How do you feel today?

Roppolo, Mattia

How do you feel today?

THE USE OF A DYNAMIC SYSTEMS APPROACH IN THE CONCEPTUALIZATION AND ANALYSIS OF HEALTH RELATED QUALITY OF LIFE IN OLDER ADULTS

MATTIA ROPPOLO

Cover picture and Design: Mattia Roppolo

Printed by: Gildeprint - www.gildeprint.nl

ISBN: 978-90-367-8238-8 (printed); 978-90-367-8237-1 (electronic)

NUR-code: 773

university of groningen

How do you feel today?

The use of a Dynamic Systems approach in the conceptualization and analysis of Health Related Quality of Life in older adults

PhD thesis

to obtain the degree of PhD at the
University of Groningen
on the authority of the
Rector Magnificus Prof. E. Sterken
and in accordance with
the decision by the College of Deans.

This thesis will be defended in public on

Monday 09 November 2015 at 12.45 hours

by

Mattia Roppolo

born on 16 june 1985
in Torino, Italy

Supervisor
Prof. P.L.C. van Geert

Co-supervisors
Dr. E.S. Kunnen
Dr. E. Rabaglietti

Assessment committee
Prof. F. Lucidi
Prof. P. de Jonge
Prof. R. Sanderman
Prof. E.M. Rizzi

UNIVERSITÀ DEGLI STUDI DI TORINO
DIPARTIMENTO DI PSICOLOGIA
SCUOLA DI DOTTORATO IN SCIENZE UMANE E SOCIALI

DOTTORATO IN
SCIENZE PSICOLOGICHE, ANTROPOLOGICHE E DELL'EDUCAZIONE
XXVI CICLO

TITOLO

How do you feel today?

The use of a Dynamic Systems approach in the conceptualization and analysis of Health Related Quality of Life in older adults

Dott. Mattia Roppolo

Tutor:
dott.ssa Rosalba Rosato
Co-tutor
dott.ssa Emanuela Rabaglietti

Coordinatore del dottorato
prof.ssa Cristina Mosso

Settore scientifico-disciplinare di afferenza
M-PSI/04 Psicologia dello sviluppo e dell'educazione

Anni Accademici
2011 - 2013

LIST OF CONTENTS

CHAPTER 1

INTRODUCTION

1. Preface

This thesis is inspired by the experiences I had working at a residential care facility while studying for my Master's Degree. My work consisted of physical rehabilitation of the older adults who lived there. Despite all my efforts to customize the activities and to advance progression and differentiation of the stimuli proposed on a daily basis, results varied greatly. Subjects often responded very well to some series of exercises one day, while they behaved opposite the day after. Other times, hard-won progress over a long period of time was completely and instantly reset by external influences that were not directly attributable to the physical sphere. Fortunately, however, sometimes individuals who had in previous months shown no progress at all, showed a sudden increase in their physical health status, without any clear reason. I could not find explanations for these changes and "strange'' patterns of development, and they raised questions that I tried to solve with the work and the articles presented in this thesis.

The same situation occurred when I started my research. During the first years, I was involved in a great Italian project called ACT ON AGEING, developed at the Department of Psychology at the University of Torino by Professor Silvia Ciairano. ACT ON AGEING aimed to increase the physical and cognitive health status in a large sample of older adults through the implementation of different interventions. Despite the good and general success of the project, results were heterogeneous in this instance as well, with some participants improving greatly, while others showed no change or even experienced worsening health conditions.

My involvement in the ACT ON AGEING project presented me with the opportunity to find answers to the following questions: why did our interventions, which are specific, scientifically valid and supported by literature, not produce consistent results in most of the participants? Why did similar stimuli on different days create different outcomes? How could external events change or reverse trends that were built week after week?

Fortunately, some research helped me find at least one way to answer my questions. I started reading books that dealt with complex systems from a philosophical, biological, economical point of view, and even though the topics were so far removed from my own field of interest, I found page after page of possible similarities between these disciplines and my specific and concrete questions. I learned that complex and Dynamic Systems were also studied and developed in Psychology. Specifically, one of the most important research groups in Dynamic Systems is the one at the Department of Developmental Psychology at the University of Groningen. This was particularly fortuitous because my late PhD promoter Prof. Silvia Ciairano defended her PhD thesis at the Groningen University, and since she had an “international soul”’’ (something she had passed on to her students) she suggested that I contact Prof. Saskia Kunnen and Prof. Paul van Geert in order to discuss my doubts and possible solutions.

Three years later, I am not sure whether the results I have found and the route I have walked have brought me to the final solution of my initial questions, but one thing is for certain: I learned a lot about human development and I acquired a “new pair of glasses” that helped me look at the world in a different way.

Il senso della ricerca sta nel cammino fatto e non nella meta; il fine del viaggiare è il viaggiare stesso e non l’arrivare.

(TizianoTerzani, 2006)

The sense of research is done in the journey, not the destination; the end of the travel is the travel itself and not the arrival.

(TizianoTerzani, 2006)

2. Demographic changes

2.1 The old Europe

The ageing of European society is well described and projected by the statistics of the World Health Organization and Eurostat. These statistics show that the general population is expected to face a slight increase between 2008 and 2060 (2.1%), and the aged population (65 years and over) is expected to show a huge growth rate in the same period (80%) (Eurostat, 2012). As a consequence, 33% of the European population is expected to be composed of aged people in 2060 (Giannakouris, 2008).

The decrease of the birth and fertility rate together with the increase of the number of older adults will generate a change in the population pyramid (Pollack, 2005): the base of the pyramid (infants and children) will get smaller, while the top will get substantially larger (Giannakouris, 2008).

If we imagine the European population as a pie, we can see that the slice of the older adults (over 65 years) is gradually becoming the largest slice. Eurostat (2012) reports that in 2000, 15.6% (min. 5.4% max. 18.1%) of the population consisted of people over age 65. Over the course of ten years, this percentage increased steadily until in 2010 it had risen to 17.4% (min. 7% and max. 20.7%)., A similar trend can be seen for the people aged 80 and over.

A relevant aspect of this change in the population is the so-called old-age dependency ratio. The old-age dependency ratio is defined as the rate between the number of economically inactive older adults and the number of persons of working age (Eurostat, 2012). Longitudinal European data from 1990 to 2010 (Eurostat, 2012) show an increase of 5.3% of this indicator (20.6% in 1990, 23.2 % in 2000, and 25.9% in 2010). This means that in 1990 in the European zone, for each inactive aged person, there were five who were economically active. In 2010, this ratio was 1:4. The Eurostat projections (Giannakouris, 2008) reveal a steady increase of this rate until 2060, when the rate is estimated to be 52.5% (this means that for each economically inactive aged person, there will be two economically active persons). These trends are relevant for both national and European governments, because social and economic adaptations will be necessary in answer to the new demands of the population.

2.2 Theories of ageing

The demographic analysis has shown that the European population is growing old rapidly. Next, we will focus on the age-related process, in order to understand what happens during the later part of life.

The current theories assume that age-related development is a complex and multifactorial process (Weinert & Timiras, 2003) in which three components play a role: the internal factor (i.e., genetics), the external factor (i.e., environment), and the stochastic factor (i.e., random events). These factors interact with each other to cause the ageing process. Theories that seek to understand the mechanism behind the ageing process aim to define why and how a person ages. The main theories of ageing are: (i) the evolutionary theory, which states that ageing is due to a lack in selection; (ii) the molecular theory, which states that the changes in genes expression are the main cause of senescence; (iii) the cellular theory, which states that senescence as a process is related to the cellular limits in replications, with a consequent alteration in the cells' physiology; (iv) systemic theories, which focus on the incapacity of the whole organism to maintain and control organs and systems and the inability to communicate and adapt environmental requests (Franceschi et al., 2000; Kirkwood, 2002; Kirkwood & Kowald, 1997; Weinert & Timiras, 2003). These theories will not be extensively discussed here, but it is important to note that they are not mutually exclusive and can act simultaneously.

In general, we can say that the ageing process is characterized by a loss of homeostasis (defined as the propriety that a system has to maintain its internal environment's stability) and a reduced ability to respond to the external requests (Weinert & Timiras, 2003) that causes an increase in incidences of disease and finally death. These descriptions make it clear that ageing is a period of change that involves the whole person.

2.3 Life expectancy

In order to understand the demographic change and its consequences, it is important and necessary to consider the most used and common population index, the Life Expectancy (LE), which is the expected numbers of years remaining at a certain age.

As previously described, the population is getting older. This demographic change is due to improvements in living conditions and medicine and medical care amelioration, with a decline in deaths due to infectious and cardiovascular diseases (Weinert & Timiras, 2003; Zweifel, Felder & Meiers, 1999). LE indicators (measured at birth, at 60 years, and at 65 years) may provide further information about the ageing trends.

Regarding the European population median age Eurostat data (Giannakouris, 2008) report a value of 40.4 years in 2008. For 2060 a median age of 47.9 years is estimated.

Over the years, LE has increased considerably. LE at birth in Europe is currently at 79.6 years (min 68 - max 85; WHO 2009), and between 1999 and 2009, LE at birth increased from 76,5 years (73 years for men and 79.6 for women) to 79.6 years (76.7 for men and 82.6 for women) (Eurostat, 2012). A similar trend is visible in the LE at age 60, when the European population has a mean value of 23.1 years (min. 18.65 – max. 25). In the period between 1999 and 2009 the mean LE at age 60 increased from 20.6 years (18.5 for men and 22.7 for women) to 23.1 years (21.1 for men and 25.1 for women).

Finally, the LE at age 65 is currently 19.1 years (min. 14.25 – max. 21). In 2009 the mean LE at age 65 for men was 17.3 years and 20.9 for women. In 1999 the same index was 14.9 years for men and 18.5 years for women (mean value of 16.7 years, Eurostat, 2012).

The data mentioned above emphasize the magnitude of the demographic change in a very short period of time. It demonstrates the general ageing of European society and how the last phase of life has become longer, resulting in a large increase in the so-called "old elderly" (80 years and over) population (Eurostat, 2012).

These data show a great achievement of contemporary society which, in combination with the amelioration of living conditions and medical progress, allows us to live longer.

2.4 Healthy Life Years

In the next chapters we will elaborate on the concept of healthy life years (HLY). This concept is connected to LE and is defined as the life expectancy in good health.

As will be argued later on, Eurostat data (2012) highlight opposite trends for LE (increasing as highlighted above) and HLY (decreasing). The information derived from Eurostat tables, based on the entire EU population in the period between 2004 and 2010 shows an unhealthy life expectancy at birth of 20 years for women and 15 years for men in 2010, and these values are higher when compared to 2004. A similar trend is observable in the HLY at age 65. From 2004 to 2010, this decreases from 9.7 to 8.8 years (12.1 unhealthy years) for women, and from 9.1 to 8.7 years for men (8.6 unhealthy years).

Data about the HLY are extremely important, because quantification of the healthy life expectancy of European population can serve as the basis for research designs, clinical interventions and sustainable policy actions that aim to increase healthy life expectancy of the aged populations. These actions may result in not just a longer but also a healthier life, with possible positive repercussions on both an individual and a societal level.

2.5 Overview

"Add life to years and not only years to life"; this could be the final statement of this section. In order to maintain or increase quality of life, it is necessary to study the underlying mechanisms of health in the ageing process and to use these conceptual notions as a springboard to the implementation of preventive interventions. The use of preventive strategies may have an impact on: (i) the individual level, with the reduction of the unhealthy life expectancy, an increase of the autonomy and a consequent reduction of institutionalization rate; (ii) societal level, with a decrease of direct (i.e., hospitalization) and indirect (i.e., loss of quality of life) costs in association with an increase of healthy and active population.

These premises are the basis of the construct of Health-Related Quality of Life (HRQOL), a central topic in the study of the ageing process. The next section addresses HRQOL and will explain its nature and definition.

3. Health-Related Quality of Life

Health-related topics are relevant on an individual and societal level due to the current demographic changes and how society is ageing. This study deals with health-related topics during the ageing process using the construct of Health-Related Quality of Life (HRQOL).

3.1 Definition and background

3.1.1 Health and health models

Health was defined by WHO (1948) as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity". This definition was revolutionary because it reversed the classical point of view; it conceptualized health in a positive way, focusing not on diseases or limitations, but on well-being. Additionally it proposes a multidimensional construct of health, including physical, mental and social determinants, stating that a complete state of health must concern the well-being in each of these domains, and not only in physical-biological aspects.

The biopsychosocial model was developed using the definition of health as a starting point (Engel, 1977). This model defined health as continuum trend-line (from worst to best possible health). The biopsychosocial model is in contrast with the classical biomedical model, in which the categories "health" and "infirmity" are on opposite sides of spectrum. Furthermore, the biopsychosocial model considers interconnections and mutual influences among health domains, with the use of a systemic approach, based on systems theory (Engel, 1977). Conversely, the biomedical model adopts a mechanistic and reductionist approach, allowing only linear and causal relationships from a lower level (biological functions) to a higher level (general health; Engel, 1977).

The biopsychosocial model made the study of health and health-related topics as systems of interconnected elements that may vary and change over time in a continuous way possible. The biopsychosocial model represents the basis of this thesis.

Engel's model (1977) was applied in many areas of research and clinical practice, and it has a wide impact and visibility (Engel's article has currently been cited 6754 times). However, despite the innovative and interesting conceptualization, recent findings (Fava & Sonino, 2008; White, 2005) affirm that, thirty years after its conceptualization, the biopsychosocial model has not yet seen any large-scale integration; despite its limitations, the biomedical model continues to be the model most often used.

This thesis applies Engel's model to the construct on HRQOL together with a Dynamic Systems approach, pursuing the following objectives: (i), to re-conceptualize the construct and, (ii) to create a theoretical and applicable framework for the expansion of the use of the biopsychosocial model in clinical practice.

3.1.2 Quality of Life and HRQOL

The construct of HRQOL is the central topic of this thesis. To start with, we will provide a general background on the concepts of Quality of Life (QOL) and HRQOL, for a better conceptual framework.

The emergence and use of the QOL concept derives from the scarce information provided by indicators of morbidity and mortality (Idler & Benyamini, 1997). QOL is a person-centered measure, which includes the individual perception of life within a context and in relation to personal goals and expectations (WHO, 1997). Over the years, a large consensus has been reached concerning the concept of QOL, with an increasing number of published articles. A basic search of the key phrase "quality of life" results in 179,742 hits, with a minimum number of published articles in between 1959 and 1964 (n= 1) and a maximum in 2012 (n= 15,330). The trend line of published papers found in PubMed is presented in Figure 1.

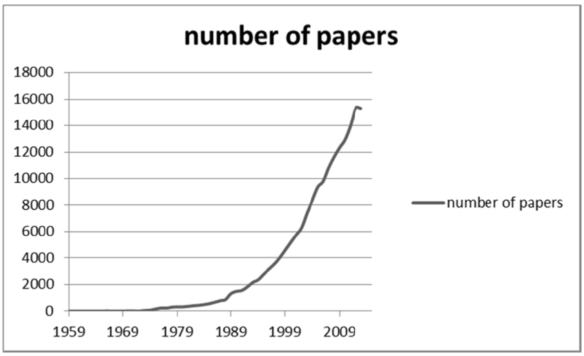

Figure 1 - Number of papers on QOL

However, despite the large number of QOL studies, this construct remains "an amorphous concept, that is used in many disciplines – geography, literature, health economics, advertising, health promotion and medical and social science" (Bowling, 1999). One of the most important and common problems concerning QOL is that it is an umbrella term, in which, theoretically, all the aspects of life are included (Bowling, 1999). Because the construct is so broad, it is difficult to operationalize and measure (because it may have different meanings in different fields of interest (cf. Farquhar, 1995; Hunt, 1997).

The concept of HRQOL was developed in order to make QOL less broad. HRQOL is based on the perceived impact of the health status (Testa & Simonson, 1996). HRQOL narrows the focus to the physical, mental and social domains of health, that are seen as aspects that can be influenced by intra- and interindividual influences. Furthermore, aspects of QOL such as cultural, societal or political factors, which are not included in the definition of health, are excluded from the concept of HRQOL (Ferrans, Zerwic, Wilbur, & Larson, 2005).

HRQOL was defined as a personal and dynamic concept, because it is a self-evaluation of health and an internal process which may be influenced by complex interactions of factors (Allison, Locker & Feine, 1997; Bastani & Kiadaliri, 2011; Dempster & Donnelly, 2000; Morris, Suissa, Sherwood, Wright & Greer, 1986). Although HRQOL is thus seen as a dynamic concept, research mainly addresses it in a static manner.

HRQOL is a useful concept to study how processes act on a person and predictions of negative health outcomes (Theofilou, 2011). Specifically, on the one hand HRQOL measures are used to test the effectiveness of interventions (as an example: Sillanpää, Häkkinen, Holviala, &Häkkinen, 2012) and diseases (cf. Lam & Lauder, 2000).In order to understand whether changes in HRQOL reflect clinically meaningful differences as well, statistically based methods were developed (Crosby, Kolotkin & Williams, 2003). These methods aim to identify the smallest possible changes in HRQOL that reflect a change in clinical differences and patient management. On the other hand, especially in older adults, measures of HRQOL are used as indicators of negative health outcomes (cf. Dominick, Ahern, Gold, & Heller, 2002; Tsai, Chi, Lee, & Chou, 2007).

Finally, HRQOL measures may be useful for national and supranational policy makers in order to understand whether health-related objectives are being reached and to implement substantial and efficient strategies to enhance the general standard of health and perceptions of individuals (Theofilou, 2011).

4. Overview of the thesis

4.1 General aim

Despite the important role of HRQOL as an outcome and predictor measure, there currently are still some gaps in the conceptualization and measurement of the construct. From a conceptual point of view, a great number of conceptual models have been developed resulting in a high number of instruments, with a low coherence. Furthermore, the most generally adopted conceptual models are based on a biomedical approach (Wilson & Cleary, 1995), while an approach based on the biopsychosocial model may result in a better comprehension of the construct. From an applicable point of view, studies that reported how HRQOL develops during time and how the different domains are related to each other during time are lacking.

Especially these two topics – the development over time and the interrelations between domains – need further study, because insight into these topics may result in a better understanding of the nature and development of HRQOL, with possible interesting applicable solutions in the area of health promotion and prevention of negative health outcomes during the ageing process.

The general aim of the thesis is to apply a Dynamic Systems approach to the construct of HRQOL, with the possibility to expand the conceptualization of the construct and to analyze dynamic trends and characteristics over time in older adults.

4.2 Structure

This thesis is a collection of papers. Specifically, three papers are included in the thesis. They cover the general aim of the thesis, starting with a conceptual study and arriving at an empirical investigation. Each paper follows the previous one, and the entire thesis creates a kind of framework in which the construct of HRQOL is studied using a Dynamic Systems approach. Each paper represents a chapter of the thesis.

The aim of the second chapter is to present a conceptual model of HRQOL based on Dynamic Systems theory. To do so, after a first look at demographical trends and age-related health changes, the chapter focuses on existing models of HRQOL, as we try to find common points and current limitations. Furthermore, similarities between HRQOL and Dynamic Systems are presented as well as a conceptual model that meets all the cited requirements is. Next, the operationalization of the model is presented, in order to give an applicable translation of the conceptual assumptions. Finally, possible developments as well as limitations of the model are presented.

The third chapter is connected to the second one, and in particular aims to analyze the validity of the conceptual model through the construction and validation of a mathematical dynamic systems model that represents the conceptual model. In this chapter, the connections and the theoretical assumptions made in the previous chapter are translated into a numerical form by the application of non-linear equations as generally used in Dynamic Systems modeling. The construction of this model is a necessary step in order to analyze the ability of the conceptual model to catch salient information of HRQOL. To test this ability, the mathematical model is tested by means of a twofold procedure with empirical data. Results show a good fit of the mathematical model with these data. Because the model is developed to represent the theory, and not just to describe variations in a data set, such as Structural Equation Models, this fit strongly indicates that the theoretical model is satisfactory. Additionally, this chapter presents possible further research and applications, as well as current limitations.

Finally, the fourth chapter, using the theoretical basis developed in the conceptual model as a starting point, analyzes daily trends of HRQOL in a small sample of institutionalized older adults.

In chapter three, we found evidence for the validity of our assumption that development of HRQOL can be viewed as a dynamic system. The perception of HRQOL as a dynamic system that changes over time opens new possibilities for research. An important characteristic in dynamic behavior, which reveals much information about the process, is variability, and especially the changes in variability over time. For that reason, in chapter four we investigate whether and how patterns of variability can provide relevant information about the development of HRQOL in individuals. Chapter four argues that the participants show dynamic and unstable daily HRQOL sequences during the research project (100 days) and it is demonstrated that day-to-day variability is related to health trends and final state. By starting from variations in intra individual data sets, this chapter is an attempt to study HRQOL from a Dynamic Systems perspective. The results seem to confirm our theoretical expectations, even if, especially in this case, extreme caution must be taken in the data handling, since the sample size is very limited.

At the end of the three main chapters, a general conclusion is presented, with the aim to summarize the work, the principal results, applicable solutions and further steps that must be addressed. Aims, methods, results and conclusions for each study are summarized in Table 1.

Chapter 2	**Older adults and Health Related Quality of Life: a conceptual model based on a dynamic systems perspective**
Aims	1. To discuss if the construct of HRQOL may be associated and conceptualized with a dynamic systems approach 2. To present a new conceptual model of HRQOL in the aged population, based on dynamic systems theory
Methods	This is a conceptual study. The concept of HRQOL was analyzed in light of a dynamic systems approach. Furthermore, a conceptual model was designed including salient characteristics and their relations during time
Results	1. HRQOL seems to fit within the dynamic systems framework 2. An operational definition of the conceptual model was delineated, in order to allow further development and tests
Conclusion	1. The conceptual model can provide new ideas and insights about the processes acting in the ageing period, due to the use of developmental view and dynamic systems approach 2. Further empirical studies are necessary to confirm these assumptions
Chapter 3	**A quantitative Dynamic Systems model of Health Related Quality of Life among older adults**
Aims	1. To translate the conceptual model in a mathematical one 2. To test the goodness of the model by a calibration and a validation procedure
Methods	1. The model building is made by translating the components of the model in a numerical form and by assigning non-linear equations to each directed relationship presented in the conceptual model (arrows in the graphical model) 2. The calibration procedure was made with theoretically plausible data in order to assess how the model reacts to different initial sets of data 3. Empirical data of 194 community dwelling older-adults are used as initial and outcome data to validate the model
Results	1. The calibration procedure detects the parameter ranges within the model reacts with theoretically acceptable trends 2. The model fits empirical data in a satisfactory way, showing no statistically or conceptually meaningful differences between empirical and simulated final data
Conclusion	1. The validation procedure returns positive results in agreement with theoretical expectations 2. Data suggests the goodness of theoretical assumptions about the dynamic development of HRQOL in the aged population
Chapter 4	**''How I feel today?'' An analysis of HRQOL variability among institutionalized older adults**
Aims	1. To test how the construct of HRQOL develops during time among older-adults 2. To analyze if indicators of variability are related with developmental trends and final health outcomes
Methods	1. 22 institutionalized older-adults participated in the longitudinal design study 2. Participants fill out daily and monthly questionnaire measures of HRQOL 3. Data analyses are conducted to find reliability and construct validity of daily measures 4. Day-to-day variability is computed and related to health outcomes and trends 5. Day-to-day variability before an extreme value in the developmental trends is compared with day-to-day variability in the whole period
Results	1. Daily measures are correlated with monthly validated questionnaires 2. Day-to-day variability is generally related with negative health outcomes and trends 3. Variability preceding an extreme value in the developmental trends, is higher than day-to-day variability in the whole period
Conclusion	1. The role of daily variability emerges as an important indicator of final outcomes and developmental trends 2. Data suggest that HRQOL may present typical characteristics of dynamic systems, however, due to the small sample size, these data need to be confirmed by other studies

Table 1 - The thesis at a glance

5. References

Allison, P. J., Locker, D., & Feine, J. S. (1997). Quality of life: A dynamic construct. *Social Science & Medicine*, *45*(2), 221–230. doi:10.1016/S0277-9536(96)00339-5

Bastani, P., & Kiadaliri, A. A. (2011). Health-related quality of life after chemotherapy cycle in breast cancer in Iran. *Medical Oncology*, *28*(1), 70–74. doi:10.1007/s12032-010-9714-x

Bowling, A. (1999, September). Health-Related Quality of Life: a discussion of the concept, its use and measurement.

Crosby, R. D., Kolotkin, R. L., & Williams, G. R. (2003). Defining clinically meaningful change in health-related quality of life. *Journal of Clinical Epidemiology*, *56*(5), 395–407. doi:10.1016/S0895-4356(03)00044-1

Dempster, M., & Donnelly, M. (2000). How well do elderly people complete individualised quality of life measures: An exploratory study. *Quality of Life Research*, *9*(4), 369–375. doi:10.1023/A:1008959925664

Dominick, K., Ahern, F., Gold, C., & Heller, D. (2002). Relationship of health-related quality of life to health care utilization and mortality among older adults. *Aging clinical and experimental research*, *14*(6), 499–508.

Engel, G. L. (1977). The need for a new medical model: a challenge for biomedicine. *Science*, *196*(4286), 129–136. doi:10.1126/science.847460

European Commission. (2012). *Active ageing and solidarity between generations. A statistical portrait of the European Union 2012* (Vol. 1). Luxembourg: Office for Official Publ. of the European Communities.

Farquhar, M. (1995). Definitions of quality of life: a taxonomy. *Journal of Advanced Nursing*, *22*(3), 502–508. doi:10.1046/j.1365-2648.1995.22030502.x

Fava, G. A., & Sonino, N. (2008). The Biopsychosocial Model Thirty Years Later. *Psychotherapy and Psychosomatics*, *77*(1), 1–2. doi:10.1159/000110052

Ferrans, C. E., Zerwic, J. J., Wilbur, J. E., & Larson, J. L. (2005). Conceptual Model of Health-Related Quality of Life. *Journal of Nursing Scholarship*, *37*(4), 336–342. doi:10.1111/j.1547-5069.2005.00058.x

Franceschi, C., Valensin, S., Bonafè, M., Paolisso, G., Yashin, A. ., Monti, D., & De Benedictis, G. (2000). The network and the remodeling theories of aging: historical background and new perspectives. *Experimental Gerontology*, *35*(6–7), 879–896. doi:10.1016/S0531-5565(00)00172-8

Giannakouris, K. (2008). Population and social conditions. Ageing characteristics the demographic perspectives of the European societies. Eurostat, Statistic in focus.

Hickey, D. A., Barker, M., McGee, H., & O'Boyle, C. (2005). Measuring health-related quality of life in older patient populations. *PharmacoEconomics*, *23*(10), 971–993. doi:10.2165/00019053-200523100-00002

Hunt, S. M. (1997). The problem of quality of life. *Quality of Life Research*, *6*(3), 0–0. doi:10.1023/A:1026402519847

Idler, E. L., & Benyamini, Y. (1997). Self-Rated Health and Mortality: A Review of Twenty-Seven Community Studies. *Journal of Health and Social Behavior*, *38*(1), 21–37. doi:10.2307/2955359

Kirkwood, T. B. . (2002). Evolution of ageing. *Mechanisms of Ageing and Development*, *123*(7), 737–745. doi:10.1016/S0047-6374(01)00419-5

Kirkwood, T. B. L., & Kowald, A. (1997). Network theory of aging. *Experimental Gerontology*, *32*(4–5), 395–399. doi:10.1016/S0531-5565(96)00171-4

Lam, C. L., & Lauder, I. J. (2000). The impact of chronic diseases on the health-related quality of life (HRQOL) of Chinese patients in primary care. *Family Practice*, *17*(2), 159–166. doi:10.1093/fampra/17.2.159

Morris, J. N., Suissa, S., Sherwood, S., Wright, S. M., & Greer, D. (1986). Last days: A study of the quality of life of terminally ill cancer patients. *Journal of Chronic Diseases*, *39*(1), 47–62. doi:10.1016/0021-9681(86)90106-2

Pollack, M. E. (2005). Intelligent Technology for an Aging Population: The Use of AI to Assist Elders with Cognitive Impairment. *AI Magazine*, *26*(2), 9. doi:10.1609/aimag.v26i2.1810

Sillanpää, E., Häkkinen, K., Holviala, J., & Häkkinen, A. (2012). Combined Strength and Endurance Training Improves Health-Related Quality of Life in Healthy Middle-Aged and Older Adults. *International Journal of Sports Medicine*, *33*(12), 981–986. doi:10.1055/s-0032-1311589

Testa, M. A., & Simonson, D. C. (1996). Assessment of Quality-of-Life Outcomes. *New England Journal of Medicine*, *334*(13), 835–840. doi:10.1056/NEJM199603283341306

Theofilou, P. (2011). Why is it Important to Assess Health - Related Quality of Life? *Journal of Palliative Care & Medicine*, *01*(01). doi:10.4172/2165-7386.1000e104

Tsai, S.-Y., Chi, L.-Y., Lee, C., & Chou, P. (2007). Health-related quality of life as a predictor of mortality among community-dwelling older persons. *European Journal of Epidemiology*, *22*(1), 19–26. doi:10.1007/s10654-006-9092-z

Weinert, B. T., & Timiras, P. S. (2003). Invited Review: Theories of aging. *Journal of Applied Physiology*, *95*(4), 1706–1716. doi:10.1152/japplphysiol.00288.2003

White, P. (2005). *Biopsychosocial Medicine: An Integrated Approach to Understanding Illness*. Oxford University Press.

