associated with a decline in mental capabilities including biologically-driven cognitive domains such as memory, executive functions, processing speed and reasoning. These skills compose the so called fluid intelligence and are important for carrying out everyday activities and for retaining an independent life [12,13].

At the same time, social and emotional experiences partly change and partly remain relatively intact with increasing age. In particular, social networks become smaller overall while remaining relatively stable in terms of the number of emotionally close others, the emotions experienced by the persons in day-to-day life tend to be more stable, and overall subjective well-being is well-maintained. In addition, social roles change quantitatively and qualitatively [14].

In NESTORE, this complex domain was composed of four subdomains: 1) **Cognitive Status** which describes a range of intelligence domains that describe biologically- and experience-/knowledge-driven facets of cognition and intelligence, 2) **Mental Status**, including traits of psychological functioning in the area of subjective well-being, self and personality and social integration/feelings of loneliness. The two domains of status or trait variables will allow describing a dispositional profile of a person’s general resources in the cognitive and mental domain. These will be complemented by 3) **Mental Behaviour and States**, which capture the within-person processes mainly in emotional functioning that are observable in daily life on the basis of self-reported experiences and as information extracted from text bodies and speech, and 4) **Social Behaviour** which analyses the social context.
of the users involved in the studies and in using the NESTORE system. The social behaviour analysis aims at measuring both qualitatively and quantitatively some core variables describing the social behaviour of users in terms of (a) existence of social interactions through self-reported diaries and with sensing devices, (b) the number and duration of such interactions, and (c) possibly, the location of the interactions.

An example of a list of variables, included in the Cognitive and Mental Status and Social Behaviour subdomain, is reported in Table 3, whereas the block-diagram representing the relationships among variables, within the same subdomain, is shown in Fig. 3.

Table 3. List of Variables included in the Mental Status subdomain which is part of the Cognitive and Mental Status and Social Behaviour domain.

| Subdomain          | Mental Status (psychological functioning)                                                                 |
|--------------------|----------------------------------------------------------------------------------------------------------|
| Variables          | Personality (Extraversion, Agreeableness, Openness to experience, Conscientiousness, Neuroticism, Control Beliefs, Self-Efficacy), Social Network/Integration (Quantity, Quality, Loneliness, Support), Subjective Well-Being (Life Satisfaction, Positive Affective States, Negative Affective States) |

Fig. 3. Relationships among variables in the Mental Status (Psychological Functioning) Subdomain.
6. NESTORE Healthy Ageing Model Outcomes

The knowledge integration model presented in this paper is mainly intended as a necessary **preliminary step** to provide a wide-ranging semantic representation of the ageing subject profiles. In this context, this model will be useful **to support specific inference within a comprehensive ontology model** of the healthy ageing-related knowledge that will be implemented in NESTORE.

The NESTORE model of healthy ageing provides the list of variables, their relationships (intra- and inter-domain), the range of normality of each variable and the measurement scenarios that represent the basic foundation of the NESTORE technological implementation and of the system intelligence.

In particular, the proposed approach has a direct effect on:

- **System Requirements.** Wearable and environmental sensors and devices, composing the monitoring system, will be selected according to the variables included in the model.

- **System Intelligence.** The decision support system will be developed according to the variables relationships and ranges reported within the model.

- **Coaching Plans Definition.** The coaching activities in physical, nutrition, cognitive and social domains are designed and tailored to the subjects profiles taking into account the information provided by the integrated knowledge.

- **Pilot Studies.** The efficacy of the system will also be evaluated in each one of the well-being domains included in NESTORE: validated clinical measurements in each health domain will be definitely defined according to the model.

7. Conclusions

The NESTORE model of Healthy Ageing is the outcome of a prolific multidisciplinary cooperation and convergence among experts belonging to different scientific fields. The NESTORE model was intended to provide a structured arrangement of the knowledge coming from such different domains in order to provide a simplified pool of information for: i) the characterization of the older adults, ii) the personalization of the coaching plans and iii) the implementation of an effective ICT system.

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