Wilson, I., & Cleary, P. (1995). Linking clinical variables with health-related quality of life: A conceptual model of patient outcomes. *JAMA*, *273*(1), 59–65. doi:10.1001/jama.1995.03520250075037

World Health Organization. (1997). *WHOQOL, measuring Quality of Life; division of mental health and prevention of substance abuse* (No. WHO/MSA/MNH/PSF/97.4) (p. 15). Geneva: WHO.

Zweifel, P., Felder, S., & Meiers, M. (1999). Ageing of population and health care expenditure: a red herring? *Health Economics*, *8*(6), 485–496. doi:10.1002/(SICI)1099-1050(199909)8:6<485::AID-HEC461>3.0.CO;2-4

CHAPTER 2

OLDER ADULTS AND HEALTH RELATED QUALITY OF LIFE: A CONCEPTUAL MODEL BASED ON A DYNAMIC SYSTEMS PERSPECTIVE

Mattia Roppolo[1-2], Saskia Kunnen[2], Anna Mulasso[1], Emanuela Rabaglietti[1], Paul van Geert[2]

1. Department of Psychology, University of Torino (IT)
2. Department of Developmental Psychology, Rijksuniversiteit of Groningen (NL)

At press in: Wolfe R, ed. *Psychological Health and Needs Research Developments*. Vol I. Psychology. Hauppauge NY: Nova Science Publishers; 2015. ISBN: 978-1-63483-332-5

Abstract

The ageing process is increasingly important in the entire western world and in particular in Europe. The analysis of demographic and health changes of the aged population is increasingly urgent in order to answer to the new individual and societal requests resulting from the increasing number of ageing people. An important concept in this regard is Health Related Quality of Life (HRQOL) during ageing, on which this paper will focus. Firstly, a general framework on demographics and health changes is provided. Secondly, the concept of HRQOL is analyzed, highlighting its strengths as well as its potential limitations. Thirdly, an analysis of HRQOL developmental trends, processes and mechanisms related to these processes is given. Finally, a conceptual dynamic systems model of HRQOL is delineated, in order to summarize the approach taken in the paper and to propose new insights in the study of HRQOL in the aged population.

Keywords: Health related quality of life; Dynamic systems; Conceptual model; Ageing

1. Demographic and health changes: a general framework

Europe is sometimes called "the old continent". This statement becomes increasingly true, due to the ageing of the European population, which will have major effects on the global economical and societal systems and especially on public health, social needs, welfare state and economic policies. For this reason, it is important to analyze demographic and health changes of the ageing population in order to answer to the new needs of individuals and society.

In the lasts decades the concept of Health Related Quality of Life (HRQOL) became more and more used, due to its ability to focus on self-rated health status and perceptions, instead of simply using mortality and morbidity indicators. The concept HRQOL allows for a more encompassing and person-centered conceptualization of health outcome. However, currently it is not clear how HRQOL evolves during the ageing process.

This question can be answered by a comprehensive theoretical model that can structure the empirical data on the relevant health processes during ageing, and, by doing so, can form the basis for further studies on health prevention and promotion.

A comprehensive model of HRQOL has to: (i) include various domains of functioning; (ii) take into account the interconnections among domains; (iii) include predictable as well as unpredictable life events; and (iv) consider the variety of developmental processes, including stability, decline or improvement.

The paper will first describe the emergent ageing process, analyze the latest data on ageing-related changes, and highlight the relevant characteristics of HRQOL and its domains. As a next step, it gives an overview of what models we already have, and in what ways these models still lack the necessary characteristics. Finally, it will present a model that meets the requirements just mentioned, namely a model focusing on HRQOL from the perspective of Dynamic Systems theory.

Such an approach enables us to focus on processes acting on health status and perceptions during ageing, which is hardly possible with traditional approaches.

1.1 Demographic changes

According to the World Health Organization and Eurostat, the aged population (65 years and over) will have a growth rate of 57% between 2008 and 2035, and of 80% between 2008 and 2060, rising from 84.2 to 151.7 million of older adults against a general EU population of 495.4 million of people in 2008 and 505.7 million in 2060 (Eurostat, 2011).

Projections claim that, in 2060, almost 30% of European population will be over 65 years (Eurostat, 2008).

Longitudinal European data from 1990 to 2010 (Eurostat, 2011) describe an increase of 5.3% (20.6% in 1990 – 23.2 % in 2000 – 25.9% in 2010) of the old-dependency ratio, defined as the proportion between the number of seniors economically inactive and the number of persons in a working age. This means that in 1990 in the European zone, for any inactive aged person, five were economically active. Currently (2010) this proportion is 1 versus 4. Eurostat projections (Giannakouris, 2008) estimate an old-age dependency ratio of 52.5% in 2060.

Over the years, life expectancy (LE - the expected numbers of years remaining at a given age) increased considerably. Currently, LE at birth in Europe is 79.6 years (min 68 for Latvia - max 85 for France; Eurostat, 2011), with a strong increase from 76.5 years in 1999 (73 years for men and 80 for women) to 79.6 in 2009 (77 for men and 83 for women; Eurostat, 2011).

Unfortunately, the increase in LE is not accompanied by an increase in the Healthy Life Years (HLY), defined as the healthy life expectancy at a certain age. The European HLY followed a negative trend from 2004 to 2010 for both genders. In particular, HLY at birth was 63.7 years for women and 62.2 years for men in 2004. In six years, it decreased with 1.1 years for women (62.6 years) and 0.5 years for men (61.7 years). If compared with LE data at birth the values highlight an average of 20 unhealthy years for women (82.6 – 62.6) and 15 years for men (76.7 – 61.7).

The WHO General Director, Dr. Hiroshi Nakajima, in 1997, said: *"Increased longevity without quality of life is an empty prize. Health expectancy is more important than life expectancy"*. The widening gap between quality of life and longevity is paid on an individual level in terms of loss of autonomy and institutionalization, and on a societal level with a higher demand for care and increasing of National Health Systems costs.

To cope with these demographic and social changes and to try to add life to years (and not only years to life), the objectives of both researchers and clinicians are: (i) to identify processes and mechanisms underlying changes of health status and quality of life in the older adults population; and (ii) to implement effective preventive interventions in seniors, in order to maintain health status and autonomy as long as possible. In the next sections, we will give a short overview of what is known about age related changes in health.

1.2 Age-related health changes

At first sight, data discussed in the previous section, confirm the expansion of morbidity theory (Manton, 1982). According to this theory, increase in LE is caused by a lower death rate for chronic diseases rather than by a decline in the incidence of these diseases. This view highlights that increasing longevity is related to increasing number of unhealthy-years.

Conversely, the dynamic equilibrium theory is based on the decrease of the impact of diseases on the health of older adults (Manton, Gu, & Lamb, 2006, Manton, 1982). This theory assumes that the lower mortality is linked to a less deterioration of the vital organs, and that diseases have a lower severity (Crimmins, 2004), however do not assume a lower incidence of pathological conditions.

The reduced impact in terms of disability (Crimmins, 2004) is not accompanied by a decrease of incidence and prevalence of chronic diseases in the seniors (Eurostat, 2011; Marengoni, Winblad, Karp, & Fratiglioni, 2008). In fact, statistics from Eurostat (2011) show that the percentage of people having an enduring illness or health problems in the European area is higher with the increase of age: 30.9% in the whole population, 54.8% in the population aged 65-74, 66.1% in the 75-84 years population and 69.5% in the over 85 years. This trend is increasing from 2004 to 2010, proportional to age: 3.2% in the whole population, 4.5% in the population aged between 65-74, 5.4% in the 75-84 age group and 6.1% in over 85 years (Eurostat, 2011). The high prevalence of non-communicable and other chronic conditions in the aged population is the most relevant cause of unhealthy years in later life.

Starting from the WHO definition of Health (1946): *''Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity'',* it is possible to analyze health changes typical of ageing process in each of the three domains (physical, mental and social) proposed by WHO.

Physical health changes are related to muscle-skeletal (Cummings, 1993; Doherty, 2001; Frontera, et al., 2000; Hannan, et al., 2000; Janssen, Heymsfield, Wang, & Ross, 2000; Johnell & Kanis, 2004; Lexell, 1995; Rogers & Evans, 1993), cardiorespiratory (Janssens, Pache, & Nicod, 1999; Kitzman, 2000; Kitzman & Edwards, 1990; Rossi, Ganassini, Tantucci, & Grassi, 1996; Rossi, et al., 1996; Sharma & Goodwin, 2006), and nervous systems (Albert & Janice E. Knoefel, 1994; Rivner, Swift, & Malik, 2001; Salat, et al., 2004), that may have negative impact on health outcomes, autonomy of daily living and HRQOL (Chien, Huang, & Wu, 2008; Janssen, Baumgartner, Ross, Rosenberg, & Roubenoff, 2004; Janssen, Heymsfield, & Ross, 2002; Roubenoff & Hughes, 2000).

In the mental domain, changes were found on cognitive (Mebane-Sims & Association, 2009; Small, Stern, Tang, & Mayeux, 1999) and psychological adjustments (Beekman, Copeland, & Prince, 1999; Beekman, et al., 1998; Blazer, Burchett, Service, & George, 1991; McAvay, Seeman, & Rodin, 1996).

Finally, the social domain shows changes in and disengagement from social activities during the ageing process (Bennet, 2002; Cumming & Henry, 1961).

1.3 Successful ageing

On the one hand the physical, mental and social changes are described as decline and disengagement from usual activities (this view is generally called usual ageing, see Atchley, 1989), on the other hand, the new and more positive thinking (successful ageing, see Baltes & Baltes, 1993) proposes an increase or maintenance of health status in the older adult population due to changes that occur in daily habits and lifestyle (i.e., participation in activities). A recent study (Haskell, et al., 2007) shows that an active lifestyle and/or a participation in physical exercises may lead to an improvement in physical fitness, health status and diseases prevention.

An active lifestyle is also correlated with a better cognitive and psychological health (Floel, et al., 2008; Netz, Wu, Becker, & Tenenbaum, 2005), with important consequences for prevention of health decline, functional loss and disability (Fratiglioni, Paillard-Borg, & Winblad, 2004; Keysor, 2003). In contradiction with disengagement theory, activity theory (Lemon, Bengtson, & Peterson, 1972), supports the active participation of seniors in social life. This participation can be beneficial to health, with a consequent reduction of mortality (Bennett, 2002; Sabin, 1993).

Finally, the Selection, Compensation and Optimization Theory (SOC) proposed by Freund and Baltes (1998) explains in a positive view on the ageing process. SOC theory expresses ageing as a complex, multifactorial process, not understandable from a linear perspective (Baltes & Smith, 2003). In addition, the approach of Baltes identifies ageing not only as a period of decline but also as a life-phase in which individuals can find new ways and strategies to maintain their normal life.

1.4 Interplay among domains

In order to understand age related health change, one of the most important aspects that emerged in the literature is the strong connection between the physical, psychological and social domain. It was demonstrated that changes in one of the health components affect the other domains directly or indirectly. Interconnections among health domains were found between (i) physical and mental (Bouchard & Shephard, 1994; Kramer, et al., 2003; Wang, Larson, Bowen, & van Belle, 2006); (ii) psychological and social (Glass, De Leon, Bassuk, & Berkman, 2006; Kawachi & Berkman, 2001); and (iii) physical and social components (Bennett, 2005; Bennett, 2002). These relations, which require further investigation, reflect the complex interplay among health components, confirming the basic assumptions of the biopsychosocial model (Engel, 1977). The biopsychosocial model is in contrast with the classical biomedical model, in which "health" is a category opposite to the category "infirmity". Furthermore, the biopsychosocial model considers interconnections and mutual influences among health domains, with the use of a systemic approach, based on systems theory (Engel, 1977). The biopsychosocial model allowed to study health and health-related topics as systems of interconnected elements, that may vary and change over time in a continuous way.

In order to understand the complex interplay among health domains, a model that considers mutual relationships, focusing on changes and non-linarites, is needed. A dynamic systems approach can be very helpful to conceptualize and study such a complex, non-linear process. It offers possibilities to analyze the mutual connections and development of HRQOL over time that are not possible with more classical approaches. Dynamic systems focus on the components of the system and their mutual influences (Kunnen, 2012).

2. The concept of Health Related Quality of Life: definition and limitations

The construct of HRQOL is suitable for the purpose of studying health process during ageing, because it addresses self-rated health, and because it is a predictive measure of health decline, mortality and institutionalization in the aged population (Bilotta, et al., 2011; Dorr, et al., 2006).

HRQOL is a concept deriving from two sources. The first is the definition of health previously cited (Age-related health changes section). The second is the definition of quality of life (QOL) as -"the subjective perception that an individual has of his own existence, in the context of culture and of a set of values in which he lives, even in relation to his objectives, expectations and concerns") proposed by WHO (1997).

2.1 A definition of HRQOL

HRQOL refers to physical, mental and social domains of health that are seen as distinct areas influenced by a person's experiences, beliefs, expectations, and perceptions (Testa & Simonson, 1996). HRQOL is a person-centered measure that can be modified in a complex way from (i) perceptions of physical and psychological-emotional health; (ii) level of independence; (iii) social role; (iv) relationships; (v) context; and (vi) environmental and working interactions (Testa & Simonson, 1996). HRQOL narrows the focus to the effects of health, illness, and treatment on QOL, and excludes aspects of QOL that are not related to health, such as cultural, political, or societal attributes (Ferrans, Zerwic, Wilbur, & Larson, 2005).

2.2 Limitations of the current conceptualization

The distinction between health-related and non-health-related quality of life is not always simple, and for this reason many models exist that include different aspects of HRQOL. For instance, Wilson and Cleary (1995) created a model based on biological/physical variables, symptoms, functional status, health perceptions and overall QOL, with the addition of individual and environmental characteristics. Other scholars suggest six fundamental dimensions of HRQOL: physical functioning, psychological functioning, social functioning, role activities, overall life satisfaction, and perceptions of health status (Berzon, Hays, & Shumaker, 1993). Patrick and Erikson (in Aaronson, 1993) use a model composed by five concepts: life span, symptoms, physical functions, health perceptions and opportunity. Spilker (1996) suggested what he called a "pyramid model" composed of three layers. The lower level contains the indicators or components of HRQOL, the mid-level represents the broad domains of HRQOL (physical status and functional abilities, psychological status and wellbeing, social interactions, economic and/or vocational status and factors, and, religious and/or spiritual status), finally, the higher level represents the overall assessment of wellbeing. Ware and Dewey (2000) described HRQOL as a series of concentric circles that spread from biological functions to HRQOL via physical/mental health and social role. Other models include physical problems, psychological problems, sexual functions, activity of daily living and perceptions of wellbeing. The only common point among these models is the multidimensional nature of the concept. As proposed by Spilker (1996), the absence of a universally accepted definition of HRQOL is a direct consequence of the diversity of approaches and specificity to the topic, and should not be seen as a problem. We agree with Spilker that, because the field of HRQOL is changing and very diverse, it is not useful to limit scholars to a specific and narrow definition. The disadvantage of this great variety of definitions and instruments to assess HRQOL is that it may limit the possibility to compare studies and results. However, it is not our goal to criticize the construct of HRQOL. On the contrary, we aim to propose another conceptualization and measure of HRQOL among other adults, namely one that fits in with our dynamic systems perspective.

Furthermore, for model building and comparison, also the modes to assess HRQOL have to be taken into consideration. Bury and Holme (1991) and Testa and Simonson (1996) argue that each dimension can be measured in an objective and subjective way. While the objective measurement refers to health status (in our conceptualization, self-report health status), the subjective evaluation is related to the perceptions of health, implying that two persons with the same health status may have different HRQOL's. This implication is supported by Henchoz et al. (2008), who found differences between health status and health perceptions among older adults, confirming the importance to assess both aspects.

The most used and detailed conceptual model of HRQOL is the one proposed by Wilson & Cleary (1995). This model conceptualizes HRQOL as a continuous and linear path from the biological functions to the overall QoL (via symptoms, functional status and general health perceptions). Furthermore, each concept included in the Wilson & Cleary model has a direct influence from the individual and the environmental characteristics. This model represents a uni-directional causal approach, based on the biomedical model (opposite than the biopsychosocial model, which allows a nonlinear multidirectional causal approach) to the analysis of HRQOL.

Although the model gives important information about the elements acting on the HRQOL, there are various limitations. The first regards the concepts of development and changes of the construct under examination. We conceive of HRQOL as a concept that arises from the match between self-reported health status and health perceptions. We may call this "experienced health" referring to deem individual evaluation of the experiential component of health. This match between self-reported health status and health perceptions is not a static condition, but should be seen as an ongoing iterated process, in which a subsequent state is strongly connected with the previous one. The conceptualization of the development of HRQOL as linear is theoretically not plausible, and it does not fit in with empirical findings. It is therefore necessary to emphasize the role of time and the iterative process in self-assessment of HRQOL. Second, the Wilson & Cleary model shows limitations regarding the interconnections among domains/variables, which it primarily conceptualizes as a structure of uni-directional links. A single direction for the links among the elements can lead to neglecting the possible interconnections and the complexity of the structure. Third, the causal model of Wilson & Cleary (1995) insufficiently accounts for the particular influences of random events. Casual events can act on each component of the models and are not presented in the conceptualization. To avoid the loss of a source of information that acts directly on HRQOL domains, the inclusion in the conceptual model of random influences is necessary.

2.3 A step forward in the definition of HRQOL

Due to the lack of consensus among models, we think that it is useful to formulate the conditions and sketch the outlines of a new and more comprehensive conceptual model of HRQOL. In particular, our aim is firstly to concentrate on the broad domains level of HRQOL (Spilker, 1996), with the use of a three dimensional structure, using physical, mental and social domains (starting from the WHO definitions of Health). The three dimensional structure is to make the model consistent with the WHO definition, but also because we need a simply, understandable and comprehensive definition and conceptualization of HRQOL and its their main domains. Moreover, we aim to use a double way of assessment (as proposed by Testa and Simonson, 1996) in order to capture both the way in which the person perceives the more “objective” (i.e., the total amount of physical activity performed during the day) part of the health (we call this the self-reported health status), and the way in which the person experiences his/her own health and the consequences of their health in daily life (we call this the “experienced health”).

The advantage of this theoretical structure is based on the usefulness and easiness to adopt the tripartite nature of health as proposed by WHO, thus avoiding the use of many different domains that hinder the comparison of the results based on assessment instruments using a more complicated definition of HRQOL (Murdaugh, 1997). Furthermore, the adoption of Testa and Simonson’s distinction between the self-report health status and experienced-health components of HRQOL, offers the possibility to understand differences in HRQOL, and to provide new ways of explanation of changes and intra- and inter-individual variability.

2.4 Strengths of the concept

Despite the lack of consensus on HRQOL definitions, the usefulness of a HRQOL measure in clinical and research fields is widely recognized.

HRQOL provides a patient perspective on effects of interventions, diseases and processes acting on people. It is a person-centered outcome measure, which is more specific and indicative, then the traditional measures of mortality and morbidity (Idler & Benyamini, 1997; Tsai, Chi, Lee & Chou, 2007).

HRQOL is important on both the individual and the societal level. On the one hand, it is important to assess HRQOL, with the goal to enhance the healthy life expectancy (Theofilou, 2011). On the other hand, measure HRQOL is recognized as an objective that must be reached by the US program Healthy People 2020 (U.S. Department of Health and

Social Services), and will help nations in monitoring to what extent health objectives have been achieved (Theofilou, 2011).

3. Developmental trends of HRQOL in the aged population

In previous research, HRQOL is mainly used as an outcome measurement that indicates the impact of processes (i.e., pathological processes) on self-rated health. Specifically, previous literature reports two types of studies on HRQOL and aged people, about: (i) the impact of diseases, (ii) the impact of activities/behaviors/interventions. In the first case, scholars reported the negative impact that different kind of diseases have on HRQOL.

In particular, chronic diseases, such as hypertension, osteoarthritis, diabetes, depression, asthma are the most studied (among other: Kempen, Ormel, Brilman, & Relyveld, 1997; Lam & Lauder, 2000). Research reveals the general negative trend that diseases and comorbidity have on HRQOL of older adults (Hopman, et al., 2009). Furthermore, the mental component was seen as the most stable, that seems to maintain its level also in the presence of various diseases (Hopman, et al., 2009; Kempen, Ormel, Brilman, & Relyveld, 1997).

Other studies (Lam & Lauder, 2000; Lima, et al., 2009) show that some diseases may affect a variety of aspects: hypertension affects the physical component in particular, asthma and joint diseases are negatively associated with autonomy in activities of daily living. Depression is a condition that highly affects the whole HRQOL (Lam & Lauder, 2000).

Secondly, evidence on the effects of various types of independent variables on HRQOL affirms that there is a strong relation between active lifestyle (i.e., active leisure time, hobbies, participation in specific interventions) and HRQOL. In particular, previous studies highlight that people who are physically active during leisure time have a higher level of HRQOL in comparison with sedentary older adults (Balboa-Castillo, Leon-Munoz, Graciani, Rodriguez-Artalejo, & Guallar-Castillon, 2011; Drageset, et al., 2009; Jenkins, Pienta, & Horgas, 2002; Lee & Russell, 2003; Thompson, Zack, Krahn, Andresen, & Barile, 2012).

Recently, various interventions were compared on their effectiveness for HRQOL. Excluding drug trials, the most common are physical and psychological/cognitive interventions.

Cognitive interventions, based on memory, reasoning or speed of processing exercises, (among others: Wolinsky, Unverzagt, Smith, Jones, Stoddard, et al., 2006;

Wolinsky, Unverzagt, Smith, Jones, Wright, et al., 2006) demonstrated their efficacy in terms of maintenance of HRQOL.

Various types of physical training showed beneficial effects; in particular, scholars reported the effectiveness on HRQOL of: strength exercises (Kimura, et al., 2010), combined strength and endurance exercises (Sillanpaa, Hakkinen, Holviala, & Hakkinen, 2012), and aerobic exercises (Ciairano, Liubicich & Rabaglietti, 2010; Deschamps, Onifade, Decamps, & Bourdel-Marchasson, 2009). All interventions have positive effects on HRQOL, compared with non-participants groups. In sum, the literature provides strong evidence for positive effects of general physical activity interventions on HRQOL (Acree, et al., 2006; Elavsky, et al., 2005; Inaba, Obuchi, Arai, Satake, & Takahira, 2008; Lee, Lee, & Woo, 2009; Penedo & Dahn, 2005; Shephard, 1993; Sillanpaa, et al., 2012; Yasunaga, et al., 2006).

Moreover, a study of Deschamps et al. (2009) compared a physical training based on Tai Chi exercises and a cognitive training, emphasizing that both interventions directly and positively act on HRQOL of participants. Another study, based on Shintaido discipline, combining mental and physical activities, demonstrated the ability to act directly and indirectly on physical and psychological health of older adults (Roppolo, Mulasso, Magistro, Roggero, Andreoli, & Liubicich, 2012).

Thus, there is a lot of research showing that HRQOL can be affected by a variety of processes. However, little attention has been paid to the developmental changes of HRQOL itself.

In our view, HRQOL should not be studied only as an outcome, but also as a process in itself, resulting from iterations and interconnections among domains.

It seems that HRQOL is a construct characterized by complex variability, modifications and variations caused by individual characteristics, activities, behaviors and social interactions. Currently, scientific evidence clearly showing developmental trends of HRQOL in the ageing process is inconsistent. Moreover, no models take into account the role of time with regard to changes in HRQOL.

Longitudinal studies are needed to explore the role of time. Cross-sectional data reported a general decrease of the physical component with the increasing of age, while the mental component seems to remain stable (Hopman, et al., 2000). Nowadays, due to the lack of studies exploring trends of HRQOL over time, it is fundamental to build a theoretical framework in order to conceptualize HRQOL as a person-centered system composed by a set of interconnected elements, that develop during time as results of the iterations and internal/external influences. The resulting conceptual model will be useful to: (i) better understand processes and mechanisms of changes in HRQOL during the ageing process; and (ii) analyze individual developmental trajectories. This approach may allow a better comprehension of the process modifying HRQOL, and may provide effective and individualized interventions for health promotion in seniors.

4. HRQOL and Dynamic Systems

The main objective of this paper is to present a new conceptual model of HRQOL that allows for understanding the change processes in the aged population. Currently, models use a large variety of components that do not allow comparability among them. Interconnections among domains, role of time and life events are not considered. Finally, the current models are linear and confine themselves to uni-directional causal relationships.

In our view, HRQOL is a system, and as a system has to be studied as a whole, in order to understand its development over time. To delineate such a system, dynamic systems represent a solid basis.

The new conceptual model aims to take into account the development of the construct and the individual trajectories of HRQOL over time. In particular, the new HRQOL conceptual model will consider the role of time, the causal interconnections among variables/domains and the influences of random effects.

The dynamic systems approach has been already applied in the field of social sciences and developmental psychology in the analysis of psychological characteristics, mainly in childhood and adolescence (Bassano & van Geert, 2007; Kunnen, 2009; Kunnen, 2012; Lichtwarck-Aschoff, Kunnen, & van Geert, 2009; Steenbeek & van Geert, 2008; van Geert, 1994). The present article aims to extend this literature, applying a dynamic systems approach on the construct of HRQOL in a population of seniors (generally not considered in the psychological dynamic systems studies). Before doing so, we will describe the most important features of dynamic systems and discuss how the concept of HRQOL fits in with these features.

4.1 General characteristics of Dynamic Systems

A dynamic system is composed by a set of interconnected interacting elements that affect each other. These interactions provide the causal ground for the development of the system during the course of time (van Geert, 1994; Weisstein, 2003). The dynamic systems approach to human development is based on the view that humans are complex and interactive systems that change (or develop) their state (for instance, their emotional state) during time. Development derives from interactions among environmental and individual variables and inter-individual characteristics (Kunnen, 2012; Kunnen & Bosma, 2000). In particular, the focus of a dynamic systems perspective is the analysis of individual changes and trajectories over time (Thelen & Ulrich, 1991), emphasizing the role of intra-individual variability and stability as fundamental notions to understand the development of the systems (Thelen & Smith, 1996; Thelen & Ulrich, 1991; van Geert & van Dijk, 2002). Development may emerge on a long-term time scale (changes that occur over the course of months or years), and on a short-term time scale (short time period representing actions on a real time basis; Kunnen, 2012). Furthermore, the process of individual changes, that represents the main objective of the dynamic systems studies, is complex and multivariate (Kunnen, 2012). Complexity involves mutual causality among interconnected components, which results in self-organization and emergent phenomena. Self-organization is defined as the emergence of a stable higher order characteristic in the system (Kunnen, 2012).

4.2 Can HRQOL be viewed as a Dynamic System?

Starting from dynamic systems theory and the current conceptualization of HRQOL, it is plausible to assume that the latter shares important characteristics with the former.

4.2.1 Developmental process

HRQOL is assumed to show intra-individual change over time (Bernhard, Lowy, Mathys, Herrmann, & Hurny, 2004; Sprangers & Schwartz, 2008). Especially, it tends to show a decline in the ageing period. The decline may be gradual or by sudden steps. Furthermore, HRQOL may show temporary increase or fluctuations. For these reasons, it is possible to hypothesize that HRQOL is a developmental process described as a sequence of states over time. Each state of the system in any time is described by the position of the relevant dimensions of the system itself (Kunnen, 2012). The position of the system in the space of relevant dimensions changes over time, and the sequence of such positions draws a path through the developmental space. The path described by the relevant dimensions over time represents the developmental process. Development, in this sense, is an iterative process. Iterative means that each step in the developmental path is related to its previous state (the starting value of a step is the outcome of the previous one).

4.2.2 Interconnected elements

Existing definitions and conceptual models agree that HRQOL is a multidimensional construct (Lipscomb, Gotay, & Snyder, 2004). Interconnections among elements are a typical characteristic of systems in the human and social sciences. Each HRQOL component can influence, change or act on the other. Interconnections exist on and between different levels of generality. Because HRQOL is multi layered, many different levels of interconnectedness can be studied. In this study we will address the interconnectedness between the main components at the middle level, as defined by Spilker (1996). As an example, mental health can influence both the physical and the social functions (i.e., the case of depressive symptoms). The interconnections among elements represent another similarity between HRQOL and dynamic systems theory.

4.2.3 Non linearity

Living systems are in general nonlinear (Kunnen, 2012; van Geert, 2008). This statement is mainly attributable to the impossibility for a human system to always proceed along continuous and stable trends (e.g. continuous and constant growth of health perception), assumption related to linear systems and their additive nature of the contribution of distinct variables. In HRQOL many factors (i.e., diagnosis of a disease, administration of a new drug) can reverse or change the growth rate of the self-report health status. Nonlinearity is also related to the number and types of influences (internal and external) to which every person is subject. In particular, mutual influences, including iterativity causes processes to become nonlinear. A very important source of nonlinearity is the fact that many processes are time dependent, (i.e. dependent on their own history) which is a major feature of an iterative process.

HRQOL, conceptualized as a system of interconnected elements that develop during time, can be expected to show nonlinear behavior over time. The interconnections among elements imply that changes in the trend of one component can influence the trends in other domains, which can feed back onto the first component.

4.2.4 Mutual causality

An important characteristic of complex and non-linear systems is that unidirectional and proportional (linear) causal relations between two variables are relatively rare or unlikely. Sometimes, a small change in one variable may cause a big change in the whole system. Other times, repeated and strong attempts to modify the system are without effect. Human systems are, characterized by the impossibility to predict the sequence of outputs, knowing the sequence of inputs and the initial state of the system. In non-deterministic systems, each initial state and inputs value corresponds with lots of possible output states. As an example, the therapeutic effect of the same intervention may have different level of efficacy in two comparable individuals, with strongly beneficial effects for one of those and completely inefficacy for the second one.

Initial conditions, mutual causality and randomness play a strong role in these relationships making the prediction almost impossible.

For these reasons, health status and in particular HRQOL may be treated as non-deterministic systems.

4.2.5 Transitions

Transitions are important phases in the development of a Dynamic System. A transition phase is a period in which the system changes from one stable state to another stable state. The change can be attributable to modifications in its components or in their interconnections, or to the emergence of new relevant variables (Kunnen, 2012). In particular, in a transition phase, the components of a system can become more or less influential to the whole system. Some of these variables could be excluded and other variables could be added into the system. However, it is important to notice that not all the dynamic systems show transition phases in their development.

Referring to HRQOL in the older adults population, the loss of a specific ability (e.g., walking autonomously) or the changes of habits due to health conditions (e.g., institutionalization) could be seen as transition phase, in which the whole system modifies its nature, and in which the person need to modifies his habits, lifestyle and activities. These changes may disturb the whole system before the creation of a new phase of equilibrium (different from the previous one).

Transition periods are accompanied by increased or uncommon variability that can be followed by a new and generally different stable condition (Kunnen, 2012).

4.2.6 Variability

Transitional phases are usually preceded by period with high and strange variability (van der Maas & Molenaar, 1992). Real and living systems are open and unstable systems, due to their interactions with the environment. Interactions with the environment and with other open systems (e.g., people) produce variability in the state of a system (Kunnen, 2012; van Geert & van Dijk, 2002). However, variability is not linearly related to the strength of the influences from the environment and open systems. Instead, it is dependent of the state of the system, regarding the vicinity to a stable self-sustaining state (attractor).

Also in this case, the concept of HRQOL, in particular in the older adults population (highly influenced by internal and external sources), fits in with this feature. It is an example of a system that may show high intra and inter individual variability (Wyrwich, 2000; Browne, 1994). The amount of variability provides important information about the developmental behavior and the state of a system. In particular, too high or too low variability may results in catastrophe or indicate problems within the system (Hollestein, 2004; van der Maas & Molenaar, 1992).

Summarizing, HRQOL seems to meet the features of a dynamic system. A dynamic systems conceptualization may solve the limitations of the existing models.

4.3 A conceptual model of HRQOL based on Dynamic Systems

The dynamic systems conceptual model of HRQOL (DSCM-HRQOL) aims: first, to apply theories and methodologies typical of dynamic systems; second, to employ the specific terminology proposed by WHO to define health, in order to create uniformity between the official definition of health and the modeling of theories; third, to apply the conceptualization proposed by Testa and Simonson (1996) for the evaluation of self-report health status and experienced-health of each component of HRQOL; and, finally, to focus primarily on the level of broad domains (mid-level) as proposed by Spilker (1996). The use of the double evaluation solves the limitation that people aged over 80 tend to underestimate the HRQOL decline, with a consequent increasing gap between the health status and perceptions (Henchoz, et al., 2008). In this way, a more comprehensive assessment may be more precise. In our view, the two components of each domain may be collected separately (by means of different scales as part of one single questionnaire), offering the opportunity to explore dynamic relations between these components. However, since HRQOL is mainly oriented to the subjective and individual judgement of one's own health, it was decided that both the health status and experienced-health dimensions will be described on the basis of self-report indicators.

The DSCM-HRQOL will focus primarily on the aged population, with the aim to tackle loss of health and functionality. Nevertheless, the feasibility of the new model of HRQOL may be extended to the whole population or to specific sub-groups.

This section will move firstly with the definition, operationalization and assessments of the principal domains of the model, secondly, it will proceed with the definition of the other components of the model and finally, the structure of the whole conceptualization will be defined.

4.3.1 Domains of DSCM-HRQOL

Physical domain - definition

The physical domain of HRQOL refers to the ability of performing physical efforts and carrying out work, in order to have autonomy in ADLs and to maintain a state of physical functioning appropriate for social and environmental demands. Our view of physical health emphasizes functions, (such as walking, climbing stairs, bathing etc.). By doing so, we follow the key concepts proposed by the International Classification of Functioning, Disability and Health (ICF) by WHO, instead of focusing mainly on limitations, as previously conceptualized (Kaplan, Bush, & Berry, 1976; Katz, Ford, Moskowitz, Jackson, & Jaffe, 1963; Ware, 1987).

Physical domain – operationalization

The physical health status assessment, making use of self-report questionnaires, must be centered on physical performance defined as the total amount of activities performed (Leidy, 1994). It goes without saying that it is impossible to measure physical capacity (maximum capacity to perform physical tasks) by means of such questionnaires.

One of the most reliable instrument is the International Physical Activity Questionnaire (Booth, et al., 2003) previously used in aged sample (Tomioka, Iwamoto, Saeki, Okamoto, 2011).

The experienced-health component of physical domain may be assessed with self-report questionnaires. The physical well-being scale of the Quality of Life Questionnaire (Evans, Burns, Robinson, & Garrett; 1985) is an example.

Finally, some validated questionnaires (i.e., the Short Form-36, Physical Composite Score) allow to assess a composite score of the physical domain. These questionnaires can be used to obtain general information about the physical domain, however, they do not capture the health status and experienced-health component separately. The Short Form-36 is an instrument composed of several (eight) scales, belonging to the physical or mental composite score. In our conceptualization, only the composite scores (physical and mental) of the Short Form-36 will be used, in order to analyze dynamics among the broad domains level, in accordance with the model of Spilker (1996). Further studies may focus on the dynamics and interrelations among the single components of each domain.

Mental domain - definition

WHO (2011) defines mental health as: "*a state of well-being in which every individual realizes his or her own potential, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to her or his community*". Furthermore, MedLine Plus (U.S. National Library of Medicine, National Institute of Health) highlights that mental health "*affects how we think, feel and act as we cope with life. It also helps determine how we handle stress, relate to others, and make choices. Mental health is important at every stage of life, from childhood and adolescence through adulthood*".

Referring to the older adults population, the evaluation of the mental domain can be subdivided in: (i) psychological; (ii) and cognitive assessment.

Mental domain – operationalization

As previously cited (section Age-related health changes), the most important mental characteristics are related to the cognitive and psychological area.

In order to measure the health status component of the mental domain, cognitive and psychological assessment may be done with the Mini Mental State Examination (Folstein, Folstein & McHugh, 1975), mainly used in the aged population. Mini Mental State Examination need an operator to be completed, and it is useful to measure the ability or performance of the older adult to respond to cognitive tasks.

In the psychological area, the focus may be oriented on the measurement of depression (i.e., Geriatric Depression Scale; Yesavage et al., 1983), anxiety (i.e., Geriatric Anxiety Inventory; Pachana et al., 2007) and, self-efficacy (i.e. General Self-Efficacy Scale; Bosscher & Smit, 1998). All these instruments are intended to measure the construct under study in an objective way, in order to provide an indication of the psychological state of the older adult.

Moreover, the experienced-health component can be measured with scales for the assessment of mental well-being (i.e., Warwick-Edinburgh Mental Well-being Scale; Tennant et al., 2007), previously used among older adults (Gale, Dennison, Cooper, Sayer, 2011). These scales are useful to measure the perceptions of the older adult about his or her well-being on the psychological and cognitive domain; that is they focus on the subjective part of the construct.

Finally, also for the mental domain, some instruments (i.e., Short Form-36, Mental Composite Score) generate a composite score including self-report health status and experienced-health oriented questions.

Social domain - definition

The social domain of our model refers to the ability of a subject to maintain his social engagement despite the ageing process. The maintenance of engagement with social life represents a protective factor (Bath & Deeg, 2005; Garcia, Banegas, Perez-Regadera, Cabrera, & Rodriguez-Artalejo, 2005) for the decline in health status and should be included in the assessment.

This ability could be assessed with measurement of social network (size) and relationships (frequency and intensity).

Social-network indicators are not always used as components of HRQOL models (Spilker, 1996). However, the choice to include social network and social relationship results is consistent with our conceptualization of self-reported health status and experienced-health in each of the selected domains, and it is supported by previous studies on HRQOL among older adults (Kelley-Gillespie, 2009)

Social domain – operationalization

The social domain may be divided in an self-report health status component, seen here as the size of the social network, and an experienced-health component, intended as the quality of social relations.

In particular, the self-report health status component (social health status) may be measured with questionnaires that analyze the social network size, as the Lubben Social Network Scale (Lubben, 1988).

In addition, the experienced-health component may be evaluated with questionnaires built to analyze the quality of the social relations, such as the Friendship Quality Scale (Hawthorne, 2006), also previously used in ageing-related studies.

4.3.2 Assessments of the domains

If we assume that HRQOL is a dynamic system that develops during time, it is necessary, after the definition and operationalization of its domain, to define how to assess and how capture the dynamic nature of such a construct.

The dynamic systems approach assumes that time is a core characteristic of the system itself (Kunnen, 2012), and in this view it is possible to observe how the system develops at different and interconnected time levels (Kunnen, 2012). Specifically, dynamic trends are detectable from very short time scales (microlevels) to very long time scales (macrolevels), all related each other, in the sense that dynamic characteristics at the microlevel influence the development at the macrolevel. The analysis of development at different time scales was previously studied and analyzed in other areas of research, defining how long-term development shapes and is shaped by everyday events (Lichtwarck-Aschoff, van Geert, Bosma, & Kunnen, 2008; Kunnen, 2012).

The use of an assessment at different time levels may be suitable also in the case of HRQOL. Specifically, such an approach gives us the possibility to match the long-term trends (i.e. the analysis of data points month away from each other) with the analysis of short-term trends. The analysis at microlevel of the indicators of the three main domains, measured very often, or sufficiently often, (i.e., day-to-day assessments) allows to detect a time series of data with which we can specify individual trajectories, including intra-individual variability. The use of such an approach may lead to a better understand of the short-term changes in the HRQOL, with the possibility to better understand also long-term trends and outcomes. In other words, a dynamic systems approach helps us to understand how long-term development of HRQOL, important indicator and predictor of negative health outcomes, emerges out of short-term (day-to-day) interactions.

The assessment of HRQOL at a short-time level, will need the set-up of a series of indicators (covering both the self-report health status and experienced-health components) that allow an easy collection and in the meanwhile, that may be representative of the construct.

4.3.3 Additional components

The three domains form the core of the dynamic systems model of HRQOL. However, to formulate a complete model, we need to specify several additional components.

Stable individual parameters

Individual parameters are essential information in complex and dynamic systems (Smith & Thelen, 2003). They can represent stable differences in characteristics between individual systems, or between groups of systems. In particular, also weak differences in the initial condition of a system can cause a great discrepancy in the developmental trajectories or in the final state (De Toni & Comello, 2005; Kunnen, 2012). For these reasons, in addition to the baseline evaluations of the three HRQOL domains, we include in our model indicators of individual parameters, which can have a considerable impact on the trend of the construct under investigation, as it unfolds in a particular individual person.

More specifically, the indicators inserted in the model are: (i) age, due to high correlation between ageing process and health decline; (ii) presence and type of morbidity, directly affecting HRQOL; (iii) lifestyle habits (protective and risk factors).

These indicators can be aggregated to create a general index of stable individual parameters, which will have a direct influence on the baseline assessment of each domain.

Random influences

In the model, we included also a stochastic influence that can act on physical, mental and social domains of HRQOL. As previously cited (see section Non-causality), living systems are subject to unpredictable and uncontrollable effects of random events (Kunnen, 2012). Random influences are a fundamental source of information in modeling of reality, especially in dynamic systems models, because in such a models the idiosyncratic nature of the random influences is a central feature, since every system is conceived as a network of interacting components, and the interaction rules are typical of the individual subjects. Furthermore, the inclusion of random influences can be useful for future translations of the conceptual model into a mathematical model.

In our DSCM, random influences may affect each of the three domains of HRQOL, and are seen as unpredictable events of everyday life. Some examples are the onset of a disease, an adverse physical situation (i.e., a fall) but also the consolidation of a friendship relation, the birth of a grandson or a new interest/hobby. All these aspects, completely unpredictable, nonlinear and idiosyncratic, influence the whole system and can explain trends and transitions.

4.3.4 Architecture of DSCM-HRQOL

After the explanations of domains included in the model, the next step in designing a conceptual model is to depict its relations during time and among components.

Developmental process (role of time)

The DSCM-HRQOL is a developmental model. The aim is to delineate the evolving patterns and trends of HRQOL during time as they occur in individual subjects. As mentioned previously, developmental systems are iterative, following a process which takes place step by step and in which the outcome of a previous step is the input value for the next step (van Geert, 1994). In our conceptualization, the three central domains of HRQOL follow these rules, evolving during time in the form of an iterative process. Iterativity implies interdependency among measures (e.g., A depends on B and B depends on A, or, physical health depends on mental health, and mental health depends on physical health).

As a simple exemplification of the iterative behaviors, we can imagine an older adult who one day by chance meets one old friend. The unexpected social contact might have an immediate short-term positive effect on the persons feeling of social well-being. This temporal increase might result in the person's decision to increase the intensity of these social contacts, which might lead to consolidation of the short-term increase in social well-being. Other examples could imply the reduction of the daily physical activity after a fall, with a consequent decrease of the HRQOL in the physical domain, or an increase in performing memory games after becoming aware of a decline in cognitive functions.

This example shows that the connections between different domains occur on the microlevel of one iteration. The dynamic development starts with the events on the microlevel. Most of these events at the microlevel consolidate the person’s stable state (attractor), but some may lead to other attractor states.

Our model describes how the different domains affect each other on the level of one iteration. However, one iteration leads to a set of consequent iterative steps that lead to changes in the person’s attractor state.

The basic structure of a dynamic systems model consists of iteration descriptions (in a mathematical model these are translated into differential equations) between the domains. The iterative character implies that these connections or equations are repeated again and again, and in this way, they describe the development of the different domains over time.

Interconnections

The upper box included in the model (see Figure 1) is the stable individual parameters. In other words, it is the condition from where the model starts to simulate further behaviors. The three domains of HRQOL, representing the central body of the model, are fully interconnected.

Arrows connecting the same domain at different times represent the influence of the previous condition of that domain on the condition in the next iteration.

Influences are delayed, meaning that arrows do not link two domains at the same time because, in our vision, the effect of one domain on another domain will be visible in the next situation. Regarding HRQOL among seniors, we hypothesize that process of change can be seen from a daily basis. In the figure we represent only the first five iterations. However, the process and thus the series of iterations continues until it reaches some end point, t_n.

Finally, each domain at every time level is connected with a random influence (R) that represents the casual and unpredictable part of the model.

The model that is presented here is a theoretical model. It is built upon existing knowledge, and it aims to integrate the merits of existing models, adding the developmental perspective. Contrary to earlier models, it allows to study and analyze changes in the construct as a result of the iterations among domains, explicating the possible mechanisms acting during the development of the construct.

The model described here meets the basic requirements described in the beginning; it takes into account: (i) the different domains that are relevant in HRQOL; (ii) the developmental processes that result in stability or change in HRQOL; (iii) the influences of each domain on the others; and (iv) the influence of unpredictable events. The model may serve as a basis, firstly, to carry out empirical research into the HRQOL of life of individuals over time and secondly, it will be the basis of a quantitative dynamic systems model.

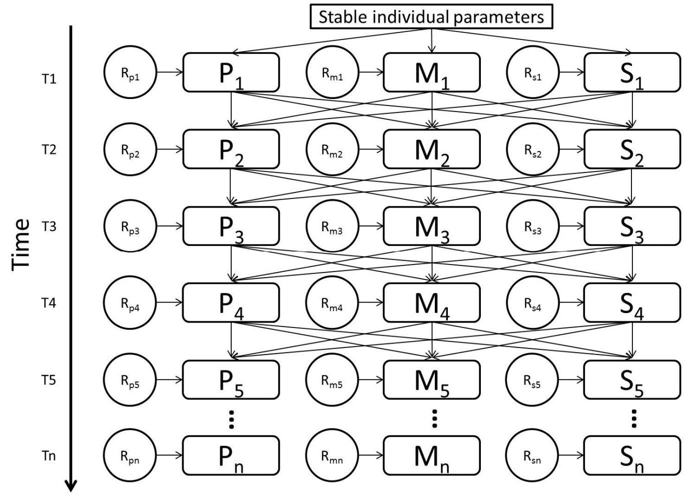

Figure 1 - The Conceptual Dynamic Systems Model of HRQOL showing the interactions between the physical, mental and social domain over time (T1 … Tn). Stable individual parameters = indicator of age, comorbidity and lifestyle, directly influencing the three main domains of HRQOL.
P= physical domain
M= mental domain
S= social domain
Rp= random factor in the physical domain;
Rm = random factor in the mental domain;
Rs = random factor in the social domain.
The model shows 5 iterations (from T1 to T5, and it shows how the process continues until a generic Tn), each arrow is a connection between domains during time, representing the influences of one factor on another, causing the influenced factor to change over time (dynamic relationship)

The translation of the DCSM-HRQOL into a quantitative model permits to test the theoretical assumptions and to compare simulated data with empirical ones. This approach may contribute to enhance knowledge of the phenomenon under study, confirming (or not) the system structure presented here.

5. Conclusions

In order to analyze, understand and intervene in people's health status, reducing negative outcomes of ageing process, the construct of HRQOL was placed in a developmental perspective, following the dynamic systems theory. The conceptual model presented here could: provide new explanations about the processes acting in the ageing, generate new hypotheses and empirical questions about mechanisms and processes of changes of HRQOL during ageing, and generate new ways of measuring HRQOL, in particular in the form of repeated multivariate time serial measurements.

The general aim of the paper was to formulate the conditions and sketch the outlines of a model that enables us to study the developmental process of HRQOL in seniors. The DSCM-HRQOL employs terminology of the health definition (WHO, 1948), adopts the mid-level analysis, focusing on the broad domains as proposed Spilker (1996), and, uses the conceptualization of Testa and Simonson (1996) for the double evaluation of the inserted domains. The use of dynamic systems theory, applied to model development in old age (Schroots, 2012), seems to be a good basis to model HRQOL in the older adults, giving possible solutions and suggestions to some open questions as, in example, how HRQOL evolves during time, how the domains interact with each other, and, how life events act on HRQOL.

Future steps, starting from the conceptualization presented here, foresee the translation of the DSCM-HRQOL model in a mathematical dynamic system model that could provide additional indications about development and trends of HRQOL in the older adults population. The usefulness of a dynamic systems mathematical model can contribute to our understanding of the underlying developmental process, as previously demonstrated in the study of development in other area of research (Kunnen, 2012; Kunnen & Bosma, 2000; Steenbeek & Van Geert, 2008). The mathematical model can be used as a simulation tool (if previously validated) to analyze trends, starting from different conditions, or to simulate interventions for the maintenance/increase of HRQOL. Finally, a specific designed study is necessary to evaluate and quantify the real dynamic trend of HRQOL construct delineated here.

6. References

Aaronson, N. (1993). Quality-of-Life Assessment - Key Issues in the 1990s - Walker,Sr, Rosser,Rm. *Quality of Life Research*, *2*, 305–306. doi:10.1007/Bf00434802

Acree, L. S., Longfors, J., Fjeldstad, A. S., Fjeldstad, C., Schank, B., Nickel, K. J., Montgomery, P. S., Gardner, A. W. (2006). Physical activity is related to quality of life in older adults. *Health Qual Life Outcomes*, *4*, 37. doi:10.1186/1477-7525-4-37

Albert, M. L., & Janice E. Knoefel, M. D. (1994). *Clinical Neurology of Aging*. Oxford University Press.

Atchley, R. C. (1989). A continuity theory of normal aging. *Gerontologist*, *29*, 183–90.

Balboa-Castillo, T., Leon-Munoz, L. M., Graciani, A., Rodriguez-Artalejo, F., & Guallar-Castillon, P. (2011). Longitudinal association of physical activity and sedentary behavior during leisure time with health-related quality of life in community-dwelling older adults. *Health Qual Life Outcomes*, *9*, 47. doi:10.1186/1477-7525-9-47

Baltes, P. B., & Baltes, M. M. (1993). *Successful Aging: Perspectives from the Behavioral Sciences*. Cambridge University Press.

Baltes, P. B., & Smith, J. (2003). New frontiers in the future of aging: from successful aging of the young old to the dilemmas of the fourth age. *Gerontology*, *49*, 123–35.

Bassano, D., & van Geert, P. (2007). Modeling continuity and discontinuity in utterance length: a quantitative approach to changes, transitions and intra-individual variability in early grammatical development. *Dev Sci*, *10*, 588–612. doi:10.1111/j.1467-7687.2007.00629.x

Bath, P. A., & Deeg, D. (2005). Social engagement and health outcomes among older people: introduction to a special section. *European Journal of Ageing*, *2*(1), 24–30. doi:10.1007/s10433-005-0019-4

Beekman, A. T. F., Bremmer, M. A., Deeg, D. J. H., van Balkom, A. J. L. M., Smit, J. H., de Beurs, E., van Dyck, R., van Tilburg, W. (1998). Anxiety disorders in later life: A report from the longitudinal aging study Amsterdam. *International Journal of Geriatric Psychiatry*, *13*, 717–726. doi:10.1002/(Sici)1099-1166(1998100)13:10<717::Aid-Gps857>3.0.Co;2-M

Beekman, A. T. F., Copeland, J. R. M., & Prince, M. J. (1999). Review of community prevalence of depression in later life. *British Journal of Psychiatry*, *174*, 307–311. doi:10.1192/bjp.174.4.307

Bennett, K. (2005). Social engagement as a longitudinal predictor of objective and subjective health. *European Journal of Ageing*, *2*, 48–55. doi:10.1007/s10433-005-0501-z

Bennett, K. M. (2002). Low level social engagement as a precursor of mortality among people in later life. *Age and Ageing*, *31*, 165–168. doi:10.1093/ageing/31.3.165

Bernhard, J., Lowy, A., Mathys, N., Herrmann, R., & Hurny, C. (2004). Health related quality of life: a changing construct? *Qual Life Res*, *13*, 1187–97.

Berzon, R., Hays, R. D., & Shumaker, S. A. (1993). International Use, Application and Performance of Health-Related Quality-of-Life Instruments - Preface. *Quality of Life Research*, *2*, 367–368. doi:10.1007/Bf00422214

Bilotta, C., Bowling, A., Nicolini, P., Case, A., Pina, G., Rossi, S. V., & Vergani, C. (2011). Older People's Quality of Life (OPQOL) scores and adverse health outcomes at a one-year follow-up. A prospective cohort study on older outpatients living in the community in Italy. *Health Qual Life Outcomes*, *9*, 72. doi:10.1186/1477-7525-9-72

Blazer, D., Burchett, B., Service, C., & George, L. K. (1991). The Association of Age and Depression among the Elderly - an Epidemiologic Exploration. *Journals of Gerontology*, *46*, M210–M215.

Bosscher, R. J., & Smit, J. H. (1998). Confirmatory factor analysis of the General Self-Efficacy Scale. *Behaviour Research and Therapy*, *36*(3), 339–343. doi:10.1016/S0005-7967(98)00025-4

Bouchard, C., & Shephard, R. J. (1994). *Physical activity, fitness, and health: international proceedings and consensus statement*. Human Kinetics Publishers.

Browne, J. P., O'Boyle, C. A., McGee, H. M., Joyce, C. R., McDonald, N. J., O'Malley, K., & Hiltbrunner, B. (1994). Individual quality of life in the healthy elderly. *Qual Life Res*, *3*, 235–44.

Chien, M. Y., Huang, T. Y., & Wu, Y. T. (2008). Prevalence of sarcopenia estimated using a bioelectrical impedance analysis prediction equation in community-dwelling elderly people in Taiwan. *Journal of the American Geriatrics Society*, *56*, 1710–1715. doi:10.1111/j.1532-5415.2008.01854.x

Ciairano, S., Liubicich, M. E., & Rabaglietti, E. (2010). The effects of a physical activity programme on the psychological wellbeing of older people in a residential care facility: an experimental study. *Ageing and Society*, *30*(04), 609–626. doi:10.1017/S0144686X09990614

Craig, C., Marshall, A., Sjöström, M., Bauman, A., Booth, M., Ainsworth, B., Pratt, M., Ekelund, U., Yngve, A., Sallis, J. F., Oja, P. (2003). International physical activity questionnaire: 12-country reliability and validity. *Medicine and Science in Sports and Exercise*, *35*(8), 1381–1395.

Crimmins, E. M. (2004). Trends in the health of the elderly. *Annual Review of Public Health*, *25*, 79–98. doi:10.1146/annurev.publhealth.25.102802.124401

Cumming, E., & Henry, W. E. (1961). *Growing old, the process of disengagement*. Basic Books.

Cummings, S. R. (1993). Bone mass and bone loss in the elderly: a special case? *Int J Fertil Menopausal Stud*, *38 Suppl 2*, 92–7.

De Toni, A. F., & Comello, L. (2005). *Prede o ragni: uomini e organizzazioni nella ragnatela della complessità*. Torino: UTET universitaria.

Deschamps, A., Onifade, C., Decamps, A., & Bourdel-Marchasson, I. (2009). Health-related quality of life in frail institutionalized elderly: effects of a cognition-action intervention and Tai Chi. *J Aging Phys Act*, *17*, 236–48.

Doherty, T. J. (2001). The influence of aging and sex on skeletal muscle mass and strength. *Curr Opin Clin Nutr Metab Care*, *4*, 503–8.

Dorr, D. A., Jones, S. S., Burns, L., Donnelly, S. M., Brunker, C. P., Wilcox, A., & Clayton, P. D. (2006). Use of health-related, quality-of-life metrics to predict mortality and hospitalizations in community-dwelling seniors. *Journal of the American Geriatrics Society*, *54*, 667–673. doi:10.1111/j.1532-5415.2006.00681.x

Drageset, J., Natvig, G. K., Eide, G. E., Bondevik, M., Nortvedt, M. W., & Nygaard, H. A. (2009). Health-related quality of life among old residents of nursing homes in Norway. *International Journal of Nursing Practice*, *15*, 455–466. doi:10.1111/j.1440-172X.2009.01794.x

Elavsky, S., McAuley, E., Motl, R. W., Konopack, J. F., Marquez, D. X., Hu, L., Jerome, G. J., Diener, E. (2005). Physical activity enhances long-term quality of life in older adults: efficacy, esteem, and affective influences. *Ann Behav Med*, *30*, 138–45. doi:10.1207/s15324796abm3002_6

Engel, G. L. (1977). The need for a new medical model: a challenge for biomedicine. *Science*, *196*, 129–36.

Eurostat. (2008). *Population projections 2008-2060* (No. 119/2008) (pp. 1–4). Luxemburg.

Eurostat. (2011). *Active ageing and solidarity between generations. A statistical portrait of the European Union 2012* (Satatistica books., Vol. 1). Luxemburg: Eurostat.

Evans, D. R., Burns, J. E., Robinson, W. E., & Garrett, O. J. (1985). The quality of life questionnaire: A multidimensional measure. *American Journal of Community Psychology*, *13*(3), 305–322. doi:10.1007/BF00914935

Ferrans, C. E., Zerwic, J. J., Wilbur, J. E., & Larson, J. L. (2005). Conceptual model of health-related quality of life. *Journal of Nursing Scholarship*, *37*, 336–342. doi:10.1111/j.1547-5069.2005.00058.x

Floel, A., Witte, A. V., Lohmann, H., Wersching, H., Ringelstein, E. B., Berger, K., & Knecht, S. (2008). Lifestyle and memory in the elderly. *Neuroepidemiology*, *31*, 39–47. doi:10.1159/000137378

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). Mini-mental state: A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, *12*(3), 189–198. doi:10.1016/0022-3956(75)90026-6

Fratiglioni, L., Paillard-Borg, S., & Winblad, B. (2004). An active and socially integrated lifestyle in late life might protect against dementia. *Lancet Neurology*, *3*, 343–353. doi:10.1016/S1474-4422(04)00767-7

Freund, A. M., & Baltes, P. B. (1998). Selection, optimization, and compensation as strategies of life management: correlations with subjective indicators of successful aging. *Psychol Aging*, *13*, 531–43.

Frontera, W. R., Hughes, V. A., Fielding, R. A., Fiatarone, M. A., Evans, W. J., & Roubenoff, R. (2000). Aging of skeletal muscle: a 12-yr longitudinal study. *Journal of Applied Physiology*, *88*, 1321–1326.

Gale, C. R., Dennison, E. M., Cooper, C., & Sayer, A. A. (2011). Neighbourhood environment and positive mental health in older people: The Hertfordshire Cohort Study. *Health & Place*, *17*(4), 867–874. doi:10.1016/j.healthplace.2011.05.003

García, E. L., Banegas, J. R., Pérez-Regadera, A. G., Cabrera, R. H., & Rodríguez-Artalejo, F. (2005). Social network and health-related quality of life in older adults: A population-based study in Spain. *Quality of Life Research*, *14*(2), 511–520. doi:10.1007/s11136-004-5329-z

Gaugler, J. E., Duval, S., Anderson, K. A., & Kane, R. L. (2007). Predicting nursing home admission in the U.S: a meta-analysis. *BMC Geriatr*, *7*, 13. doi:10.1186/1471-2318-7-13

Giannakouris, C. (2008). *Population and social conditions. Ageing characteristics the demographic perspectives of the European societies* (No. KS-SF-08-072-EN-N) (pp. 1–12). Luxemburg.

Glass, T. A., De Leon, C. F. M., Bassuk, S. S., & Berkman, L. F. (2006). Social engagement and depressive symptoms in late life - Longitudinal findings. *Journal of Aging and Health*, *18*, 604–628. doi:10.1177/0898264306291017

Gleick, J. (1996). *Chaos: making a new science.* London: Minerva.

Grammenos, S. (2005). *Implications of demographic ageing in the enlarged EU in the domains of quality of life, health promotion and health care* (pp. 1–199). Bruxelles: Center for European Social and Economic Policy.

Hannan, M. T., Felson, D. T., Dawson-Hughes, B., Tucker, K. L., Cupples, L. A., Wilson, P. W., & Kiel, D. P. (2000). Risk factors for longitudinal bone loss in elderly men and women: the Framingham Osteoporosis Study. *J Bone Miner Res*, *15*, 710–20. doi:10.1359/jbmr.2000.15.4.710

Haskell, W. L., Lee, I. M., Pate, R. R., Powell, K. E., Blair, S. N., Franklin, B. A., Macera, C., Heath, G. W., Thompson, P. D., Bauman, A. (2007). Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. *Circulation*, *116*, 1081–93. doi:10.1161/CIRCULATIONAHA.107.185649

Hawthorne, G. (2006). Measuring Social Isolation in Older Adults: Development and Initial Validation of the Friendship Scale. *Social Indicators Research*, *77*(3), 521–548. doi:10.1007/s11205-005-7746-y

Henchoz, K., Cavalli, S., & Girardin, M. (2008). Health perception and health status in advanced old age: A paradox of association. *Journal of Aging Studies*, *22*(3), 282-290. doi:10.1016/j.jaging.2007.03.002

Hollenstein, T., Granic, I., Stoolmiller, M., & Snyder, J. (2004). Rigidity in parent-child interactions and the development of externalizing and internalizing behavior in early childhood. *J Abnorm Child Psychol*, *32*, 595–607.

Hopman, W. M., Harrison, M. B., Coo, H., Friedberg, E., Buchanan, M., & VanDenKerkhof, E. G. (2009). Associations between chronic disease, age and physical and mental health status. *Chronic Diseases in Canada*, *29*, 108–116.

Hopman, W. M., Towheed, T., Anastassiades, T., Tenenhouse, A., Poliquin, S., Berger, C., Joseph, L., Brown, J. P., Murray, T. M., Adachi, J. D., Hanley, D. A., Papadimitropoulos, E. (2000). Canadian normative data for the SF-36 health survey. *Canadian Medical Association Journal*, *163*, 265–271.

Idler, E. L., & Benyamini, Y. (1997). Self-rated health and mortality: a review of twenty-seven community studies. *J Health Soc Behav*, *38*, 21–37.

Inaba, Y., Obuchi, S., Arai, T., Satake, K., & Takahira, N. (2008). The long-term effects of progressive resistance training on health-related quality in older adults. *J Physiol Anthropol*, *27*, 57–61.

Janssen, I., Heymsfield, S. B., & Ross, R. (2002). Low relative skeletal muscle mass (sarcopenia) in older persons is associated with functional impairment and physical disability. *Journal of the American Geriatrics Society*, *50*, 889–896. doi:10.1046/j.1532-5415.2002.50216.x

Janssen, I., Heymsfield, S. B., Wang, Z. M., & Ross, R. (2000). Skeletal muscle mass and distribution in 468 men and women aged 18-88 yr. *J Appl Physiol*, *89*, 81–8.

Janssen, Ian, Baumgartner, R. N., Ross, R., Rosenberg, I. H., & Roubenoff, R. (2004). Skeletal Muscle Cutpoints Associated with Elevated Physical Disability Risk in Older Men and Women. *American Journal of Epidemiology*, *159*, 413–421. doi:10.1093/aje/kwh058

Janssens, J. P., Pache, J. C., & Nicod, L. P. (1999). Physiological changes in respiratory function associated with ageing. *Eur Respir J*, *13*, 197–205.

Jenkins, K. R., Pienta, A. M., & Horgas, A. L. (2002). Activity and health-related quality of life in continuing care retirement communities. *Research on Aging*, *24*, 124–149. doi:10.1177/0164027503024001008

Johnell, O., & Kanis, J. A. (2004). An estimate of the worldwide prevalence, mortality and disability associated with hip fracture. *Osteoporos Int*, *15*, 897–902. doi:10.1007/s00198-004-1627-0

Kaplan, R. M., Bush, J. W., & Berry, C. C. (1976). Health status: types of validity and the index of well-being. *Health Services Research*, *11*(4), 478–507.

Katz, S., Ford, A. B., Moskovitz, R. W., Jackson, B. A., & Jaffe, M. W. (1963). Studies of illness in the aged. The index of adl: a standardized measure of biological and psychosocial function. *JAMA: The Journal of the American Medical Association*, *185*, 914–919.

Kawachi, I., & Berkman, L. F. (2001). Social ties and mental health. *Journal of Urban Health-Bulletin of the New York Academy of Medicine*, *78*, 458–467. doi:10.1093/jurban/78.3.458

Kelley-Gillespie, N. (2009). An integrated conceptual model of quality of life for older adults based on a synthesis of the literature. *Applied Research in Quality of life*, *4*(3), 259-282. doi: 10.1007/s11482-009-9075-9

Kempen, G. I., Ormel, J., Brilman, E. I., & Relyveld, J. (1997). Adaptive responses among Dutch elderly: the impact of eight chronic medical conditions on health-related quality of life. *Am J Public Health*, *87*, 38–44.

Keysor, J. J. (2003). Does late-life physical activity or exercise prevent or minimize disablement? A critical review of the scientific evidence. *American Journal of Preventive Medicine*, *25*, 129–136. doi:10.1016/S0749-3797(03)00176-4

Kimura, K., Obuchi, S., Arai, T., Nagasawa, H., Shiba, Y., Watanabe, S., & Kojima, M. (2010). The influence of short-term strength training on health-related quality of life and executive cognitive function. *J Physiol Anthropol*, *29*, 95–101.

Kitzman, D. W. (2000). Diastolic dysfunction in the elderly. Genesis and diagnostic and therapeutic implications. *Cardiol Clin*, *18*, 597–617, x.

Kitzman, D. W., & Edwards, W. D. (1990). Age-related changes in the anatomy of the normal human heart. *J Gerontol*, *45*, M33–9.

Kramer, A. F., Colcombe, S. J., McAuley, E., Eriksen, K. I., Scalf, P., Jerome, G. J., Marquez, D. X., Elavsky, S., Webb, A. G. (2003). Enhancing brain and cognitive function of older adults through fitness training. *Journal of Molecular Neuroscience*, *20*, 213–221. doi:10.1385/Jmn:20:3:213

Kunnen, E. S. (2009). Qualitative and quantitative aspects of commitment development in psychology students. *J Adolesc*, *32*, 567–84. doi:10.1016/j.adolescence.2008.06.002

Kunnen, E. S. (2012). *A Dynamic Systems Approach of Adolescent Development*. Taylor & Francis.

Kunnen, E. S., & Bosma, H. A. (2000). Development of meaning making: A dynamic systems approach. *New Ideas in Psychology*, *18*, 57–82. doi:10.1016/S0732-118X(99)00037-9

Lam, C. L. K., & Lauder, I. J. (2000). The impact of chronic diseases on the health-related quality of life (HRQOL) of Chinese patients in primary care. *Family Practice*, *17*, 159–166. doi:10.1093/fampra/17.2.159

Latham, N. K., Bennett, D. A., Stretton, C. M., & Anderson, C. S. (2004). Systematic review of progressive resistance strength training in older adults. *J Gerontol A Biol Sci Med Sci*, *59*, 48–61.

Lee, C., & Russell, A. (2003). Effects of physical activity on emotional well-being among older Australian women: cross-sectional and longitudinal analyses. *J Psychosom Res*, *54*, 155–60.

Lee, L. Y., Lee, D. T., & Woo, J. (2009). Tai Chi and health-related quality of life in nursing home residents. *J Nurs Scholarsh*, *41*, 35–43. doi:10.1111/j.1547-5069.2009.01249.x

Leidy, N. K. (1994). Functional status and the forward progress of merry-go-rounds: toward a coherent analytical framework. *Nursing Research*, *43*(4), 196–202.

Lemon, B. W., Bengtson, V. L., & Peterson, J. A. (1972). An exploration of the activity theory of aging: activity types and life satisfaction among in-movers to a retirement community. *J Gerontol*, *27*, 511–23.

Lexell, J. (1995). Human Aging, Muscle Mass, and Fiber-Type Composition. *Journals of Gerontology Series a-Biological Sciences and Medical Sciences*, *50*, 11–16.

Lichtwarck-Aschoff, A., Kunnen, S. E., & van Geert, P. L. (2009). Here we go again: a dynamic systems perspective on emotional rigidity across parent-adolescent conflicts. *Dev Psychol*, *45*, 1364–75. doi:10.1037/a0016713

Lichtwarck-Aschoff, Anna, van Geert, P., Bosma, H., & Kunnen, S. (2008). Time and identity: A framework for research and theory formation. *Developmental Review*, *28*(3), 370–400. doi:10.1016/j.dr.2008.04.001

Lima, M. G., Barros, M. B., Cesar, C. L., Goldbaum, M., Carandina, L., & Ciconelli, R. M. (2009). Impact of chronic disease on quality of life among the elderly in the state of Sao Paulo, Brazil: a population-based study. *Rev Panam Salud Publica*, *25*, 314–21.

Lipscomb, J., Gotay, C. C., & Snyder, C. (2004). *Outcomes Assessment in Cancer: Measures, Methods and Applications*. Cambridge University Press.

Lubben, J. E. (1988). Assessing social networks among elderly populations. *Family & Community Health: The Journal of Health Promotion & Maintenance*, *11*(3), 42–52.

Luppa, M., Luck, T., Weyerer, S., Konig, H. H., Brahler, E., & Riedel-Heller, S. G. (2010). Prediction of institutionalization in the elderly. A systematic review. *Age Ageing*, *39*, 31–8. doi:10.1093/ageing/afp202

Manton, K. G. (1982). Changing concepts of morbidity and mortality in the elderly population. *Milbank Mem Fund Q Health Soc*, *60*, 183–244.

Manton, K. G., Gu, X., & Lamb, V. L. (2006). Change in chronic disability from 1982 to 2004/2005 as measured by long-term changes in function and health in the U.S. elderly population. *Proc Natl Acad Sci U S A*, *103*, 18374–9. doi:10.1073/pnas.0608483103

Marengoni, A., Winblad, B., Karp, A., & Fratiglioni, L. (2008). Prevalence of chronic diseases and multimorbidity among the elderly population in Sweden. *Am J Public Health*, *98*, 1198–200. doi:10.2105/AJPH.2007.121137

McAvay, G. J., Seeman, T. E., & Rodin, J. (1996). A longitudinal study of change in domain-specific self-efficacy among older adults. *Journals of Gerontology Series B-Psychological Sciences and Social Sciences*, *51*, P243–P253.

Mebane-Sims, I., & Association, A. (2009). 2009 Alzheimer's disease facts and figures. *Alzheimers & Dementia*, *5*, 234–270. doi:10.1016/j.jalz.2009.03.001

Murdaugh, C. (1997). Health-related quality of life as an outcome in organizational research. *Medical Care*, *35*, Ns41–Ns48. doi:10.1097/00005650-199711001-00005

Netz, Y., Wu, M. J., Becker, B. J., & Tenenbaum, G. (2005). Physical activity and psychological well-being in advanced age: A meta-analysis of intervention studies. *Psychology and Aging*, *20*, 272–284. doi:10.1037/0882-7974.20.2.272

Pachana, N. A., Byrne, G. J., Siddle, H., Koloski, N., Harley, E., & Arnold, E. (2007). Development and validation of the Geriatric Anxiety Inventory. *International Psychogeriatrics*, *19*(01), 103–114. doi:10.1017/S1041610206003504

Penedo, F. J., & Dahn, J. R. (2005). Exercise and well-being: a review of mental and physical health benefits associated with physical activity. *Curr Opin Psychiatry*, *18*, 189–93.

Rivner, M. H., Swift, T. R., & Malik, K. (2001). Influence of age and height on nerve conduction. *Muscle & Nerve*, *24*, 1134–1141. doi:10.1002/Mus.1124

Rogers, M. A., & Evans, W. J. (1993). Changes in skeletal muscle with aging: effects of exercise training. *Exerc Sport Sci Rev*, *21*, 65–102.

Roppolo, M., Mulasso, A., Magistro, D., Roggero, A., Andreoli, P., & Liubicich, M. E. (2012). Shintaido in the elderly: The new way for physical and psychological health. *Advances in Aging Research*, *01*(02), 22–30. doi:10.4236/aar.2012.12003

Rossi, A., Ganassini, A., Tantucci, C., & Grassi, V. (1996). Aging and the respiratory system. *Aging (Milan, Italy)*, *8*(3), 143–161.

Roubenoff, R., & Hughes, V. A. (2000). Sarcopenia Current Concepts. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *55*(12), M716–M724. doi:10.1093/gerona/55.12.M716

Sabin, E. P. (1993). Social Relationships and Mortality among the Elderly. *Journal of Applied Gerontology*, *12*, 44–60. doi:10.1177/073346489301200105

Salat, D. H., Buckner, R. L., Snyder, A. Z., Greve, D. N., Desikan, R. S. R., Busa, E., Morris, J. C., Dale, A. M., Fischl, B. (2004). Thinning of the cerebral cortex in aging. *Cerebral Cortex*, *14*, 721–730. doi:10.1093/cercor/bhh032

Schroots, J. J. F. (2012). On the Dynamics of Active Aging. *Current Gerontology and Geriatrics Research*, *2012*, 1–10. doi:10.1155/2012/818564

Sharma, G., & Goodwin, J. (2006). Effect of aging on respiratory system physiology and immunology. *Clinical Interventions in Aging*, *1*, 253–260. doi:10.2147/ciia.2006.1.3.253

Shephard, R. J. (1993). Exercise and aging: extending independence in older adults. *Geriatrics*, *48*, 61–4.

Sillanpaa, E., Hakkinen, K., Holviala, J., & Hakkinen, A. (2012). Combined strength and endurance training improves health-related quality of life in healthy middle-aged and older adults. *Int J Sports Med*, *33*, 981–6. doi:10.1055/s-0032-1311589

Small, S. A., Stern, Y., Tang, M., & Mayeux, R. (1999). Selective decline in memory function among healthy elderly. *Neurology*, *52*, 1392–1396.

Smith, L. B., & Thelen, E. (2003). Development as a dynamic system. *Trends in Cognitive Sciences*, *7*(8), 343–348. doi:10.1016/S1364-6613(03)00156-6

Spilker, B. (Ed.). (1996). Quality of Life and Pharmacoeconomics in Clinical Trials (2nd ed.). Lippincott-Raven, Philadelphia. ISBN 0-7817-0332-8

Sprangers, M. A., & Schwartz, C. E. (2008). Reflections on changeability versus stability of health-related quality of life: distinguishing between its environmental and genetic components. *Health Qual Life Outcomes*, *6*, 89. doi:10.1186/1477-7525-6-89

Steenbeek, H., & van Geert, P. (2008). An empirical validation of a dynamic systems model of interaction: do children of different sociometric statuses differ in their dyadic play? *Dev Sci*, *11*, 253–81. doi:10.1111/j.1467-7687.2007.00655.x

Tennant, R., Hiller, L., Fishwick, R., Platt, S., Joseph, S., Weich, S., Parkinson, J., Secker, J., Stewart-Brown, S. (2007). The Warwick-Edinburgh Mental Well-being Scale (WEMWBS): development and UK validation. *Health and Quality of Life Outcomes*, *5*(1), 63. doi:10.1186/1477-7525-5-63

Testa, M. A., & Simonson, D. C. (1996). Assessment of Quality-of-Life Outcomes. *New England Journal of Medicine*, *334*, 835–840. doi:10.1056/NEJM199603283341306

Thelen, E., & Smith, L. B. (1996). *A Dynamic Systems Approach to the Development of Cognition and Action*. Mit Press.

Thelen, E., & Ulrich, B. D. (1991). Hidden skills: a dynamic systems analysis of treadmill stepping during the first year. *Monogr Soc Res Child Dev*, *56*, 1–98; discussion 99–104.

Theofilou, P. (2011). Why is important to aseess health-Related Quality of Life? *J Palliative Care Med*, *1*, e104. doi:10.4172/2165-7386.1000e104

Thompson, W. W., Zack, M. M., Krahn, G. L., Andresen, E. M., & Barile, J. P. (2012). Health-related quality of life among older adults with and without functional limitations. *Am J Public Health*, *102*, 496–502. doi:10.2105/AJPH.2011.300500

Tomioka, K., Iwamoto, J., Saeki, K., & Okamoto, N. (2011). Reliability and Validity of the International Physical Activity Questionnaire (IPAQ) in Elderly Adults: The Fujiwara-kyo Study. *Journal of Epidemiology*, *21*(6), 459–465.

Tsai, S. Y., Chi, L. Y., Lee, C. H., & Chou, P. (2007). Health-related quality of life as a predictor of mortality among community-dwelling older persons. *Eur J Epidemiol*, *22*, 19–26. doi:10.1007/s10654-006-9092-z

Van der Maas, H. L., & Molenaar, P. C. (1992). Stagewise cognitive development: An application of catastrophe theory. *Psychological Review*, *99*(3), 395–417. doi:10.1037/0033-295X.99.3.395

Van Geert, P. (1994). *Dynamic systems of development: change between complexity and chaos*. Harvester Wheatsheaf.

Van Geert, P. (2008). Complex dynamic systems of development. In R. A. Meyers (Ed.), *Encyclopedia of complexity and system science* (Vol. 2, pp. 1872–1916). New York: Springer.

Van Geert, P., & van Dijk, M. (2002). Focus on variability: New tools to study intra-individual variability in developmental data. *Infant Behavior and Development*, *25*, 340–374. doi:10.1016/S0163-6383(02)00140-6

Wang, L., Larson, E. B., Bowen, J. D., & van Belle, G. (2006). Performance-based physical function and future dementia in older people. *Archives of Internal Medicine*, *166*, 1115–1120. doi:10.1001/archinte.166.10.1115

Ware, J. E., & Dewey, J. (2000). Health status and outcome assessment tools. *Int Electronic J Health Education*, *3*, 138–148.

Ware, J. E. J. (1987). Standards for validating health measures: Definition and content. *Journal of Chronic Diseases*, *40*(6), 473–480. doi:10.1016/0021-9681(87)90003-8

Weisstein, E. W. (2003). *CRC Concise Encyclopedia of Mathematics*. Chapman & Hall/CRC.

Wilson, I. B., & Cleary, P. D. (1995). Linking clinical variables with health-related quality of life: A conceptual model of patient outcomes. *JAMA*, *273*, 59–65.

Wolinsky, F. D., Unverzagt, F. W., Smith, D. M., Jones, R., Stoddard, A., & Tennstedt, S. L. (2006). The ACTIVE cognitive training trial and health-related quality of life: protection that lasts for 5 years. *J Gerontol A Biol Sci Med Sci*, *61*, 1324–9.

Wolinsky, F. D., Unverzagt, F. W., Smith, D. M., Jones, R., Wright, E., & Tennstedt, S. L. (2006). The effects of the ACTIVE cognitive training trial on clinically relevant declines in health-related quality of life. *J Gerontol B Psychol Sci Soc Sci*, *61*, S281–7.

Wyrwich, K. W., & Wolinsky, F. D. (2000). Identifying meaningful intra-individual change standards for health-related quality of life measures. *J Eval Clin Pract*, *6*, 39–49.

Yasunaga, A., Togo, F., Watanabe, E., Park, H., Shephard, R. J., & Aoyagi, Y. (2006). Yearlong physical activity and health-related quality of life in older Japanese adults: the Nakanojo Study. *J Aging Phys Act*, *14*, 288–301.

Yesavage, J. A., Brink, T. L., Rose, T. L., Lum, O., Huang, V., Adey, M., & Leirer, V. O. (1982). Development and validation of a geriatric depression screening scale: A preliminary report. *Journal of Psychiatric Research*, *17*(1), 37–49. doi:10.1016/0022-3956(82)90033-4

CHAPTER 3

A QUANTITATIVE DYNAMIC SYSTEMS MODEL OF HEALTH RELATED QUALITY OF LIFE AMONG OLDER ADULTS

Mattia Roppolo[1-2], Saskia Kunnen[2], Emanuela Rabaglietti[1], Paul van Geert[2], Anna Mulasso[1]

1. Department of Psychology, University of Torino (IT)
2. Department of Developmental Psychology, Rijksuniversiteit of Groningen (NL)

At press in: Clinical Interventions in Aging

Abstract

Health Related Quality of Life (HRQOL) is a person-centered concept. The analysis of HRQOL is highly relevant in the aged population, which is generally suffering from health decline. In the previous chapter, we developed a conceptual dynamic systems model that describes the development of HRQOL in individuals over time. Specifically, that model describes how HRQOL in three main domains (physical, mental and social) interact over time. This study aims to develop and test a quantitative Dynamic Systems model that was based on this conceptual model, in order to reveal the possible dynamic trends of HRQOL among older adults. The model is tested in different ways: firstly, with a calibration procedure to test whether the model produces theoretically plausible results, and secondly, a limited validation procedure using empirical data of 194 older adults. In this limited validation we tested the prediction that given a particular starting point (the 1st measurement) the model will generate dynamic trajectories that bring us to the observed endpoint, that is to say the 2nd and last measurement. The quantitative model produces theoretically plausible trajectories and shows a good fit between empirical and simulated results. This provides an initial basis of evidence of the dynamic nature of HRQOL during the ageing process.

Keywords: Health Related Quality of Life; Older Adults; Dynamic Systems Model

1. Introduction

Health Related Quality of Life (HRQOL) refers to the perceptions of physical, mental and social domains of health (Testa & Simonson, 1996). The three components are seen as distinct domains that can be influenced, in a complex way, by the individual's experiences, beliefs, expectations, and perceptions (Testa & Simonson, 1996). HRQOL narrows the focus on quality of life (QOL) to the effects of health, illness, and treatment and excludes aspects of QOL that are not related to health, such as cultural, political, or societal attributes (Ferrans, Zerwic, Wilbur, & Larson, 2005). Both health status and perceptions can be captured in each of the HRQOL domain (Haas, 1999; Testa & Simonson, 1996). HRQOL is a person-centered outcome measure, which differs from traditional measures of mortality and morbidity, in the sense that it provides information about an individual's personal point of view.

The evaluation of subjective assessment (i.e., self-rated health) is considered increasingly important by researchers and clinicians, because it gives fundamental information about the processes that may affect a person (i.e., drug administration, diseases). The use of HRQOL indicators allows: (i) to monitor individual trends of health status and perceptions, and (ii) to point out the achievement of specific health objectives in research (i.e., implementation of innovative intervention strategies) and public health (i.e., prevention campaigns; Theofilou, 2011). However, although the evaluation of HRQOL appears to have many advantages the use of HRQOL indicators (especially in hospitals and medical centers) is still limited, and as a consequence, knowledge concerning HRQOL processes has little influence on clinical decision making (Greenhalgh, Long, & Flynn, 2005).

The limited use in clinical practice may be related to the still existing lack of consensus among the available HRQOL models and instruments (Taillefer, Dupuis, Roberge, & LeMay, 2003). In fact, several authors (among others: Aaronson, 1993; Berzon, Hays, & Shumaker, 1993; Ware & Dewey, 2000) include different domains in their HRQOL conceptualization. Diversity in theoretical models is reflected also in too many and diverse instruments.

In an attempt to overcome the diversity in models and instruments, in the previous chapter, we analyzed various perspectives (i.e., demographic changes, health costs, ageing theories) and aspects (i.e., health decline in different functional domains) related to the self-rated health in the ageing process. In particular, some key aspects of HRQOL were highlighted, such as: (i) its three-dimensional nature, starting from the definition of the World Health Organization of health (WHO, 1948), that assumes health as complete physical, mental and social state of well-being, and (ii) the twofold way (self-report health status and experienced-health) of assessment for each component, as proposed by Testa and Simonson (1996). Furthermore, a new conceptual model based on the theory of Dynamic Systems was outlined to highlight that HRQOL (i) should be regarded as a dynamic construct (i.e., a phenomenon that can undergo changes during time), (ii) could be viewed from a developmental perspective, that is to say, each step is the starting point of the following one, and the continuous iterations on a short time scale (i.e., daily) are associated with long term development (i.e., monthly or yearly developmental trends), (iii) may have domains connected to one other, indicating the inadequacy of direct and simple causal relations, (iv) is subjected to random influences not directly assessable. The previous chapter in the dissertation delineated possible complexity and dynamic aspects of HRQOL, particularly in the aged population. A short overview of the conceptual model is presented in the next section.

It is well known that everywhere in the western world and in particular, in Europe, the population is growing older (Giannakouris, 2008). From an individual point of view, consequences of the ageing process are: (i) health decline (Eurostat, 2012; Marengoni, Winblad, Karp, & Fratiglioni, 2008), (ii) loss of autonomy (Grammenos, 2005), and (iii) institutionalization (Gaugler, Duval, Anderson, & Kane, 2007; Grammenos, 2005; Luppa et al., 2009). From a societal point of view, health decline and loss of autonomy translate into an increase of direct (i.e., health system) and indirect (i.e., loss of productivity for caregivers) costs (Allegri et al., 2007; Chen, 2010; Hagell, Nordling, Reimer, Grabowski, & Persson, 2002; Lajas et al., 2003; Mebane-Sims, 2009; Wilson, Brown, Shin, Luc, & Subak, 2001). The increasing costs stimulate policy makers, practitioners and researchers to find effective and low cost solutions to reduce age-related expenditure. Conceptualizing, measuring and analyzing HRQOL developmental trajectories in the older adults' population are fundamental steps to understand the role of ageing process on self-rated health and to early prevent health decline, implementing health promotion interventions and strategies.

In order to obtain information about trends of changes in HRQOL, it is necessary to test theoretical assumptions in an empirical setting. A first step towards this aim is to build and conceptually test mathematical models that can reproduce and predict empirically found developmental trends of HRQOL. Mathematical models represent mechanisms of development, and therefore, they can be used to test qualitative and quantitative properties of the process under study. Furthermore, a mathematical model is a good tool that permits to test, simulate and receive information about a system (Kunnen, 2012; van Geert, 1994). Dynamic system models are not data-focused in the statistical sense of the word (they do not represent statistical associations among patterns of empirical data, such as structural equation models) but they describe mechanisms of the system studied.

Furthermore, these models are dynamics because they describe how one state of the system (intended as the state of an individual person) changes into another state of the system over the course of time (Kunnen, 2012; van Geert, 1994). A mathematical dynamic systems model of a developmental process includes: (i) the concepts that are considered to be important for understanding the temporal course of a particular process, and (ii) the dynamic relations between those concepts that are theoretically expected. These relations are translated into mathematical equations. The mathematical translation enables to simulate the process under study. In other words, the model shows what happens over time in different conditions, with the possibility to test if theoretical assumptions concerning the process are valid (Kunnen, 2012).

It is relatively uncommon in social and psychological sciences to develop theory-based dynamic models. These models are capable of explaining change, explicitly specifying how one state of the system changes into another state of the system over the course of time, for all possible states that the system can occupy, in a way that generates a description of actual trajectories of change. Such models have various advantages such as the possibility: (i) to take into account a large number of phenomena under study, (ii) to analyze the structure of a system and its development during time, (iii) to express types and directions of connections among domains, (iv) to develop the model into a simulation tool, in order to test different situations and compare simulated results with empirical ones. In this way, a mathematical model may result in a better understanding of the phenomenon under study and may bring new knowledge to the specific sector of investigation (Kunnen, 2012).

The Dynamic Systems conceptual model (Roppolo, et al., 2015) contributes to the conceptualization of HRQOL, integrating domains, self-report health status and experienced-health components, stable individual parameters and random influences. Theoretical assumptions include the choice of variables and domains, and the notions of how they affect each other. In order to test the validity of the theoretical assumptions, it is necessary to translate the conceptual model into a mathematical model that will be analyzed and validated.

The mathematical model reflects theories of HRQOL and represents the conceptual model as a dynamic system, reproducing its structure and connections. The reason to translate the conceptual model into a mathematical one is that it offers the possibility to express theoretical assumptions and relations in a quantitative/numerical form (Kunnen & Bosma, 2000; Kunnen, 2012). The advantages are related to the possibility to test hypotheses and compare simulated (based on the assumptions made in the conceptual model) and empirical data. Furthermore, the dynamic systems model allows to analyze and represent differences among groups starting from different set of initial and parameter values and to simulate perturbations (e.g., a physical trouble) in the systems, in order to test its reactions to perturbations in life.

Once built, the model will be tested and validated with empirical data, in order to analyze the goodness of fit. The validation of the model is a mandatory step, because the system is based on the assumptions about the relevant variables acting on different time levels (i.e., day-to-day level). The model will be able to simulate developmental trajectories of HRQOL, because it is assumed (starting from the conceptual model) that HRQOL is an iterative process. Iterative means that the process is reproduced again and again on a daily basis. The outcome of each day (each calculation in the mathematical model) is the starting point of the next day (next calculation). The equations in the model describe how the different variables affect each other on the level of one iteration, thus how they change, influenced by all components in the model, from one day to the next (Kunnen, 2012).

The aim of the article is to make a first step in the validation procedure by: (i) translating the conceptual model in a mathematical model, taking into account all the specifics and features of the theoretically assumptions; (ii) testing the model, to assess whether it produces theoretically acceptable trajectories; (iii) comparing empirical and simulated data.

The conceptual model was conceived and designed specifically for the aged population, but it can be adjusted to other target populations. It is composed of: (i) three main components (called growers, for their ability to change over time), following the broad domains level proposed by Spilker (1996), namely the physical (P), mental (M) and social (S) domain of health. Each domain is seen as a subsystem, composed by self-reported health status and experienced-health indicators; (ii) a component that consists of stable individual parameters. The stable individual parameters are: age, presence of diseases, presence of protective or risk factors; (iii) a random influence (stochastic part of the model) that directly acts on the three growers, and that is seen as a comprehensive term for the variety of unpredictable life events; (iv) a parameter (called adaptability) regarding the individual's ability to cope with random fluctuations or internal and external stressors. This parameter is a direct representation of inter-individual differences, and it will act directly on the variability of HRQOL trends. The ability to cope with stressful life events is a central characteristic in the ageing process. In fact, several authors (Buchner & Wagner, 1992; Fried et al., 2001; Rockwood, Hogan, & MacKnight, 2000) delineated how a low level of adaptability, or functional reserve, may develop in the frailty syndrome, a precursor of negative health outcomes (death, institutionalization, loss of autonomy); (v) a parameter that regulates the strength of the relation between the growers in the system.

The specific way in which the different components affect each other plays an important role in a dynamic systems model. In particular, the conceptual model is a fully connected model, in which each component is linked to the other. The interconnections among health domains derive from the biopsychosocial model, described by Engels (1977), in which health is seen in a systemic way, with a mutual interactions among components. This is included because each of the health components and the stable individual parameters may affect each other (see Figure 1).

In addition to the above specifics, and in order to define the conceptual model as a Dynamic Systems model, the following characteristics are relevant: (i) the role of time, assuming that HRQOL is a construct that can develop in time; (ii) the non-linearity, assuming that the relations among components may be non-linear with the possibility of drastic changes, reductions or resources limitations.

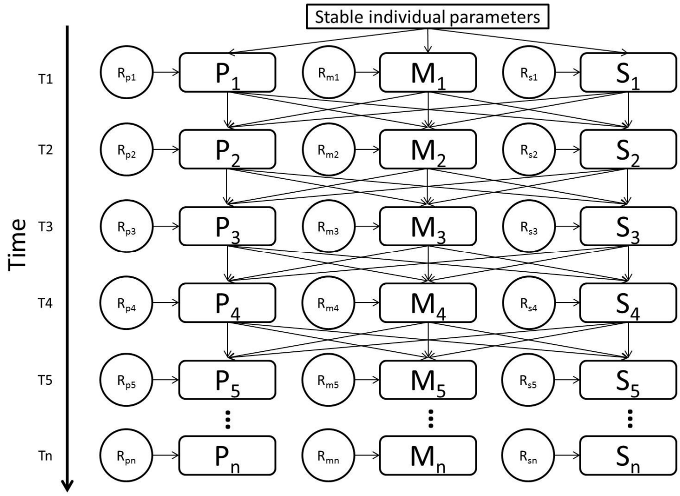

Figure 1 - The Conceptual Dynamic Systems Model of HRQOL showing the interactions between the physical, mental and social domain over time (T1 … Tn). Stable individual parameters = indicator of age, comorbidity and lifestyle, directly influencing the three main domains of HRQOL.
P= physical domain
M= mental domain
S= social domain
Rp= random factor in the physical domain;
Rm = random factor in the mental domain;
Rs = random factor in the social domain.
The model shows 5 iterations (from T1 to T5, and it shows how the process continues until a generic Tn), each arrow is a connection between domains during time, representing the influences of one factor on another, causing the influenced factor to change over time (dynamic relationship)

Figure 1 represents the dynamic systems conceptual model of HRQOL. In particular, the upper box represents the stable individual parameters, including age, presence of diseases and health behaviors (protective and risk factors). The central part of the model is composed by the three health domains. Since the HRQOL model aims to represent longitudinal trends, each domain is connected with itself in a subsequent time point. Furthermore, the systemic approach (based on the Engel's model) is represented by the connections between each domain and the other two. Finally, each of the three domains of health is connected with a random influence, representing the unpredictable life events that may occur in any time point. In the figure, we represent only the first five iterations. However, the process and thus the series of iterations continue until some end point Tn.

2. Methods

A three steps procedure is performed to develop and test the model. Firstly, a mathematical version of the conceptual model was built; secondly, the model was tested with a "hybrid" procedure and, thirdly, the model was validated in order to test the validity of its predictions.

2.1 Mathematical translation of the conceptual model

2.1.1 Translation procedure

In order to translate the model presented in Figure 1 in a mathematical model it was necessary to replace arrows with equations. The translation procedure implies that all variables and relations need to be quantified. Measurements of HRQOL components are represented in a continuum between two extreme points, seen as the lowest and highest possible functions and perceptions in each health domain. It was chosen as an arbitrary scale of continuous values between 0 (worst HRQOL condition) and 1 (best HRQOL condition) for all components. Note that the choice of the scale is arbitrary, and the numbers have no intrinsic meaning, they only have meaning in relation to each other. The only exceptional range is those of the random influence, that vary between -1 (worst possible random influence) and 1 (best possible influence). Theoretically and intuitively, this implies that chance events can act enhancing, maintaining stable or reducing each HRQOL component.

The development of the system and its components is iterative, as expressed in Figure 1. Each iteration produces an outcome, which is generated by the quantitative relationships expressed in equations. This outcome serves as input in the next iteration (Kunnen & Bosma, 2000; Steenbeek & Van Geert, 2008). Depending on one's research interests, the system can simulate few iterations, or a long range of iterations, representing a long period of time. From a dynamic systems point of view, the iterations should be frequent enough to reproduce a trajectory of change on a particular time scale, which in this particular case is the timescale of change over months or years.

The HRQOL quantitative model consists of one equation for each grower, thus for each health domain (expressed as the average level between the self-report health status and experienced-health components). The equations specify how the grower changes as a function of itself and the other components in the system in each iteration. Specifically, each health domain grower is a function of the values of: (i) itself, (ii) other growers inside the system, (iii) stable individual parameters, (iv) random influences, (v) additional parameters.

The mathematical model presented here is a non-linear model of connected growers based on Dynamic Systems theory. Previous studies (among others; Kunnen & Bosma, 2000; Steenbeek & van Geert, 2005; van Geert, 1991; Steenbeek & van Geert, 2008) have built this type of model starting from the dynamic growth theory and the dynamic growth models (van Geert, 1994). The basic equation that supports these models is the logistic growth equation (Kunnen & Bosma, 2000; Kunnen, 2012). Such equation is particularly suitable in the analysis of living systems development, due to its non-linear trend and limitations of resources (intended as maximum growth capacity), typical characteristics in human and psychological sciences (Kiel & Elliott, 1996; van Geert, 1993). The logistic growth model will also serve as the basis for our model of HRQOL development.

Each equation needs some numerical input. In particular: (i) an initial value, (ii) a growth rate, (iii) the level of growth capacity, representing the limitations of resources. The basic form of the logistic growth equation is the following (Equation 1).

$$L_{t+1} = (L_t + L_t r - r L_t^2)/K \qquad \text{Equation 1}$$

Where: (i) L_t is the value of the grower at a certain time t (at the first iteration it is the initial value); (ii) r is the growth rate for each grower. (iii) K is the growth capacity.

The model was created and written on a Microsoft Office Excel spreadsheet.

2.1.2 Description of the equations

In this section, the specific equations used in the model of HRQOL are explained. The three domains of HRQOL (physical, mental, and social) are each quantified by a logistic growth equation. Inter-subject differences are represented in a set of parameters. This set is composed by: (i) stable individual parameters, assumed as age, presence of diseases and presence of protective-risk factors; (ii) a change rate for the stable individual parameters for each grower, due to the different effect that the development of the stable individual parameters may have on the three main components, (iii) initial value for each grower, since that it is necessary to enter a starting point in order to run a simulation. The starting point can be chosen by the researcher, in that case, the simulation is purely theoretical; otherwise, if the aim is to simulate the development of an individual, the initial value derives from empirical measurements; (iv) growth rate for each grower, that can be empirically assessed and that it is discussed in the next section; (v) adaptability to internal-external influences, intended as the individual ability to cope and react to stressful life events, avoiding negative impact on health status and functions. The connection between the three domains (or growers) is realized by including in the equation for each grower the value of both other growers

As previously described, parameters are stable characteristics in the model. The development over time of the model is described in the series of iterations. In our model, each iteration represents one day, because it is assumed that one day is a kind of unit, and that the next day can be seen as a next unit. A daily time level represents a useful unit of experience.

In each iteration, the growers' equations are influenced by their own previous value, their growth rate, the parameters, the rate of changes of the other growers, and a random number representing the chance-related influence. The model is a continuous model in which each iteration represents a data point in a developmental path.

The model starts with the initial value for each grower. The following iteration is a function of the previous level of the grower and the growth rate.

$$L_{t+1} = L_t + R_{Lt} \qquad \text{Equation 2}$$

The general growth rate (R_{Lt}) depends on the previous level of the grower, a composite growth rate and the growth capacity.

$$R_{Lt} = \left(L_t \times r_{Lt} \times (1 - L_t/K)\right) \qquad \text{Equation 3}$$

The composite growth index is function of the increase part of the equation and the chance value.

$$r_{Lt=}I_{Lt} \times C_{Lt} \qquad \text{Equation 4}$$

The chance component is the difference between two randomly selected numbers comprised from 0 to 1. This technical solution was adopted to guarantee randomization in the chance component of the model.

$$C_{Lt} = \left(random\ (0-1) - random(0-1)\right) \qquad \text{Equation 5}$$

This result in the generation of a random number in the range between -1 and +1, in which the chance that a number around 0 is generated is higher than the chance that an extreme value (close to -1 or +1) is generated. This number, computed for each iteration, may be a good representation of daily unpredictable events, that are very often small (close to zero), while bigger life events, (with a value close to 1 or -1) are less common.

Finally, the increase part depends on the adaptability parameter, on the growth rate of the other growers and on its growth rate parameter.

$$I_{Lt} = (A \times ((R_{Mt} + R_{Nt})/2) + G_L) \text{ Equation 6}$$

Where: (i) L_t is the value of the grower at a certain time t; (ii) R is the general growth rate for each iteration; (iii) r is the composite growth index; (iv) K is the growth capacity, representing the limitations of resources; (v) I is the increase rate; (vi) C is the random part of the model; (vii) A is the adaptability parameter; (viii) R_M and R_N are the growth rate of other growers (called here M and N), in the first iteration the initial condition parameter is used in place of R_M and R_N; (ix) G is the growth parameter.

The equation is computed for each iteration in each grower. If the model is run for several cycles, it produces a set of points (one for each iteration) that make up developmental trajectories of the three components. Some examples of developmental trajectories produced by the model are presented in the next section.

2.2 First procedure to test the validity of the model

Before proceeding with an empirical validation analysis, the model was tested with a hybrid procedure. This procedure is called '"hybrid" because it combines theoretical assumptions and numerical trajectories (Kunnen, 2012). In sum, it is a step that matches the bipartite nature of the model (built from the theory but useful for empirical research).

In this paper, this procedure (called calibration) aimed to estimate the theoretical adherence of simulated data starting from sets of numerical data. The scopes of this analysis are: (i) to test if the simulated trajectories, produced by the model, are theoretically plausible, starting from a given set of initial and parameter values; (ii) to identify within which ranges the parameters generate realistic trajectories (that do not get stuck to zero or explodes into infinite). For all models, the range of parameter values is selected in such a way that a more or less realistic trajectory will result out of them. In other words: outside that range the models explode to infinity or get stuck at zero.

The aim is to test the plausibility of the model and to identify patterns of data that result in plausible and non-plausible trajectories. In the validation process empirical data have to be translated into parameter values. The definition of the possible range of values helps to make this translation. For example, low empirical values should be translated into values at the lower end of the range.

Several different set of initial and parameter values, selected on theoretical possibilities, were simulated and analyzed in order to calibrate the model. For simplicity, just a selection of these patterns is reported here. Each pattern was run two-hundred times and qualitative results about developmental trends were collected.

2.2.1 Set 1

The first set of initial and parameter data refers to normal conditions of life, and so normal starting values. It is to notice that, normal is intended as a common and more or less average situation in real life. Three different patterns of starting data were used. The choice was arbitrary, with a selection of different combination of values. High and low values were defined on the basis of predefined range (0 to 1). Values seemed plausible, on a theoretical basis, in their combination, and covered a big part of the predefined range. These patterns represent different types of people. In particular, the first hypothetical person depicted here is related to an older adult (named “X”) who have some physical impairments. These physical problems limit his ability to walk autonomously inside and outside his home, making his HRQOL poor in all of the three domains. For this reason, the initial levels of the growers are set at .20. Since the chronic nature of the physical impairment, it is expected that the health conditions will decrease; so the growth rates for each domain are negative (- .20). Despite the poor health condition (e.g., presence of a chronic disease) “X” is relatively young (e.g., 67 years old) and so with a mid-level of the stable individual parameters parameter, that is set at .50. Furthermore, “X” continues to have a fairly good adaptability to stresses events; this is the reason why the adaptability parameter is set at .80. The developmental trajectory of “X” is presented in Figure 2.

The second hypothetical older adult (called “Y”) have a better, but not optimal, health condition. The initial level for each domain is set at .40. Furthermore, his health is increasing, because he was engaged in a physical training class in the last month. This new habit allows “Y” to have a better physical and mental health status, in association with an increasing in his social activities. For these reasons the growth rates are all set at .20. The stable individual parameters (due to age and presence of diseases) are medium (.60) as well as the adaptability parameter (.60). The developmental trajectory of “Y” is presented in Figure 3.

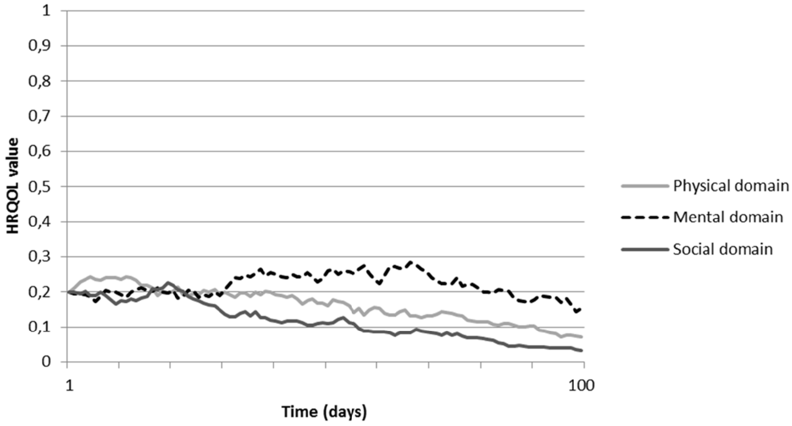

Figure 2 – HRQOL developmental trajectory of subject X with low initial values in all domains.
Time (X axis) is represented by means of the number of iterations computed by the model, assuming that one iteration represents one day
The Y axis represents the level of HRQOL on a scale ranging from 0 to 1
P= Physical domain
M= Mental domain
S= Social domain
Note: in this particular simulation the mental domain shows a slight increase, followed by a later decline whereas the physical and social domains start to decline relatively early

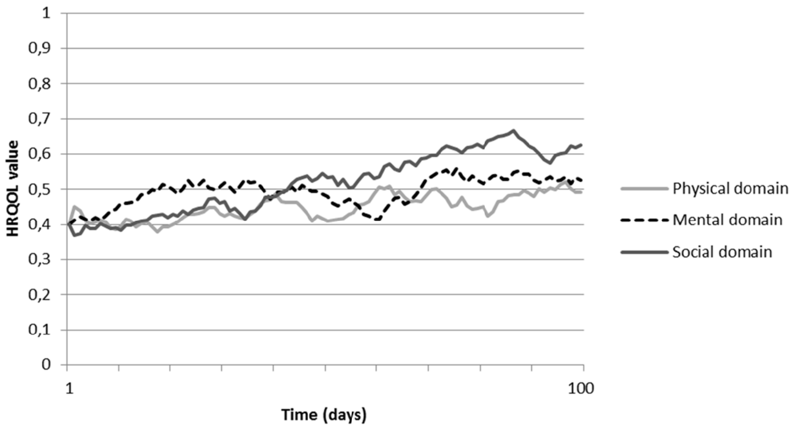

Figure 3 – HRQOL developmental trajectory of subject Y with moderate initial values in all three domains.
Time (X axis) is represented by means of the number of iterations computed by the model, assuming that one iteration represents one day
The Y axis represents the level of HRQOL on a scale ranging from 0 to 1
P= Physical domain
M= Mental domain
S= Social domain
Note: in this simulation all the three domains show an increasing trend. The mental domain have more fluctuations than the other two, whereas the social domain presented the highest increase

The third hypothetical subject (called "Z") is a healthy and "young" older adult, with a medium to high initial levels for each domain (.60). Unfortunately, due to the death of a relative, the general condition of "Z" is decreasing, with negative growth rates in each domain (- .20). However, the stable individual parameters, due to young age (e.g., 65 years) and absence of diseases are good (parameter set at .70). Finally, "Z" continues to cope fairly well to life events, with an adaptability parameter set at .80. The developmental trajectory of "Z" is presented in Figure 4.

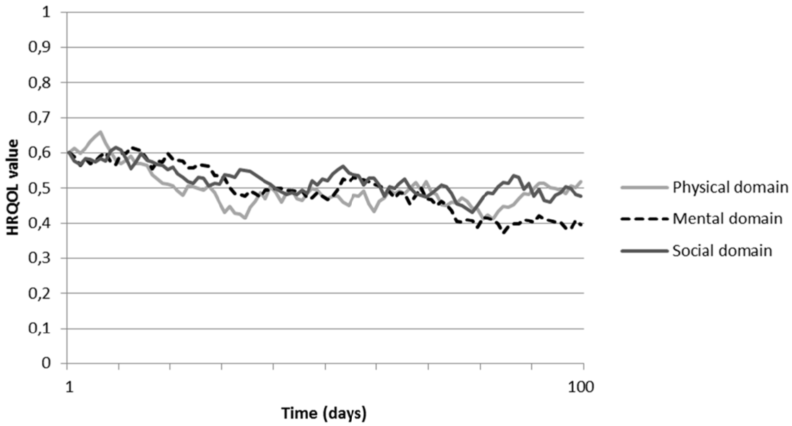

Figure 4 - HRQOL developmental trajectory of the healthy and young subject Z with high initial values in all domains
Time (X axis) is represented by means of the number of iterations computed by the model, assuming that one iteration represents one day
The Y axis represents the level of HRQOL on a scale ranging from 0 to 1
P= Physical domain
M= Mental domain
S= Social domain
Note: all the domains shows a decreasing trend, more evident in the first iterations. In the final iterations physical and social domains show an increase, while the mental domain remains more stable

Results of the simulated trajectories of "X", "Y" and "Z" are reported in Table 1 (first three rows). The first 8 columns of the table report the patterns of data that were used to simulate trajectories. The following columns represent the behavior of the simulations, expressed in percentages. It was tested whether the simulations exploded or get stuck to 0, whether they showed an increase or a decrease as compared to the initial situation, and it was made a qualitative estimation of the theoretical plausibility of the trajectory.

Information about the distribution of outcomes derived by specific sets of initial and parameter values is useful to get an impression of the plausibility of model's behavior.

In particular, it was hypothesized that the majority of cases in the trajectories of first and third sets of initial and parameter data would produce lower final results in comparison with the baseline data, because of their negative growth rates. This assumption is found to be true approximately 80% of times (see table 1). The remaining 20% of cases explain that, during the iterations, connections among variables and random fluctuations produced higher final results. This condition is compliant with reality, because it is possible to observe in real life that negative stable individual parameters (i.e., an accident) not always develop in negative outcomes. A similar reasoning was made for the second condition: this represents a rather positive situation, and we expected and found overall positive development.

Finally, it is important to notice that all conditions produced dynamic trends, with fluctuations and sudden jumps, and without stable or exploded trajectories.

2.2.2 Set 2

The second set of initial and parameter data refers to particular conditions in which positive or negative accidental life events, occur, or in which the starting point may be unusual. For example, a physical healthy subject has an accident causing a low physical change rate. On a theoretical basis we would expect that in such cases the physical domain often shows a decreasing trend, which can afflict also other domains.

On the contrary, a depressed older adult may meet an old friend, which may help him to be more satisfied about his life. It is conceivable that mental domain may have an increasing trend most of the time, influencing positively also other domains.

Finally, it is also possible to hypothesize subjects with mixed situations, in which a high social starting point is associated with a low change rate and vice versa for the psychological domain etc. These are just some examples, but they can represent real situations. For this reason it is important to test the models behavior for such hypothetical subjects as well. Also in this case we used three different conditions to calibrate the model. In summary, we ran simulations with six different sets of initial and parameter data: the first three represent non-optimal, moderately optimal and optimal initial conditions respectively, and the last three represent a combination of optimal and non-optimal conditions. For each set we assessed how often the model generated a completely static trajectory (assumed to be less plausible) and how often the simulation exploded to infinity (assumed to be impossible). In addition we assessed how often the simulation showed the increase or decrease over time that was assumed to be most plausible on a theoretical basis as explained above. Results are shown in Table 1.

Table 1 -. Qualitative outcomes of the calibration procedure, analyzing trends and final results of simulated data starting from different sets of initial and parameter values

Initial and parameter values									Trend (%)		Output (%)		
P_I	P_{CR}	M_I	M_{CR}	S_I	S_{CR}	Ini	Ad	Domain	Static	Explosion	Increase	Equal	Decrease
								P	0	0	18	2	80
.20	-.20	.20	-.20	.20	-.20	.50	.80	M	0	0	14	4	82
								S	0	0	20	8	72
								P	0	0	70	2	28
.40	.20	.40	.20	.40	.20	.65	.60	M	0	0	92	0	8
								S	0	0	76	0	24
								P	0	0	18	0	82
.60	-.20	.60	-.20	.60	-.20	.70	.80	M	0	0	20	0	80
								S	0	0	20	0	80
								P	0	0	14	0	86
.75	-.30	.45	-.10	.50	.10	.30	.60	M	0	0	28	1	71
								S	0	0	40	0	60
								P	0	0	35	2	63
.35	-.10	.08	.50	.63	-.20	.40	.80	M	0	0	0	0	100
								S	0	0	16	6	78
								P	0	0	32	0	78
.60	-.15	.15	.40	.65	-.45	.60	.40	M	0	0	4	0	96
								S	0	0	13	2	85

PI= Initial value of the physical domain
PCR= change rate of the physical domain
MI= Initial value of the mental domain
MCR= change rate of the mental domain
SI= Initial value of the social domain
SCR= change rate of the social domain
Ini= stable individual parameters
Ad=Adaptability parameter

Within a wide range of initial and parameter values the model generates theoretically plausible trends, because no stable or exploding trajectories were seen and, in addition, theoretical expectations (related to the mix of initial values and growth rates of the three domains) were generally confirmed. As stated before, the calibration procedure is intended here just as a first attempt to transform theoretical assumptions in numerical expression.

The qualitative results proposed in Table 1 support the goodness of the model, but it is important to notice and to take into account for further analysis that the model does not work with some so called “dangerous initial and parameter data”. These data are patterns of values that make the trajectories completely stable or completely random. In particular, very low change rates (lower then .02) in the three growers, in association with a low adaptability parameter (lower then .40) produce very stable (with very low fluctuations during the whole trajectory) and unchangeable developmental trajectories. In addition to this, low levels of initial values in the three growers seem to increase the stability (see Figure 5). Values producing such low level rigid trajectories can be hypothesized to form the lower limits of the plausible data range.

On the contrary, higher change rates (higher then .80) in association with high values of the adaptability parameter (higher then .80) and with the increase of the growers initial values bring trajectories to the maximum capacity level, after a first phase of dynamic trends (see Figure 6). The values generating such extreme high level trajectories could be seen as the upper limits of the usable data range.

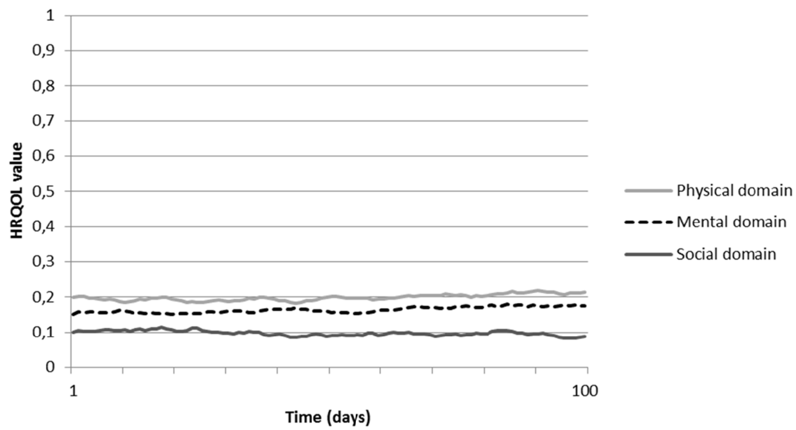

Figure 5: Extremely low developmental trajectory
Time (X axis) is represented by means of the number of iterations computed by the model, assuming that one iteration represents one day
The (Y axis represents the level of HRQOL on a scale ranging from 0 to 1

P= Physical domain
M= Mental domain
S= Social domain
Note: with this set of parameters and initial data all the domains remain stable for the entire period showing very subtle fluctuations

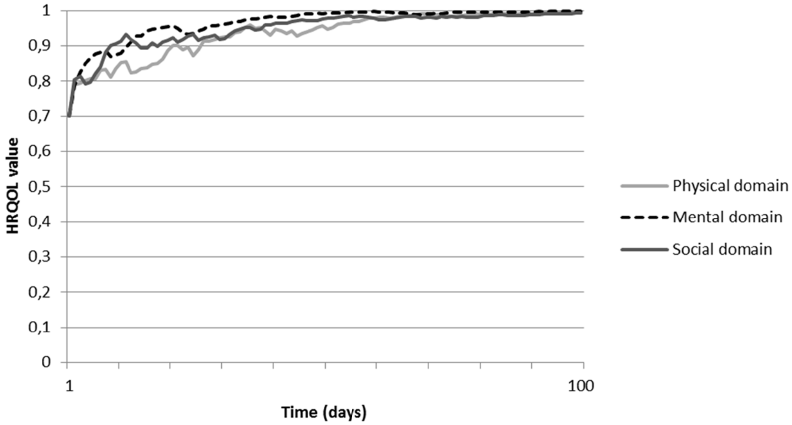

Figure 6: Extremely high developmental trajectory
Time (X axis) is represented by means of the number of iterations computed by the model, assuming that one iteration represents one day
The (Y axis represents the level of HRQOL on a scale ranging from 0 to 1
P= Physical domain
M= Mental domain
S= Social domain
Note: with this set of parameters and initial data all the domains rapidly increase to the maximum values and then remain stable

Furthermore, the change rates for the stable individual parameters were always set between - .1 and .1. These parameters allow to compute the role and the impact of changes in individual conditions on the three growers during time.

2.3 Validation procedure

Now that the model passed the first test, and has shown the capability to produce temporal trajectories that are qualitatively and theoretically acceptable, it is possible to proceed with the empirical validation. The first validation procedure is a minimal requirement that is needed to assume the model resemble empirical data in a satisfactory way (Kunnen & Bosma, 2000).Of course, the best way to test an empirical model is to compare simulated trajectories with intensive individual time series of data. However, such data are often not available. In that case it is possible to perform an initial validation with two data points, an initial value and a value after a period that is long enough to produce considerable change (see for example Kunnen and Bosma, 2000; Vleioras and Bosma, 2005). The use of two waves of assessments is very limited for the validation of a dynamic systems model, because between the initial and final data points there is a long sequence of changes that are generated by the model, but not documented by empirical data. However, the aim of this analysis is to understand if a theoretically based dynamic systems model of HRQOL is capable to predict the outcomes, based on a set of initial and parameter values, on the basis of a model of realistic mechanisms of change, to connect at least two time points. Once this objective is reached, it will be possible to proceed with further and more powerful validation analyses, with the use of time serial data.

Empirical baseline values are used as initial data in the model. The model is run for a given number of iterations (i.e., the number of days between the assessments). The procedure generates simulated final values that can be compared with the empirical ones, in order to analyze the empirical representativeness of the model. In other words, a known initial condition was entered in the model. The trajectories simulated by the model are compared with the empirical ones (based on real data).

In the next paragraphs, the different steps of the validation procedure will be described.

2.3.1 Participants

Data used in the validation procedure derive from a sample of older adults (over 65 years) involved in an Italian Regional project, called ACT ON AGEING, funded by Regione Piemonte. A total of 367 community dwelling older adults were involved.

The following inclusion criteria have been set: (i) age over 65 years, (ii) Mini-Mental State Examination score higher than 25 (indicating absence of cognitive impairments), (iii) independence in the activities of daily living, (iv) ability to walk 500mt without assistance. While the exclusion criteria were: (i) myocardial infarction and/or coronary bypass surgery in the last year, (ii) uncontrolled diabetes or hypertension, (iii) orthopedic impairment and/or limbs fracture within the last 6 months, (iv) contemporary participation to another study. These criteria were chosen in order to have a sample of autonomous and quite healthy participants, with the possibility to participate in an intervention study design.

Baseline and post test data of 194 subjects have been used in this study. Subjects who miss at least one question were excluded from the analysis. This method was preferred instead of a replacement method, because using only real data increases the reliability of the outcomes. The price paid for greater reliability was the reduction of the sample size. However, a total sample of 194 individuals was sufficient for the validation procedure.

The whole sample was slightly unbalanced in terms of gender composition. The majority of participants were women (n=130; 67%). However, this composition reflects the Italian gender distribution among older adults. In fact, demographic data (Istat, 2013) state that, in Italy, the number of aged (over 65) women is 7,129,842 (68%) while men are 5,240,980 (32%).

The mean age of the participants was 73.5 years (range65 - 90) and their score of Mini-mental State Examination was comprised between 25.2 and 30.0. All the participants were independent and non-institutionalized.

The Ethical Committee of the University of Torino approved the study. All participants were informed about the voluntary and confidential participation to the study. All the selected individuals gave their written informed consent in accordance with Italian law and the ethical code of the American Psychological Association (2002).

Descriptive characteristics of the participants are presented in Table 2.

Table 2 - Baseline characteristics of participants

VARIABLE	N	Valid %
Gender (N)		
Women	130	67
Men	64	33
Level of education (N)		
Low	89	46.6
High	102	53.4
Family condition (N)		
Never married	5	2.6
Married	107	55.4
Widow	71	36.8
Divorced	10	5.2
Work position (N)		
Retired	163	98.8
Working	2	1.2
Past job (N)		
Manual labor	65	34.2
Nonmanual labor	125	65.8
VARIABLE	Mean	Standard Deviation
Age	73.5	6
Mini-Mental State Examination	28.4	2.5

2.3.2 Research protocol

The general aim of ACT ON AGEING was to determine the effectiveness of both physical and cognitive interventions on the health status of participants. After the baseline assessment, the whole sample was split in three subgroups: two experimental groups that took part in physical or cognitive intervention and one control group. The experimental groups performed 16-weeks of activities, two sessions per week. The control group did not change its habits while performed only the evaluation trials. Measures were collected before and after the interventions on the whole sample.

For this study, the initial aim was to simulate HRQOL trajectories for each subgroup separately. However, no differences in HRQOL scores were found between initial and final data in each group. For this reason, it was decided to not consider the experimental allocation for each subject. Instead, different groups were differentiated by performing a cluster analysis in order to split the sample in groups with different starting values and change rates in time.

2.3.3 Measures

To capture the tripartite nature of the HRQOL conceptual model, the physical, mental and social components were collected with validated self-report questionnaires.

The Short Form 36 Health Survey (SF-36; Ware & Sherbourne, 1992), the Lubben Social Network Scale-6 (LSNS-6; Lubben, 1988) and the Friendship Quality Scale (FQS; Hawthorne, 2006) were used to assess the three components of HRQOL delineated in the conceptual model. Specifically, physical domain was rated with the SF-36 physical health summary measure (PCS), mental domain was assessed with the SF-36 mental health summary measure (MCS), social domain was measured with the LSNS-6 and the FQS.

The SF-36 is one of the most used instruments to assess health status and HRQOL. It is a generic measure (not specifically designed for a target population) allowing to compare data from different samples (Ware & Dewey, 2000). The SF-36 has a three levels structure: the thirty-six items are aggregated in eight scales from whose union derives the two summary measures (PCS, composed by 21 items – MCS, composed by 14 items). Our focus is on the analysis of the dynamics on the broad domains level (Spilker, 1996), and for this reasons PCS and MCS will be used here. The use of the SF-36 in the aged population is well documented in previous researches (Hörder, Skoog, & Frändin, 2012; Meng, King-Kallimanis, Gum, & Wamsley, 2013; Stadnyk, Calder, & Rockwood, 1998; Walters, 2001; Yang, Selassie, Carter, & Tilley, 2011).

The LSNS-6 (Lubben, 1988) is a six items scale widely used to assess social network in aged persons. The LSNS-6 is composed by two subscales, each of three items. The first scale is related to the family social network, while the second one assesses the friends' social network (Lubben et al., 2006). The LSNS-6 is specifically designed for older adults and it is useful for measuring their social isolation.

Finally, the FQS (Hawthorne, 2006; Hawthorne & Griffith, 2000) is an instrument specifically designed for aged population that measures social isolation. FQS is a one-dimensional scale composed by six items, covering aspects related to perceptions of isolation and easiness to make contact with people. Both questionnaires were chosen to assess the social domain for the following reasons: (i) social domain is a crucial component of HRQOL, especially in an older adults population. Furthermore, many aspects need to be taken into account, in order to have a view of the social domain that is as complete as possible. For these reasons, we decide to use both scales, also in order to have a comparable numbers of items with respect to the other two domains. (ii) The two scales used to measure the social sphere capture different aspects of the domain. In particular, the LSNS-6 questions are more self-report health status oriented, asking the number of persons attended in the last month. The FQS tends to capture more experienced-health about social life. As expressed in our theoretical model, and in accordance with Kelley-Gillespie (2009), the simultaneous use of these two measures allows us to analyze both dimensions.

All the instruments are self-report; however, a psychologist was present during the initial and final assessments to give support in case of doubts or difficulties in the questionnaires completion (i.e., difficulty to read questions or to understand their meaning).

Data from the two waves were transformed in order to :(i) give them the same directions, and (ii) make them comparable with the simulated data produced by the model. Since the simulated data ranged between 0 and 1, the following formula was used to transform the empirical data to the same scale:

$$y = (x - min)/(max - min) \qquad \text{Equation 7}$$

Where, y is the output of the transformation (a number varying from 0 to 1 on a continuous scale); x is the empirical data; min is the minimum theoretical value of the scale and max is the theoretical maximum value of the measure. This transformation maintains the original distributions characteristics allowing an easy good comparison between simulated and empirical data.

To test the indexes reliability, a Cronbach's α analysis was performed. All the domains in both initial and final assessments were found to have a satisfactory internal consistency, with an α level always higher than .70 (Nunnally, 1978; see Table 3). For these reasons, it was decided to use a single index of social domain aggregating the scores of LSNS-6 and FQS questionnaires.

Table 3 - Indexes Cronbach's α

Wave	1	n
P	.862	.876
M	.870	.873
S	.797	.756

Wave 1= baseline assessment
Wave n= final assessment
P= physical index
M= mental index
S= social index

Finally, a hierarchical and a K-means cluster analysis was performed, combining baseline and change rate values (final – baseline data), in order, firstly, to understand in how many subgroups the whole sample can be split and, secondly, to set and compute central values for each cluster. The best solution turned out to be a four-cluster solution. The cluster centers are reported in Table 4.

Table 4 - Cluster centers

Cluster	1	2	3	4
N	39	27	88	40
P_I	.629	.351	.757	.348
P_{CR}	.001	.365	-.003	.051
M_I	.533	.329	.800	.434
M_{CR}	.096	.419	-.058	.011
S_I	.533	.617	.733	.679
S_{CR}	.058	.046	-.019	-.056

PI= Initial value of the physical domain
PCR= change rate of the physical domain
MI= Initial value of the mental domain
MCR= change rate of the mental domain
SI= Initial value of the social domain
SCR= change rate of the social domain

2.3.4 Statistical Analyses

The starting values used to run the model are the empirical clusters data. The model needs an initial value for each grower and a change rate, and we based these on the outcomes of the cluster analysis. In addition to the growers values, a set of parameters must to be set.

To determine the value for the parameter called stable individual parameters we created an index based on the age of participants and the presence of diseases. For the growers, the parameter value is located on a continuous scale ranging between 0 and 1, where 1 is the best possible score (i.e., 65 years and without diseases). The cluster values for this parameter were: Cluster 1: .530; Cluster 2: .547; Cluster 3: .557; Cluster 4: .563.

The adaptability parameter was always set at .80, due to the generally good health conditions of the sample. The change rates for the stable individual parameters were set between - .1 and .1. This range was chosen for theoretical reasons and after the good results achieved in the calibration procedure. The growth capacity was set at 1.0.

Once that the values of the parameters and the initial conditions have been chosen,, it is possible to run the model. With this procedure, the model simulates data for the numbers of iterations requested. In this study, we used one-hundred iterations. Each iteration represents a day. In this way, we simulated a number of days that is similar to the time between baseline and final measurement in the empirical sample. The values for each grower (P, M and S) at T100 represent the simulated final data.

A three step statistical analysis was performed to compare the empirical and the simulated outcomes for the validation of the model. Firstly, a Monte Carlo simulation test was used to analyze differences between the empirical and simulated final data for each cluster group. Secondly, the final empirical and simulated distributions were compared using non-parametric tests (Wilcoxon test), in order to analyze differences among the results. Thirdly, a series Kruskall-Wallis test in addition to Mann-Withney U test post-hoc with the use of Dunn-Sidak correction, were performed in order to analyze the correspondence among statistical differences (among clusters) in: (i) empirical vs empirical, (ii) simulated vs simulated, and (iii) simulated vs empirical data. In other words, these tests allow us to know if the prediction made with the model reflects real data.

While the first two steps aim to analyze similarities between simulated and empirical results in the same cluster, the third procedure aims to highlight correspondences in the differences among different clusters.

The Monte Carlo simulation technique was used to test differences between the output values produced by the model and the empirical final data. An in depth explanation about the Monte Carlo technique was published by Kunnen (2012). Specifically, this method generates a given number (1,000 in this case) of simulated final data, comparing these results with the empirical ones. During the procedure, the number of times that simulated data are higher or lower then empirical ones is computed, giving an associated p level, to understand the probability that the differences between the model and the data could be explained on the basis of chance while in fact, the empirical and simulated data are both part of the same set of data. The best fit is represented by a level of p near .50, meaning that the model produces for 50% of times higher simulated data and the other

50% of times lower simulated data in respect to the empirical ones. For this reason, a level of p which deviates much from .50 (e.g., p= .70) becomes unacceptable. Three Monte Carlo procedures were carried out for each cluster. This was done in order to test if the selected range for the change rate of the stable individual parameters was acceptable. Firstly, the Monte Carlo technique was run using the extreme data range (- .1 and .1) in each grower. Secondly, for the definitive analyses it was used the change rate values of the stable individual parameters that resulted in the best fit.

Moreover, a comparison between simulated and measured final results was given with non-parametric test for dependent sample (Wilcoxon test). The Wilcoxon test was chosen for the non-normality of data, for the low clusters sample size (min= 20; max= 88).The final data produced by the model consisted of one-thousand simulated outcomes. A random subsample of simulated outcomes with the same size of the empirical sample was extracted with a shuffle technique (that allows to extract cases from the simulated distributions without replacement). This was done, because a large sample of empirical data would increase the chance of significant findings, and by using same numbers for the empirical and the simulated samples we can compare the levels of significance. Finally, the Wilcoxon test between the two distributions was performed, in order to highlight the statistically significant differences. The optimal outcome in terms of validity of the model is represented by the absence of statistically significance differences among the distributions, meaning that a sub-sample of data produced by the model is not different from the empirical data.

A series of Kruskal Wallis tests were computed in order to analyze differences among clusters. This analysis was performed to compare different empirical clusters, different simulated clusters, and simulated with empirical clusters. If the Kruskal Wallis shows that the difference among the clusters is statistically significant, a series of Mann Withney U tests with Dunn Sidak corrections were performed to test the pairwise significant level. This step was necessary to test whether the model generates clusters that differ from each other in the same way as the empirical data. The best outcome is to find statistically significant differences among the clusters that are comparable in the empirical and in the simulated data sets.

3. Results

3.1 Simulated VS empirical final data

Monte Carlo test was used to compare 1,000 simulated data with the empirical final data. We compared simulated and empirical data sets with the same sets of stable parameters. The results of the Monte Carlo procedure are reported in Table 5.

Table 5 - Monte Carlo analysis of the compared empirical and simulated outcomes, for different sets of initial change-rates for each of the domains P, M and S, and for the four different clusters.

Cluster	1			2			3			4		
Domain	P	M	S	P	M	S	P	M	S	P	M	S
Ini_CR	- .1	- .1	- .1	- .1	- .1	- .1	- .1	- .1	- .1	- .1	- .1	- .1
Average	.644	.568	.562	.605	.687	.643	.766	.782	.738	.375	.451	.668
Median	.651	.572	.567	.619	.745	.648	.774	.798	.746	.380	.451	.687
Min	.358	.385	.351	.090	.071	.346	.472	.316	.421	.191	.197	.238
Max	.864	.675	.695	.966	.983	.808	.914	.951	.920	.544	.686	.916
SD	.084	.052	.059	.195	.213	.061	.070	.094	.082	.060	.085	.120
p value	.589	.078	.314	.327	.494	.386	.604	.632	.650	.360	.531	.688
Ini_CR	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
Average	.664	.640	.601	.638	.683	.680	.784	.815	.754	.413	.475	.698
Median	.673	.656	.608	.679	.725	.688	.793	.820	.762	.413	.478	.704
Min	.358	.178	.255	.051	.040	.218	.501	.673	.490	.078	.191	.499
Max	.879	.946	.916	.973	.990	.930	.919	.895	.904	.762	.746	.817
SD	.087	.152	.125	.212	.205	.116	.063	.035	.063	.125	.100	.052
p value	.665	.565	.541	.441	.460	.608	.723	.912	.772	.535	.614	.901
Ini_CR	- .1	.1	.1	-.075	- .1	.1	- .1	- .1	- .1	.085	- .1	- .1
Average	.647	.642	.604	.656	.711	.660	.766	.782	.738	.403	.454	.654
Median	.650	.654	.612	.704	.772	.669	.774	.798	.746	.400	.455	.668
Min	.345	.116	.185	.042	.045	.318	.472	.316	.421	.118	.174	.164
Max	.875	.952	.955	.990	.995	.912	.914	.951	.920	.706	.696	.924
SD	.086	.147	.129	.219	.219	.112	.070	.094	.082	.114	.085	.118
p value	.601	.555	.559	.483	.544	.535	.604	.632	.650	.506	.550	.636

P= the physical domain
M= mental domain
S= the social domain
Ini_CR= change rate for the stable individual parameters
SD= standard deviation
Average = the average outcome of 1000 simulations.
Minimum = the lowest outcome of the 1000 simulations.
maximum = the highest outcome of the 1000 simulations.
p value = chance that the empirical outcomes and the simulated outcomes stem from the same distribution of data

In general, no differences were found in any of the comparisons among domains and all clusters. The final data produced by the model resemble the empirical ones. The selected range for the change rate of the stable individual parameters resulted in a good fit of the model with empirical data. In fact, no differences were detected in each pairwise comparison, both for the lower (- .1) and for the higher (.1) bound of the range. The values for the change rates were estimated, since it was not possible to assess this parameter. The values that created distributions that are closest to the empirical ones were chosen.

The average p value level in the model is .57 (P= .55; M= .57; S= .59). This outcome shows that the distribution of the final measurement simulated data is in about 50% of the simulations higher than the average of the empirical data, and in about 50% lower than the empirical data.

The similarity between measured and simulated data is visible also in their median values, presented in Table 6. These median values are highly comparable.

The high similarity between empirical and simulated data is a first result for the validation procedure, giving important information about the representativeness of the model.

The second step in the validation analysis was the comparison between simulated and empirical distributions with the same sample size. The results of the Wilcoxon test are shown in Table 6.

The absence of significant differences between the empirical and the simulated distributions indicates that the model faithfully reproduces reality. The results reported in Table 6 show that the p value in each cluster and in each domain never achieves the level of significance set at .05 (min= .214; max= .923).

The simulated median values have an average dispersion rates of 3.68% (min= .13%; max= 12.69%) compared to the empirical ones. This information suggests that the simulated data are comparable with the real data.

Table 6 - Wilcoxon test for dependent samples, empirical VS simulated final data
P= Physical domain

Cluster	Domain	N	Z	p	CI (95%)	Empirical		Simulated	
						Median	SD	Median	SD
1	P	39	-1.744	.080	.074 - .085	.631	.207	.656	.082
	M	39	- .628	.530	.523 - .542	.629	.193	.647	.136
	S	39	- .684	.494	.497 - .506	.592	.139	.666	.119
2	P	27	- .336	.737	.739 - .756	.717	.225	.720	.227
	M	27	- .216	.829	.833 - .847	.748	.166	.786	.231
	S	27	- .505	.614	.611 - .630	.663	.168	.686	.126
3	P	88	- .994	.320	.308 - 326	.754	.162	.749	.071
	M	88	- 1.369	.171	.162 - .176	.764	.151	.767	.095
	S	88	-1.123	.261	.252 - .269	.715	.138	.717	.079
4	P	40	- .739	.460	.456 - .475	.399	.162	.374	.134
	M	40	-1.505	.132	.127 - 140	.445	.159	.467	.072
	S	40	- .672	.502	.498 - .518	.623	.116	.648	.127

M= Mental domain
S= Social domain
SD= standard deviation
Z= zed scores based on the Wilcoxon test
CI= confidence interval

3.2 Cross-comparisons among different domains

Once that the similarities between the model and the real data are tested, it is necessary to understand how the model reacts to differences in stable individual parameters. As stated before, stable individual parameters affect the developmental outcome, and we want to test whether differences in stable individual parameters show the same differences in outcome in the empirical and in the simulated trajectories.

To test the effect of different stable individual parameters, the empirical outcome distribution in each cluster is compared with (i) empirical outcome distributions of the other clusters, (ii) simulated outcome distributions of the other clusters, and (iii) simulated vs empirical outcome distributions. In order to provide an indication of the validity of the model, the empirical and the simulated outcome distributions should show similar differences in the same couples of clusters.

Simulated distributions were selected with a random extraction procedure.

The Kruskal Wallis test reported significant differences in physical domain for empirical ($H(3)=55.792$, $p< .001$), simulated ($H(3)=96.381$, $p< .001$) and empirical vs simulated ($H(3)=71.202$, $p< .001$) data. Similar results were found in mental domain for empirical ($H(3)=62.596$, $p< .001$), simulated ($H(3)=88.170$, $p< .001$) and empirical vs simulated ($H(3)=70.200$, $p< .001$) data. Finally, the results in the social domain were for empirical (H(3)=14.171, p= .003), simulated (H(3)=18.970, p< .001) and empirical vs simulated (H(3)=13.924, p< .001) data.

Since all the Kruskall Wallis tests showed significant results, post-hoc analysis with Mann Witheny U tests were conducted applying a Dunn Sidak correction. The correction resulted in a significance level set at p < .008. Post-hoc results are presented in Table 7.

The outcomes show strong resemblances both for the simulated and for the simulated vs empirical comparison in respect to the empirical results. Just in three cases (M domain cluster 1 vs cluster 2, simulated and empirical vs simulated; S domain cluster 3 vs cluster 4, simulated vs empirical data), we found a difference between empirical and simulated results, due to the fact that comparisons did not reach the p level of the Dunn-Sidak's correction. In all the other cases, similarities were found among the three conditions. The results highlight the ability of the model to discriminates among equal and different clusters distributions. Even so, in most of the cases the model discriminate between different and equal distributions, and these findings are sufficiently accurate for the first validation procedure.

Table 7 - Mann – Withney U pairwise comparisons of simulated and empirical final data with Dunn-Sidak corrections

					Empirical (I –J)		**Simulated (I – J)**		**Sim (I) vs Emp (J)**	
Domain	Cluster (I)	Cluster (J)	N (I)	N (J)	Z	p	Z	p	Z	p
P	1	2	39	27	-1.076	.282	- .789	.430	-1.376	.169
	1	3	39	88	-3.606	.000*	-6.058	.000*	-4.422	.000*
	1	4	39	40	-3.555	.000*	-6.658	.000*	-4.158	.000*
	2	3	27	88	-1.759	.079	-1.149	.136	-1.650	.099
	2	4	27	40	-3.733	.000*	-4.538	.000*	-4.167	.000*
	3	4	88	40	-7.279	.000*	-8.739	.000*	-7.860	.000*
M	1	2	39	27	-2.719	.007*	-2.119	.034	-2.367	.018
	1	3	39	88	-3.559	.000*	-5.545	.000*	-5.138	.000*
	1	4	39	40	-3.942	.000*	-5.354	.000*	-3.716	.000*
	2	3	27	88	- .148	.882	- .046	.963	- .831	.406
	2	4	27	40	-5.369	.000*	-4.385	.000*	-5.458	.000*
	3	4	88	40	-7.323	.000*	-8.811	.000*	-7.516	.000*
S	1	2	39	27	-1.369	.163	- .776	.438	-1.337	.181
	1	3	39	88	-2.993	.003*	-5.533	.000*	-4.429	.000*
	1	4	39	40	- .098	.922	- .157	.875	- .726	.468
	2	3	27	88	- .670	.503	-1.759	.073	-1.537	.124
	2	4	27	40	-1.470	.141	- .793	.428	- .971	.331
	3	4	88	40	-3.120	.002*	-3.578	.000*	-2.416	.018

P= Physical domain
M= Mental domain
S= Social domain
Z= zeta score based on the Mann Withney U test
** significant after Dunn-Sidak correction*

4. Discussion

This work focused on the construction of a mathematical dynamic systems model of HRQOL. The goal of this dynamic systems model is to represent the theoretical mechanisms of the change of HRQOL over time, and not to represent a data set. That means that the dynamic system model is a mathematical formalization of the conceptual developmental model.

We followed a three-step procedure to develop and validate the model: (i) first the conceptual Dynamic Systems model was translated in a mathematical tool, replacing arrows with equations; (ii) secondly, the new mathematical model was tested with a hybrid procedure (called calibration), in order to verify if its simulated trends were theoretically plausible; and (iii) finally, the model was subjected an initial empirical validation test based on the simplest possible empirical validity case, namely by connecting an initial measurement with a final measurement, separated by a duration that is long enough to correspond with considerable change.

Results reported in this paper are positive and encouraging with regard to the validity of the model. The model was found to produce theoretically acceptable developmental trends. Furthermore, the three-step validation procedure returned positive results: the generated trajectories behaved according to our theoretical expectations.

The results obtained in the analyses give fundamental information at two different levels. The first level is purely theoretical. In fact, the adherence between real and simulated data is a first confirmation of the theoretical model underlying the mathematical model, and thus, that it makes sense to consider HRQOL in the ageing population as a dynamic system. This confirmation may represent a milestone in the study of ageing development, making room for a clearer idea about structures, ways and mechanisms of development of the construct under study. In particular, our results seem to confirm our theoretical assumptions that: (i) the domains included in the conceptual model are connected and are influencing each other; (ii) the developmental process is non-linear; (iii) the measures are dependent in time; (iv) random influences are relevant aspects of the dynamics. Furthermore, the development of the mathematical tool gives a quantitative translation to the theoretical assumptions, providing more information that is useful for further theoretical enhancement. The second level is more related to practical applications. The mathematical Dynamic Systems model was written and developed not just to bring confirmation to the theoretical assumptions, but also because it may be a useful tool in applied researches. In particular, the model may serve to simulate developmental trajectories for a wide number of situations (e.g. the application of an intervention, the effects of a fall). Furthermore, it can be used to compare longitudinal data with the simulated ones, analyzing differences and similarities. Finally, the mathematical Dynamic Systems model can be used as a screening tool, identifying persons with at risk conditions, intended here as a set of initial and parameter values that produce highly instable or decreasing trends most of the time (given a large number of simulations).

The combination of these two levels may make the mathematical Dynamic Systems model suitable for both research and indirectly, also for clinical practice, in particular among older people. However, before we define the model as completely validated and ready for a wider use, other steps must to be completed.

The future steps that need to be addressed are, at least: (i) a sensitivity analysis of the model, to check whether small changes in the individual parameters cause major changes in the outcomes, using more and more closely spaced initial data, and (ii) the development of a longitudinal study with time-serial data, in order to investigate the comparability between simulated and real trends more thoroughly.

Finally, it is necessary to discuss the limitations of the study. The first limitation is related to the fact that only 2 waves of assessment (initial and final) have been used in the comparison between the data and the simulations. The focus on the association between baseline and final data is just the first step towards the final validation of the model. However, two assessment points were sufficient for the first validation procedure, the aim of which was to show that given a particular set of initial states, the model can predict a set of "final" states, i.e. states after a duration long enough to create sufficient change in the variables of interest. It goes without saying that, in the future, a longitudinal study with a considerably greater number of assessments is necessary. A second limit regards the experimental allocation of subjects. It was necessary to split the group by means of cluster analysis, which allowed us to adopt a more person-oriented approach, recommended for Dynamic Systems studies (Kunnen, 2012). A further limitation refers to the empirical initial data that, in general, represent groups of people in good health conditions. In addition, in this case, in order to test the model with more robust procedures it will be necessary to simulate and to compare individual trajectories from different persons with different baseline health conditions.

As a conclusion, the resulting model presented here has stood the first tests of conceptual and empirical validation. It may be of considerable interest to the field, giving new theoretical and practical insights in the study of HRQOL and its development in time in the ageing population. However, the study has several limitations and the model needs to be tested with other procedures before it will be completely usable in research and clinical practice.

5. References

Aaronson, N. (1993). Quality of life assessment: Key issues in the 1990s. *Quality of Life Research*, *2*(4), 305–306. doi:10.1007/BF00434802

Allegri, R. F., Butman, J., Arizaga, R. L., Machnicki, G., Serrano, C., Taragano, F. E., Lon, L. (2007). Economic impact of dementia in developing countries: an evaluation of costs of Alzheimer-type dementia in Argentina. *International psychogeriatrics / IPA*, *19*(4), 705–718. doi:10.1017/S1041610206003784

Berzon, R., Hays, R. D., & Shumaker, S. A. (1993). International use, application and performance of health-related quality of life instruments. *Quality of Life Research*, *2*(6), 367–368. doi:10.1007/BF00422214

Buchner, D., & Wagner, E. (1992). Preventing frail health. *Clinics in geriatric medicine*, *8*(1), 1–17.

Chen, J. J. (2010). Parkinson's disease: health-related quality of life, economic cost, and implications of early treatment. *The American journal of managed care*, *16 Suppl Implications*, S87–93.

Dominick, K., Ahern, F., Gold, C., & Heller, D. (2002). Relationship of health-related quality of life to health care utilization and mortality among older adults. *Aging clinical and experimental research*, *14*(6), 499–508.

Engel, G. L. (1977). The need for a new medical model: a challenge for biomedicine. *Science*, *196*, 129–36.

Eurostat. (2012). *Active ageing and solidarity between generations. A statistical portrait of the European Union 2012* (Vol. 1). Luxembourg: Office for Official Publ. of the European Communities.

Ferrans, C. E., Zerwic, J. J., Wilbur, J. E., & Larson, J. L. (2005). Conceptual Model of Health-Related Quality of Life. *Journal of Nursing Scholarship*, *37*(4), 336–342. doi:10.1111/j.1547-5069.2005.00058.x

Fried, L. P., Tangen, C. M., Walston, J., Newman, A. B., Hirsch, C., Gottdiener, J., McBurnie, M. A. (2001). Frailty in Older Adults Evidence for a Phenotype. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *56*(3), M146–M157. doi:10.1093/gerona/56.3.M146

Gaugler, J. E., Duval, S., Anderson, K. A., & Kane, R. L. (2007). Predicting nursing home admission in the U.S: a meta-analysis. *BMC Geriatrics*, *7*(1), 13. doi:10.1186/1471-2318-7-13

Giannakouris, K. (2008). Population and social conditions. Ageing characteristics the demographic perspectives of the European societies. Eurostat, Statistic in focus.

Grammenos, S. (2005). Implications of demographic ageing in the enlarged EU in the domains of quality of life, health promotion and health care Various studies on policy implications of demographic changes in national and Community policies. Center for European Social and Economic Policy.

Greenhalgh, J., Long, A. F., & Flynn, R. (2005). The use of patient reported outcome measures in routine clinical practice: lack of impact or lack of theory? *Social science & medicine (1982)*, *60*(4), 833–843. doi:10.1016/j.socscimed.2004.06.022

Haas, B. K. (1999). Clarification and Integration of Similar Quality of Life Concepts. *Image: the Journal of Nursing Scholarship*, *31*(3), 215–220. doi:10.1111/j.1547-5069.1999.tb00483.x

Hagell, P., Nordling, S., Reimer, J., Grabowski, M., & Persson, U. (2002). Resource use and costs in a Swedish cohort of patients with Parkinson's disease. *Movement Disorders*, *17*(6), 1213–1220. doi:10.1002/mds.10262

Hawthorne, G. (2006). Measuring Social Isolation in Older Adults: Development and Initial Validation of the Friendship Scale. *Social Indicators Research*, *77*(3), 521–548. doi:10.1007/s11205-005-7746-y

Hawthorne, G., & Griffith, P. (2000). *The Friendship Scale: Development and properties* (working paper).

Hörder, H., Skoog, I., & Frändin, K. (2012). Health-related quality of life in relation to walking habits and fitness: a population-based study of 75-year-olds. *Quality of Life Research*, *22*(6), 1213–1223. doi:10.1007/s11136-012-0267-7

Kelley-Gillespie, N. (2009). An integrated conceptual model of quality of life for older adults based on a synthesis of the literature. *Applied Research in Quality of life*, *4*(3), 259-282. doi: 10.1007/s11482-009-9075-9Kiel, L. D., & Elliott, E. W. (1996). *Chaos Theory in the Social Sciences: Foundations and Applications*. University of Michigan Press.

Kunnen, S. E. (2012). *A Dynamic Systems Approach of Adolescent Development*. Psychology Press.

Kunnen, S. E., & Bosma, H. A. (2000). Development of meaning making: A dynamic systems approach. *New Ideas in Psychology*, *18*(1), 57–82. doi:10.1016/S0732-118X(99)00037-9

Lajas, C., Abasolo, L., Bellajdel, B., Hernández-García, C., Carmona, L., Vargas, E., Jover, J. A. (2003). Costs and predictors of costs in rheumatoid arthritis: a prevalence-based study. *Arthritis and rheumatism*, *49*(1), 64–70. doi:10.1002/art.10905

Lubben, J., Blozik, E., Gillmann, G., Iliffe, S., von Renteln Kruse, W., Beck, J. C., & Stuck, A. E. (2006). Performance of an Abbreviated Version of the Lubben Social Network Scale Among Three European Community-Dwelling Older Adult Populations. *The Gerontologist*, *46*(4), 503–513. doi:10.1093/geront/46.4.503

Lubben, J. E. (1988). Assessing social networks among elderly populations. *Family & Community Health: The Journal of Health Promotion & Maintenance*, *11*(3), 42–52.

Luppa, M., Luck, T., Weyerer, S., Konig, H.-H., Brahler, E., & Riedel-Heller, S. G. (2009). Prediction of institutionalization in the elderly. A systematic review. *Age and Ageing*, *39*(1), 31–38. doi:10.1093/ageing/afp202

Marengoni, A., Winblad, B., Karp, A., & Fratiglioni, L. (2008). Prevalence of Chronic Diseases and Multimorbidity Among the Elderly Population in Sweden. *American Journal of Public Health*, *98*(7), 1198–1200. doi:10.2105/AJPH.2007.121137

Mebane-Sims, I. (2009). 2009 Alzheimer's disease facts and figures. *Alzheimer's & Dementia*, *5*(3), 234–270. doi:10.1016/j.jalz.2009.03.001

Meng, H., King-Kallimanis, B. L., Gum, A., & Wamsley, B. (2013). Measurement bias of the SF-36 Health Survey in older adults with chronic conditions. *Quality of Life Research*. doi:10.1007/s11136-013-0373-1

Nunnally, J. C. (1978). *Psychometric theory* (2d ed.). New York: McGraw-Hill.

Rockwood, P. K., Hogan, D. B., & MacKnight, C. (2000). Conceptualisation and Measurement of Frailty in Elderly People. *Drugs & Aging*, *17*(4), 295–302. doi:10.2165/00002512-200017040-00005

Spilker, B. (Ed.). (1996). Quality of Life and Pharmacoeconomics in Clinical Trials (2nd ed.). Lippincott-Raven, Philadelphia. ISBN 0-7817-0332-8

Stadnyk, K., Calder, J., & Rockwood, K. (1998). Testing the Measurement Properties of the Short Form-36 Health Survey in a Frail Elderly Population. *Journal of Clinical Epidemiology*, *51*(10), 827–835. doi:10.1016/S0895-4356(98)00061-4

Steenbeek, H., & van Geert, P. (2005). A dynamic systems model of dyadic interaction during play of two children. *European Journal of Developmental Psychology*, *2*(2), 105–145. doi:10.1080/17405620544000020

Steenbeek, H., & Van Geert, P. (2008). An empirical validation of a dynamic systems model of interaction: do children of different sociometric statuses differ in their dyadic play? *Developmental Science*, *11*(2), 253–281. doi:10.1111/j.1467-7687.2007.00655.x

Taillefer, M.-C., Dupuis, G., Roberge, M.-A., & LeMay, S. (2003). Health-Related Quality of Life Models: Systematic Review of the Literature. *Social Indicators Research*, *64*(2), 293–323. doi:10.1023/A:1024740307643

Testa, M. A., & Simonson, D. C. (1996). Assessment of Quality-of-Life Outcomes. *New England Journal of Medicine*, *334*(13), 835–840. doi:10.1056/NEJM199603283341306

Theofilou, P. (2011). Why is it Important to Assess Health - Related Quality of Life? *Journal of Palliative Care & Medicine*, *1*(e104), 104. doi:10.4172/2165-7386.1000e104

Tsai, S.-Y., Chi, L.-Y., Lee, C., & Chou, P. (2007). Health-related quality of life as a predictor of mortality among community-dwelling older persons. *European Journal of Epidemiology*, *22*(1), 19–26. doi:10.1007/s10654-006-9092-z

Van Geert, P. (1991). A dynamic systems model of cognitive and language growth. *Psychological Review*, *98*(1), 3–53. doi:10.1037/0033-295X.98.1.3

Van Geert, P. (1993). A dynamic systems model of cognitive growth: Competition and support under limited resource conditions. In L. B. Smith & E. Thelen (Eds.), *A dynamic systems approach to development: Applications* (pp. 265–331). Cambridge, MA, US: The MIT Press.

Van Geert, P. (1994). *Dynamic systems of development: change between complexity and chaos*. New York: Harvester Wheatsheaf.

Vleioras, G., & Bosma, H. A. (2005). Predicting change in relational identity commitments: Exploration and emotions. *Identity*, *5*(1), 35-56.

Walters, S. J. (2001). Using the SF-36 with older adults: a cross-sectional community-based survey. *Age and Ageing*, *30*(4), 337–343. doi:10.1093/ageing/30.4.337

Ware, J., E., & Dewey, J. (2000). Health status and outcome assessment tools. *Int Electronic J Health Education*, *3*(3), 138–148.

Ware, J. E., & Sherbourne, C. D. (1992). The MOS 36-ltem Short-Form Health Survey (SF-36): I. Conceptual Framework and Item Selection. *Medical Care*, *30*(6), 473–483. doi:10.1097/00005650-199206000-00002

Wilson, L., Brown, J. S., Shin, G. P., Luc, K. O., & Subak, L. L. (2001). Annual direct cost of urinary incontinence. *Obstetrics and gynecology*, *98*(3), 398–406.

Yang, C., Selassie, A. W., Carter, R. E., & Tilley, B. C. (2011). Measuring QoL with SF-36 in Older Americans with TBI. *Applied Research in Quality of Life*, *7*(1), 63–81. doi:10.1007/s11482-011-9148-4

CHAPTER 4

"HOW I FEEL TODAY?" AN ANALYSIS OF HRQOL VARIABILITY AMONG INSTITUTIONALIZED OLDER ADULTS

Mattia Roppolo[1-2], Saskia Kunnen[2], Anna Mulasso[1], Emanuela Rabaglietti[1], Paul van Geert[2]

1. Department of Psychology, University of Torino (IT)
2. Department of Developmental Psychology, Rijksuniversiteit of Groningen (NL)

Submitted to: Non-linear Dynamics, Psychology, and Life Science

Abstract

Intra-individual variability is a central topic in Dynamic Systems studies, because the theory predicts that particular forms or properties of intra-individual variability will serve as indicators or predictors of transitions phases, bifurcations, and stable states in individual development. Currently, there are almost no studies that address intra-individual changes and variability of Health Related Quality of Life in old age. The main aim of this paper is to analyze the role of day-to-day HRQOL variability and long term HRQOL and ADL development in a sample of institutionalized older adults. 22 older adults took part in this longitudinal study. Daily diary-based assessments were made for a period of 100 days. Furthermore, monthly assessments of HRQOL and ADL with validated questionnaires were performed. The intra individual variability on a day-to-day basis was found to be related to HRQOL and ADL development. Furthermore, life events as operationalized by HRQOL extreme values were related to the level of day-to-day HRQOL variability. As predicted by dynamic systems theory, day-to-day variability emerges as an important indicator of levels of and changes in HRQOL and ADL and as such, it may be an important indicator of the age-related developmental process.

Keywords: Intra-individual variability; Dynamic Systems; institutionalized older adults; Health Related Quality of Life

1. Introduction

To live longer, better and in a good health condition is one of the main challenges of contemporary society. The objective of the European Commission is to add two Healthy Life Years by 2020, and to promote health status and quality of life in the European population. A comparable objective has been formulated by the Department of Health and Social Services of the US (Healthy People 2020 program).

Despite the great effort invested by policy makers to increase health status and quality of life, current data show that these aims are not reached yet. In Europe, the indicator called Healthy Life Years (HLY), which is defined as the healthy life expectancy at a given age, followed a negative trend between 2004 and 2010 (Eurostat, 2012), meaning that the number of years lived in a poor health condition has increased. Furthermore, Zack et al. (2004) found a decrease in both health status and Health Related Quality of Life (HRQOL) in the US population between 1993 and 2001, confirming that the objectives proposed by Healthy People were not yet being met.

Over the years, the construct of HRQOL took an important role in the assessments of populations and individuals. HRQOL is a person-centered measure, and provides more precise information about the health status, and health perceptions, than the traditional indicators of morbidity and mortality (Idler & Benyamini, 1997; Jones, 1977). In this article, HRQOL is conceptualized as a tri-dimensional construct (physical, mental, social). Each dimension is in turn characterized by a self-report health status and an experienced-health aspect (Testa & Simonson, 1996; WHO, 1948). HRQOL is mostly used in research and clinical practice to rate the effects of processes (i.e., treatment, intervention, disease) on people's health status and their perceptions of it (see among others: Balboa-Castillo, León-Muñoz, Graciani, Rodríguez-Artalejo, & Guallar-Castillón, 2011; Hopman et al., 2009; Lima et al., 2009; Sillanpää, Häkkinen, Holviala, & Häkkinen, 2012; Wolinsky et al., 2006).

In addition to its role as an outcome-measure, HRQOL is a good predictor of mortality and health care utilization in the aged population. Tsai and colleagues (2007) found that the baseline scores of HRQOL (physical and mental composite scores) predict three-year mortality among a large sample of community-dwelling older adults. Singh and colleagues (2005) described the relations among the physical and mental components of HRQOL, and hospitalization, mortality, hospitalizations per year and outpatient-visits per year, in older adults with arthritis. They found significantly higher odds for each health-outcome indicator in subjects with a low score (lower tertile) on the two components. Furthermore, the study of Dominick and colleagues (2002) indicated that the dimensions of HRQOL play a role as predictors for both short-term and long-term adverse health events among older adults. Finally, in a review study, Idler and Benyamini (1997) compared results from twenty-seven community studies, confirming the predictive relations between HRQOL and mortality. In addition, they highlighted the dynamic nature of HRQOL, emphasizing the need to analyze trajectories of self-rated health instead of exclusively focusing on the current level.

Currently, only few scholars have actually studied the change (intended as long-term average trajectories) in HRQOL and its consequences. However, it is promising that the existing literature shows strong associations between changes in mental and physical components of HRQOL and mortality (Kroenke, Kubzansky, Adler, & Kawachi, 2008; Otero-Rodríguez et al., 2010). In addition, a French study (Audureau, Rican, & Coste, 2013) found that the decrease of HRQOL is related with disparities in demographic and socio-economic aspects among older adults, between 2005 and 2013.

The important insight into the impact of changes in HRQOL in terms of clinical outcomes emerged from research as well as from clinical practice. Various statistical tests were carried out to find out whether changes of HRQOL have clinical relevance (Crosby, Kolotkin, & Williams, 2003). These tests aimed to understand if a process (e.g., disease or intervention) with an impact on HRQOL may be clinically meaningful, causing change in a patient's clinical management (Crosby et al., 2003). However, these methods are designed on a group- and average-base, and do not incorporate: (i) the analysis of changes over time, (ii) the developmental process, and (iii) the relations between short- and long-term time scales.

Changes in HRQOL may have theoretical as well as applied impacts. From a conceptual point of view, knowledge about health trends in the ageing process (specifically if they are assessed and analyzed on an individual basis), may be crucial to obtain a better understanding about development in later life, in order to increase healthy life expectancy. From an applied perspective, the discovery of patterns of changes may have a strong impact on preventive strategies, ensuring better health conditions on an individual basis and a decrease of health related costs on a societal basis.

However, despite the long list of possible interesting applied solutions and the numbers of papers emphasizing the complex and dynamic nature of HRQOL (Adamson & Elliott, 2005; Haas, 1999; Hickey, Barker, McGee, & O'Boyle, 2005; Zubritsky et al., 2013), currently it is not clear: (i) how HRQOL evolves during the ageing process; (ii) which are the characteristics of the developmental trends; (iii) how patterns of changes are related to health outcomes, and (iv) how individual characteristics (e.g., age, presence of disease, frailty status, lifestyle habits etc.) are related to intra- and inter-individual variability in developmental trajectories. We know how HRQOL generally behaves, on a long-term time scale, before and after particular kinds of events (e.g., life events, interventions), but we do not know how the long-term trends emerge from a shorter time-scale (i.e., daily iterations). Like a spectator who slept through the greatest part of a movie, we know the starting and the ending point of the movie, we can hypothesize how the story proceeded during the central part, but we do not know anything about twists, development of the story, unexpected events, relations among protagonists etc. In order to obtain a complete picture of the storyline, it is important to carefully watch the whole process, which, in this particular case, pertains to the actual developmental trajectories of HRQOL, with the identification of indicators of variability in the system.

The study and analysis of HRQOL development can be done by using a Dynamic Systems approach. Such an approach is focused on processes of change and developmental patterns during time (Kunnen, 2012; Thelen, Ulrich, & Wolff, 1991). The process of change that represents the main objective of Dynamic Systems studies, is complex and multivariate, and depends on continuous and mutual interactions among environmental, individual and inter-individual characteristics during time (Kunnen, 2012). Development is a recursive process in which time represents the first engine and in which the outcome of one-step in the process is the starting point of the subsequent one (also called iteration). The emphasis of Dynamic Systems is on variability and stability as they occur in individual subjects, and which are seen as fundamental characteristics for the understanding of a system's development (Thelen, 1996; Thelen et al., 1991; van Geert & van Dijk, 2002).

Variability was defined by van Geert & van Dijk (2002) as differences in the individual level of behaviors on successive time points. Variability is not just the average level of fluctuations during a given period of time, but it is a property that changes and follows a particular trajectory over time. According to dynamic systems theorists, the variability provides important information about the developmental process (Kunnen, 2012; van der Maas & Molenaar, 1992; van Dijk & van Geert, 2007; van Geert & van Dijk, 2002). They reject the hypothesis of the true score and added random error, which views variability as experimental noise, distributed around a true and stable score (Kunnen, 2012; van Geert & van Dijk, 2002). Measures of variability are informative about and provide possible explanations for eventual transition phases, bifurcations, and stable states (van Dijk & van Geert, 2007; van Geert & van Dijk, 2002).

Focus on shifts, sudden jumps, perturbations and discontinuity are of special interest in Dynamic Systems studies, because they are indicators of self-organization of a system from a lower to a higher level of organization (Savelsbergh, van der Maas, & van Geert, 1999; van Dijk & van Geert, 2007). In particular, discontinuity points are described as jumps from one level to another without any intermediate point (Van der Maas & Molenaar 1992; van Dijk & van Geert, 2007).

Indicators of variability are increasingly used in various areas of research. For example, Piek (2002) investigated the role of variability in early motor development, finding that low level of variability in the first phases of motor development may result in poor movement outcome. Furthermore, indicators of variability were used to assess developmental trends in language acquisition (Bassano & van Geert, 2007; van Dijk & van Geert, 2007; Verspoor, Lowie, & Van Dijk, 2008); or were used to analyze trends in cognitive development (Siegler, 1994; Siegler, 2007).

Currently, no studies report indicators of variability in time serial analyses of HRQOL in the aged population. In order to fill this gap we designed a study, with the aim to capture HRQOL indicators of variability in institutionalized older adults. Variability is considered relevant as a characteristic that differentiates between people, but when studied over time within one individual, it also gives relevant information about individual processes. In particular, we are interested to understand what happens in the case of perturbations in the daily life of the older-adults. For this reason, the focus is on the extreme values of the HRQOL scores, as possible indicators of such perturbations. Extreme values give information about instability and perturbations of a system, relevant characteristics in Dynamic Systems studies. The focus was on institutionalized older adults because: (i) they generally suffer of higher decrease in HRQOL compared to community dwelling older adults (Noro & Aro, 1996); (ii) they are generally more frail (Rockwood et al., 2004), meaning that they may have reduced ability to cope with stressful life events (Fried, et al., 2001); (iii) they live in a controlled environment, giving us the possibility to better understand external and random influences; (iv) they are generally worried about their health (Wisocki, 1988), and (v) the use of a process based assessment can make them more aware about their health.

The purpose was to assess indicators of HRQOL on different time levels. It was decided that a day-to-day measurement can give us salient information on a short time scale. It was assumed that a daily scale is a sort of mean value of the uncountable actions and influences occurring each day. It was supposed that one day can be seen as a kind of unit for the analysis of long-term trajectories, revealing temporal trends as well as variability. Furthermore, a day can be seen on an experiential level, in which each day is an organic whole, with a new start or beginning every new day. In such a vision, a daily time level can be seen as a useful unit of experience.

An assessment of characteristics on a daily basis is uncommon and rarely used among older adults. However, few studies did actually report day-to-day data about physiological (cortisol level, hearth rate) and psychosocial (social interactions, worries) indicators in such a population (Adam, Kudielka, & Cacioppo, 2006; Brosschot, Van Dijk, & Thayer, 2007; Nezlek, Richardson, Green, & Schatten-Jones, 2002). Unfortunately, no studies reported a day-to-day analysis of HRQOL among older adults.

However, in other fields of research, the use of diary-based daily measurements is well documented (among others: Curran, Beacham, & Andrykowski, 2004; Bratteby, Sandhagen, Fan, & Samuelson, 1997; Kunnen, 2012; Lichtwarck-Aschoff, Kunnen, & van Geert, 2009; Peters et al., 2000).

The main objective of this study is to demonstrate that variability at a time scale of days is meaningfully related to perturbations (extreme values) and developmental health outcomes in a sample of institutionalized older adults. In order to reach the main objective the following research questions have been addressed: (i) is day-to-day variability related to developmental health outcomes (HRQOL and ADL) and trends? (ii) Do the day-to-day HRQOL trajectories proceed with a linear/gradual/smooth or jagged path? (iii) How do individuals differ with regard to the distribution of extreme values over time and domains? (iv) Is day-to-day variability around life events (as defined by an extreme value) higher than the average variability in the whole period of investigation?

2. Method

2.1 Participants

The study involved twenty-eight institutionalized older adults, living in four residential care facilities in Italy. The following inclusion criteria have been set: (i) living in residential care facilities permanently, at least for six months; (ii) older than 70 years; (iii) Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975) score higher than 25 (indicating absence of cognitive impairments); (iv) absence of severe functional impairment in the Autonomy of Daily Living (Katz ADL score ≥ 2; Wallace & Shelkey, 2007). The simultaneous participation in another study was also set as exclusion criterion.

From the original sample (n= 28), 6 participants dropped-out, for reasons not related to study participation: illness, hospitalization, and transfer to other residential care facilities. All the analyses were performed using data from the 22 subjects (n=15 female, 68%) who completed the whole research period (100 days).

The participation was voluntary, and the residential care facilities were selected for their availability to participate in the study and their comparable levels of health care and proposed activities.

The Ethical Committee of the University of Torino approved the study. All participants were informed about the voluntary and confidential participation to the study. Each individual gave his or her written informed consent in accordance with Italian law and the ethical code of the American Psychological Association (2002).

Descriptive characteristics of the participants are presented in Table 1.

Table 1 - Baseline characteristics of participants

VARIABLE	N	Valid %
Gender (N)		
Women	15	68
Men	7	32
Level of education (N)		
Low	10	46
High	12	54
Work position (N)		
Retired	20	91
Not retired	2	9
Past job (N)		
Manual labor	7	37
Nonmanual labor	10	52
Unemployed	2	11
Presence of diseases (N)		
Maximum one disease	5	23
More than one disease	17	77
VARIABLE	**Mean**	**Standard Deviation**
Age	84	6
Mini-Mental State Examination	28	2

2.2 Research protocol

A day-to-day assessment was performed during the whole project period, which lasted 100 days. The daily evaluation consisted of self-report questions. All the participants were instructed to individually complete the questions in the evening (generally after dinner), to rate the overall daily health status and health perceptions. In order to have the highest possible adherence to the research design, both researchers and staff members reminded the participants daily to complete the questionnaire. As a result, the total number of missing answers was 33 on a sample of 4,400 data. Missing data were excluded from the analyses.

In addition to the daily measurements, five waves of more extensive assessment were made. Validated self-report questionnaires were used and a trained psychologist was always present during the assessments, to give support in case of doubts or difficulties in the completion of the questionnaires (e.g. difficulty to read questions or to understand their meaning).

Since all participants received similar health and physical activity treatments, the sample was not divided into subgroups.

2.3 Measures

The measures collected can be divided in three categories (baseline, monthly, and daily).

2.3.1 Baseline measures

During baseline measures, preceding the period of daily measurements, various socio-demographic characteristics and health related information were collected (i.e., age, gender, place of birth, marital status, level of education, and presence, type and number of diseases).

Finally, the Italian version of the questionnaire Survey of Health, Ageing and Retirement in Europe - Frailty Instrument was administered (SHARE-FI; Romero-Ortuno, O'Shea, & Kenny, 2011; Romero-Ortuno, Walsh, Lawlor, & Kenny, 2010). SHARE-FI is a valid, reliable and free tool assessing functional decline and physical frailty among older adults (Romero-Ortuno et al., 2011). SHARE-FI consists of five indicators: exhaustion, weight loss, weakness, slowness, level of activity (Romero-Ortuno et al., 2010), and provides a continuous score (highest score corresponds to the frailest subject) with an associated categorical label (non-frail; pre-frail, frail).

2.3.2 Monthly measures

Monthly measures were collected through validated self-report questionnaires.

The Short Form 12 Health Survey (SF-12; Gandek et al., 1998; Jones, 1977), the Lubben Social Network Scale-6 (LSNS-6; Lubben, 1988) and the Friendship Quality Scale (FQS; Hawthorne, 2006) were used to assess the three components of HRQOL. Specifically, physical domain was rated with the SF-12 physical health summary measure (PCS), mental domain with the SF-12 mental health summary measure (MCS), social domain with the LSNS-6, that investigates the self-report health status dimension of social status (namely size of the social network) and the FQS, that, on the contrary, focuses on the quality of social relations.

The SF-12 represents the short version of the SF-36, and it is one of the most frequently used instruments to assess health status and HRQOL in the aged population (see for instance Everard, Lach, Fisher, & Baum, 2000; Li et al., 2004; Ozcan, Donat, Gelecek, Ozdirenc, & Karadibak, 2005; Resnick & Nahm, 2001). It is a generic measure (not specifically designed for a target population). The SF-12 is composed of two dimensions, the physical health composite measure (PCS) and the mental health composite measure (MCS), each covered by 6 items. A higher level in the summary score reflects a better health condition. The use of the SF-12 in the aged population is well documented in previous researches (among others: Everard, Lach, Fisher, & Baum, 2000; Li et al., 2004; Ozcan, Donat, Gelecek, Ozdirenc, & Karadibak, 2005; Resnick & Nahm, 2001).

The LSNS-6 is a six items scale widely used to assess social networks in aged persons (Lubben, 1988). The LSNS-6 is composed of two subscales, each consisting of three items. The first scale is related to the family social network, while the second one assesses the social network of friends (Lubben et al., 2006). The items are all scored from 1 to 6, in which the highest value represents the maximum level of social network. The LSNS-6 is specifically designed for older adults and is useful for measuring their social isolation.

Finally, the FQS is an instrument specifically designed for aged populations that measures social isolation (Hawthorne, 2006; Hawthorne & Griffith, 2000). FQS is a one-dimensional scale composed of six items, covering aspects related to perceptions of isolation and difficulties with making contact with other people. The scores of the six items range between 0 (worst social relations) to 4 (best social relations).

The latter two questionnaires were chosen to assess the social domain for the following reasons: (i) the social domain is a crucial component of HRQOL, especially in an older population; (ii) the two scales capture complementary aspects of the social domain. In particular, the LSNS-6 questions are more objectively oriented, asking for instance about the number of persons encountered during the last month. The FQS captures more subjective perceptions about social life.

The monthly measures were assessed in the baseline (one day before the beginning of the study), and after 28, 56, 84 days from the beginning and on day 100, the last day of the study.

2.3.3 Daily measures

For this study, we created a structured diary composed of six visual analogic scale (VAS) questions. This diary instrument should meet three requirements.

Firstly, it should be an easy instrument, in order to give each participant the possibility to fill it out every day, spending just few minutes and limited effort. This condition was mandatory in order to obtain the least possible rate of dropout due to boredom or difficulty in the daily compilation of the diary. Previous studies have demonstrated the ability of very short instruments to capture HRQOL (Boer et al., 2004; Bowling, 2005; DeSalvo et al., 2006; Sloan et al., 1998).

Secondly, the six questions had to represent the conceptual model of HRQOL, composed of three domains, divided into a self-report health status and experienced-health component.

Finally, we decided to use a VAS scale because this method allows to quantitatively measure a construct on a continuous scale, which is very suitable for the aim of this study. Various scholars have reported on the appropriateness of a VAS scale to measure HRQOL (Boer et al., 2004; Hiratsuka & Kida, 1993; Katsura, Yamada, & Kida, 2003; Nishiyama et al., 2000).

In sum, the instrument was composed of six questions (two for each domain) scored with a 20 cm VAS. The self-report health status questions asked about the time spent during the day in specific conditions, while the experienced-health questions relate to perceptions and feelings. In the physical domains, we used the following questions: (i) How long, during the day, have you performed activities requiring some physical effort? (e.g., housework, walking, hobbies, etc.), (ii) How would you rate your physical health today? In the mental domain, the questions were: (i) How long, during the day, did you feel in a good mood? (e.g., calm, peaceful, lively, happy, etc.), (ii) How would you rate your psychological/mental health today? Finally, in the social domain the following questions were included: (i) How long, during the day, have you performed social activities? (e.g., meetings with relatives and friends, phone calls, card games etc), (ii) How satisfied are you about the social activities performed today?

The VAS scales range from "never" (0) to "whole day" (100) for the self-report health status questions, while the extreme points in the experienced-health indicators vary from 0 (worst health possible or completely unsatisfied, in the social domain) to 100 (best health possible or completely satisfied, in the social domain; see Appendix for the English version of the instrument).

Data were rescaled (on a continuous scale between 0 and 1) in order to guarantee quantitative and qualitative comparability. The following formula was used to transform data from the validated questionnaires into the same range:

$$y = (x - min)/(max - min) \qquad \text{Equation 1}$$

Where, y is the output of the transformation (a number varying from 0 to 1 on a continuous scale); x is the empirical data; min is the minimum theoretical value of the scale and max is the theoretical maximum value of the measure. This transformation maintains the original distribution characteristics allowing an easy and good comparison between daily and monthly measures.

2.4 Statistical analyses

All the analyses were conducted with Statistical Package for Social Sciences (SPSS), version 20.0 (Spss Inc, Chicago, IL, USA).

First, the reliability (Cronbach's α) of the composite scores measured with validated questionnaires, and descriptive statistics was calculated to sketch the baseline characteristics of participants.

Secondly, an analysis of HRQOL trends, measured with the validated questionnaires (SF-12, LSNS-6, FQS), was made using a non-parametric repeated measures test for dependent samples (Friedman test) and a series of Wilcoxon tests with Bonferroni adjustment. These longitudinal trends will be related to the level of day-to-day variability.

Finally, day-to-day measures of the experienced-health and self-report health status of each domain were analyzed in seven different ways:

(i) Cronbach's α analysis, in order to assess whether the combined self-report health status and experienced-health components of the three domains had a good level of consistency on a daily basis. This would allow for a composite score of the two. The threshold for an acceptable reliability was set at .60 following the guidelines of Nunnally (1978).

(ii) Spearman's correlations between validated questionnaires and daily measures, to explore if daily and validated questionnaires data were related to each other. By means of this analysis, it was tested whether the assumption is correct that with just a few items

HRQOL can be assessed in a valid way. Because of the different time scales investigated by the different instruments (four weeks versus one day), the correlations were made using the raw scores of the validated questionnaires and the four weeks' median values of the daily questions, in order to capture the same time span. The baseline data assessed with validated questionnaires were not taken into account because they refer to the four weeks before the beginning of the study.

(iii) An analysis of day-to-day variability. Variability is operationalized as (the sum of) the absolute difference between two subsequent daily data points in each of the three HRQOL domains.

(iv) Spearman's correlational analysis to test if a general indicator of variability (the mean value of the day-to-day variability) was related to health outcomes and trends (HRQOL and ADL). Specifically, the general amount of variability in daily assessments of HRQOL was compared with long-term trends (from day 1 to day 100) and measurements of HRQOL and ADL at day 100.

(v) Analysis of extreme values in daily trends by means of Autoregressive Integrated Moving Average Model (ARIMA) performed with the Expert Modeler package of SPSS. The ARIMA model was used here just to detect extreme values and not for forecasting. The use of ARIMA models in detection of extreme data is well known and studied (Maimon & Rokach, 2005). The types of extreme values considered here were: (a) additive, and (b) level shifts. The additive extremes affect a single observation, and after the perturbation, the series returns to its normal trend. The level shifts extremes imply a change in the mean of the process after a point, with a consequent transformation of the trend in a non-stationary process. ARIMA parameters (p, d, q), using the Expert Modeler package, were automatically computed for each time series, with the detection of the specified extreme values. The extreme data were also used to specify individual developmental characteristics. Specifically, data from three subjects (selected as typical examples of stable and unstable patterns) were used to illustrate various patterns of stability in the developmental trends of HRQOL.

(vi) a Monte Carlo simulation procedure to analyze differences in individual variability the week before and the week after an extreme value in the daily data. This analysis was made to compare the distributions of daily variability before and after a positive or negative extreme value, in order to understand if there are differences in variability before and after an extreme value.

(vii) a Monte Carlo simulation procedure to analyze differences in individual day-to-day variability nearby an extreme value (one week before and after) compared to the general variability of that individual (average level of variability in the whole period). The

Monte Carlo comparisons were made with a random permutation procedure, in which we compared the day-to-day variability close to the extreme value with the variability measures in the whole data set (for further details see Kunnen, 2012). The comparisons were made using data of subjects who showed extreme values. This method generates a given number (1,000 in this case) of simulated data sets that are drawn from the total sample and compares these data with the average variability in the complete series of data. The null hypothesis was that there was no difference in variability and thus, that the difference between the empirically found variability around the extreme value and the whole empirical data set, is caused by chance, and that in fact, all data are drawn from one underlying distribution. During the procedure, the number of times that variability near the extreme value was higher or lower than the general average was computed, giving an associated p-level, to understand the statistically significant difference between the two. These analyses offered information about the behavior of the system nearby a critical point (extreme values).

3. Results

3.1 Reliability and descriptive statistics

The three HRQOL components (physical, mental and social) in the five monthly assessment points, measured with validated questionnaires (SF-12, LSNS-6 and FQS) reached a satisfactory internal consistence, with a value of α higher than .60 (Nunnally, 1978). Just in one case (physical domain wave 3) α was found equal to the threshold (.599), while the average level for the physical domain was .750 (min= .599; max= .857). In the mental domain the average α level was .703 (min= .605; max= 787). Finally, for the social domain an average α of .786 (min= 771; max= 798) was found.

In the first assessment, the group score of the participants corresponded with middle scores (general range 0 to 1) in the three domains. The average value for the physical domain was .474 (± .192), for the mental domain .511 (± .167) and, for the social domain .551 (± .157). The lower level in the physical domain may be explicated by the medical conditions of the subjects, because they all suffer from diseases strictly related to physical functions. In particular, 11 seniors suffer from hypertension, 9 subjects received a diagnosis of osteo-articular disorders (osteoporosis, arthritis), 9 subjects had cardio-vascular diseases (vasculopathy, heart disorders, myocardial infarction, blood disorders, stroke), 5 subjects reported respiratory diseases (BPCO) and 5 subjects were diagnosed with neurological diseases (multiple sclerosis, Parkinson disease, restless leg syndrome).

In the baseline, there were no significant gender differences. However, moderate to high effect sizes (ES) were found, in which women had lower scores than men in each of the three HRQOL domains. Specifically, the average levels for men in the physical domain was .571 (± .202) while for women this was .429 (± .175), the ES was .751 and the p value .145. In the mental domain male subjects had a mean value of .558 (± .207) and female of .489 (± .148), the ES was .384 and the p value .453. Finally, in the social domain men scored a mean value of .598 (± .149) and the women.529 (± .160). The ES was .388 and the p value .359. These differences did not reach the significance level, but they have medium to large ES, that may be attributed to age differences, because men had a mean age of 82 (± 7) years, and women a mean age of 85 (± 5) years, and to comorbidity, because men suffer on average from 2 (± 1) diseases while women 3 (± 1). Similar small and not significant differences were also reported in the work of Kroenke and colleagues (2008). For this reason, we did not differentiate between men and women in the rest of the study.

Regarding the ADL (autonomy in the activity of daily living) score, the average level was 4.456 (± 1.143), where 6 represents the maximum level of autonomy, confirming that participants were, on average, reasonably autonomous in the activities of daily living. Most of the subjects (n= 12; 55%) had a score level of 5. The minimum level was 2 (n= 2; 9%) while the maximum level was reached by three participants (14%). An insignificant gender unbalance was present also in the case of ADL, showing higher level in favor of males (4.857; ± .900) compared to females (4.400; ± 1.242; p=.347; ES= .421. The possible incongruence between non-significant p values and moderate to high ES can be explained by the small sample size that requires large ES's in order to reach statistical significance. From the 22 participants, 11 (50%) were detected as frail, 5 (23%) as pre-frail, and 6 (27%) non-frail. The average score assessed with SHARE-FI was 1.932 (± 1.682), with a minimum value of - .701 and a maximum of 4.659. For physical frailty gender distributions were unbalanced. In fact, 66% (n=10) of the women were found frail, while 14% (n=1) of the men were evaluated as frail. Furthermore, 27% (n= 4) of the women and 14% (n= 1) of the men were found in the pre-frail condition. Finally, 7% (n= 1) of the women and 72% (n= 5) of the men were assessed as non-frail. The distribution of physical frailty was unbalanced between genders, implying that women were frailer than man, with a chi-square p value of .006.

3.2 HRQOL monthly trends

The monthly trend of HRQOL (computed as aggregated changes in the individual data) show a general decrease. Specifically, the baseline value of the physical domain was .474 (± .192) and the last score was .455 (± .206). For the mental domain the baseline level was .511 (± .167) and the last score was .431 (± .180). Finally, for the social domain the starting value was .551 (± .157) while the last score was .418 (± .114). However, these trends did not follow a linear decrease, but showed also increases and changes of slope (see Figure 1); suggesting that on a monthly basis, the domains of HRQOL may show fluctuations, and that individual subjects differed in terms of long-term scores of HRQOL (see Table 2).

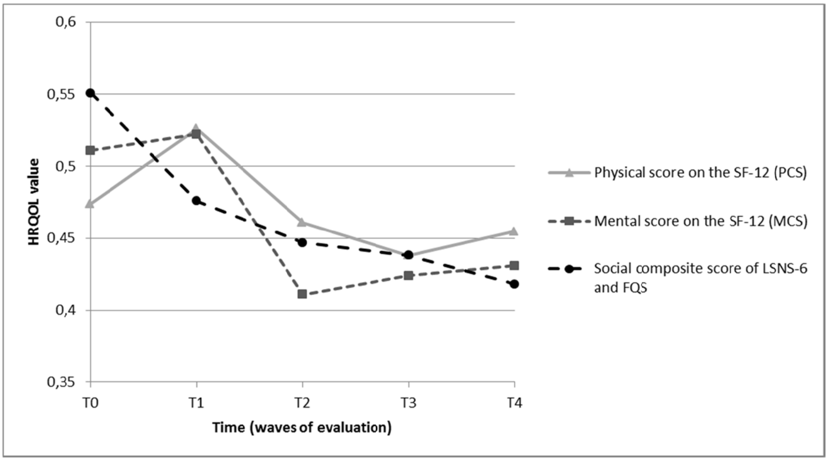

Figure 1 – Average monthly trends of HRQOL over a period of four months.
Time (X axis) is presented as waves of evaluation of the monthly measures
HRQOL value (Y axis) is the level of HRQOL on a scale ranging from 0 to 1
Data cover a narrow range between 0.411 to 0.551

Table 2 - Monthly changes of HRQOL in individuals

Wave/ Domain	Type of change	Physical, n (%)	Mental, n (%)	Social, n (%)
T0-T1	Inc.	11 (50%)	13 (59%)	7 (32%)
	Sta.	3 (14%)	0	0
	Dec.	8 (36%)	9 (41%)	15 (68%)
T1-T2	Inc.	5 (23%)	4 (18%)	7 (32%)
	Sta.	8 (36%)	4 (18%)	1 (4%)
	Dec.	9 (41%)	14 (64%)	14 (64%)
T2-T3	Inc.	7 (32%)	6 (27%)	6 (27%)
	Sta.	7 (32%)	12 (55%)	5 (23%)
	Dec.	8 (36%)	4 (18%)	11 (50%)
T3-T4	Inc.	9 (41%)	6 (27%)	3 (14%)
	Sta.	4 (18%)	9 (41%)	10 (45%)
	Dec.	9 (41%)	7 (32%)	9 (41%)

Inc.= increase
Sta.= stable
Dec.= decrease
T0-T1= changes between baseline and first month
T1-T2= changes between first and second month
T2-T3= changes between second and third month
T3-T4= changes between third month and last assessment

To test whether the average monthly changes of HRQOL measured with validated questionnaires (SF-12, LSNS-6, FQS) were statistically significant, a series of repeated measure Friedman’s tests were performed, analyzing the overall changes in time (from T0 to T4).

No statistical differences were found in the physical domain χ^2= (4, n= 22) = 2.944, p= .567. Statistically significant differences were found for both mental, (χ^2= (4, n= 22) = 14.921, p= .005), and social domains (χ^2= (4, n= 22) = 21.215, p< .001).

Post-hoc analysis with Wilcoxon signed-rank tests were conducted applying a Bonferroni correction in mental and social domains. The Bonferroni correction resulted in a significance level set at p < .005. None of the pairwise comparisons in the mental domain reached the significance level, despite an overall reduction of the domain during time.

Conversely, in three cases the difference between two measurements did reach significance in the social domain: T0 vs T2 (Z= - 3.216, p= .001), T0 vs T3 (Z= - 2.971, p= .003), and T0 vs T4 (Z= - 3.328, p= .001).

3.3 Perturbation in daily measures

As expected, the first period is characterized by low consistency, probably due to perturbations related to the daily requirement of filling out questionnaires, misunderstandings on the side of the participants, and possible adaptations of their feelings about health conditions rated on the VAS questionnaire. In particular, the first 3 weeks (day from 1 to 20) were less reliable. The average α's in this period were: .408 (min= .024; max= .643) in the physical domain; .328 (min= .017; max= 743) in the mental domain, and .694 (min= .439; max= .894) in the social domain.

After the first three weeks, the consistency between the two components of daily measures reaches the fixed threshold. Specifically, the average α's between the time points 21 and 100 were: .694 (min= .433; max= 839) in the physical domain; .761 (min= .535; max= 860) in the mental domain; and .865 (min= .668; max= .959) in the social domain. As shown, the consistency strongly increased from week four. However, in the physical and mental domains the threshold of acceptability was not always reached. Specifically, in few occasions (6 in the physical domain and 1 in the mental domain) the level of α was lower than .60. For this reason, it was decided not to use an aggregated score in these data points, and to exclude them from further analysis. In all other cases, a composite score of the two components was used in each domain.

3.4 Correlations between daily and monthly HRQOL

Correlational analysis showed positive and significant relations between domains measured with validated questionnaires (SF-12, LSNS-6, FQS) and aggregated daily measures in all waves (see Table 3). These results are a first confirmation of the construct validity of the HRQOL daily measures, since the Spearman's coefficient was always positive, and the size of correlations were medium to high (average= .551; min= .426; max= .712).

Table 3 - Spearman's correlations between daily and monthly indexes for the three domains

		Daily median			
Monthly measures	Wave	T1	T2	T3	T4
Physical	T1	.500*			
	T2		.594*		
	T3			.426*	
	T4				.458
Mental	T1	.622**			
	T2		.712**		
	T3			.456*	
	T4				.474*
Social	T1	.533*			
	T2		.579*		
	T3			.617**	
	T4				.644**

Daily median= monthly median value of the daily data
T1= first month assessment; T2= second month assessment; T3= third month assessment; T4= final assessment
** p< .05; ** p< .01*

3.5 Day-to-day variability

The day-to-day variability was computed for each subject for each day starting from day 21. The mean value of the day-to-day variability was used as indicator of variability in the whole period.

The average levels of intra-individual variability were .057 (± .039), .069 (± .040), and .08 (± .038), in the physical, mental and social domain respectively. This means that, on average, the daily fluctuations were comprised between 6% and 8% of the total range, with values of 12% - 14% in some individuals. Men and women seemed to differ in terms of variability. In general, men showed a lower variability as compared to women and this difference was found in all the domains. Variability in the physical domain was .039 (± .019) for men and .067 (± .043) for women. The Monte Carlo comparison returned an associated p value < .001. In the mental domain, men showed a variability of .048 (± .030) while women showed a variability of .076 (± .030), with an associated p value, based on the Monte Carlo procedure of .003. Finally, in the social domain, males had an average level of variability of .054 (± .034) and females .092 (± .034). Also in this case the Monte Carlo analysis showed a statistically significant difference (p< .001).

Differences in variability were also found in relation to the frailty condition. Frail subjects had higher levels of variability as compared to pre-frail and non-frail participants. Frail older adults had a variability of .074 (± .039), .089 (± .035), and .094 (± .028) in the physical, mental, and social domain respectively. Day-to-day variability of pre-frail and robust individuals amounted to .042 (± .034), .045 (± .035), and .067 (± .043), again in the physical, mental and social domains. The differences, analyzed with the Monte Carlo procedure, were significant in the physical (p= .002), mental (p< .001) and social (p= .022) domain.

3.6 Correlations between day-to-day variability and health development

Results (presented in Table 4) show, in general, significant correlations between day-to-day variability and developmental HRQOL outcomes. Variability in the physical and in the mental domain was negatively correlated (Spearman's rho) with the final state of the same domain measured with validated questionnaires (SF-12, LSNS-6 and FQS), as well as the change score (the difference between first and last assessment) in the same domain. A negative correlation means that a higher variability is related to a decrease in the outcome and vice versa. In the social domain, the correlations were in the expected direction but weaker and not significant.

Furthermore, correlations between variability and ADL scores were computed, and significant results were found in each HRQOL domain, for raw scores of ADL in the last evaluation and ADL change between first and last assessment. In addition, in this case the correlational coefficients were found negative, indicating that higher variability is related to decreasing and lower ADL and vice versa.

Table 4 - Spearman's correlations between daily variability and health outcomes

	Physical daily variability	Mental daily variability	Social daily variability
Physical T4	-.450*		
Mental T4		-.620**	
Social T4			-.421
Physical change T4-T1	-.430*		
Mental change T4-T1		-.472*	
Social change T4-T1			-.083
ADL T4	-.445*	-.624**	-.498*
ADL change T4-T1	-.525*	-.596**	-.585**

Daily variability= level of day-to-day variability, computed as the mean value of the individual absolute change between two subsequent data point in each domain
T4= final assessment
T4-T1= difference between final assessment and first month assessment
ADL= autonomy in the activity of daily living
** p< .05*
*** p< .01*

3.7 Extreme values

The ARIMA analysis reported a total number of 121 extreme values in the whole sample in the three domains in the period between days 21 and 100. Extreme values correspond, in some cases, with detectable life events, such as a hospitalization or an unexpected social relationship (e.g., a meeting with relatives). However, in other cases these extremes are not directly related to "special events" but they can be related to more subjectively oriented perceptions. The extreme values were not evenly distributed over the whole population. Specifically, 41 (34% of the total number of extreme values) extreme data were found in the physical domains in 13 (60% of all subjects) subjects, who, on average, had 3 extreme values each. 44 (36% of the total number of extreme values) extreme data were found in the mental domain, in 14 (64%) participants, with an average extreme value rate of 3. Finally, 12 (55%) older adults presented extreme values in the social domain, with an amount of 36 (30% of the total number of extreme values) extreme values, meaning an individual average rate of 3 extreme values.

In the whole sample, the extreme values were almost equally distributed, with 61 of these on the negative side and 60 on the positive side (that means an increase of the HRQOL scores). Data about the presence and distribution of the extreme values are presented in Table 5.

From the whole sample of participants, 13 showed a higher number (intended as equal as or higher than the 75th percentile of the numbers of the extreme values distribution) of extreme values in at least one domain. Of these 13 participants, 6 presented a high number of extreme values in two domains, and just one subject had a high number of extreme values in all three domains. On the contrary, subjects with high presence of extreme values just in one domain may suffer from instability just in that domain, with the possibility to maintain a stable or little changeable level in the other domains of HRQOL.

Six participants showed a median number of extreme values (intended as comprised between the 25th and 75th percentile of the number of extreme values distribution) in at least one domain. From this subgroup, two individuals had a median number in each domain, two participants in two domains, and two just in one domain. Finally, three participants had developmental trajectories without extreme values.

Table 5 - ARIMA analysis of number of outliers for each subject

	PHYSICAL				MENTAL				SOCIAL			
Subj	ARIMA param.	N of outliers			ARIMA param.	N of outliers			ARIMA param.	N of outliers		
	p, d, q	Tot.	Pos.	Neg.	p, d, q	Tot.	Pos.	Neg.	p, d, q	Tot.	Pos.	Neg.
1	(1,0,0)	0	0	0	(1,0,0)	5	3	2	(1,0,0)	5	4	1
2	(0,0,1)	4	0	4	(1,0,0)	4	0	4	(1,0,0)	2	1	1
3	(0,0,0)	0	0	0	(0,0,0)	0	0	0	(0,0,0)	5	5	0
4	(1,0,0)	0	0	0	(1,0,0)	0	0	0	(0,0,2)	6	0	6
5	(0,1,1)	0	0	0	(0,0,0)	1	1	0	(1,0,0)	1	0	1
6	(1,0,0)	0	0	0	(0,0,1)	0	0	0	(1,0,0)	0	0	0
7	(1,0,0)	2	2	0	(1,0,0)	2	2	0	(0,0,1)	1	0	1
8	(0,0,0)	3	3	0	(0,1,1)	1	0	1	(0,0,0)	0	0	0
9	(1,0,0)	0	0	0	(1,0,0)	5	5	0	(0,0,0)	1	1	0
10	(0,0,1)	8	6	2	(1,0,0)	1	0	1	(1,0,0)	4	0	4
11	(1,1,2)	2	2	0	(0,0,0)	1	1	0	(0,1,1)	0	0	0
12	(0,1,1)	3	2	1	(0,1,1)	2	1	1	(0,1,1)	4	3	1
13	(1,0,7)	0	0	0	(0,0,5)	0	0	0	(0,0,0)	0	0	0
14	(0,0,0)	5	1	4	(0,0,0)	3	0	3	(1,0,0)	4	0	4
15	(1,0,0)	3	3	0	(0,1,1)	5	1	4	(2,0,0)	0	0	0
16	(1,0,0)	2	0	2	(1,0,0)	2	1	1	(1,0,1)	2	2	0
17	(0,0,2)	0	0	0	(1,0,0)	0	0	0	(1,0,0)	0	0	0
18	(0,1,1)	2	0	2	(0,0,2)	0	0	0	(0,1,5)	1	1	0
19	(2,1,0)	3	1	2	(0,0,1)	0	0	0	(1,0,0)	0	0	0
20	(0,0,0)	3	3	0	(1,0,0)	10	3	7	(1,0,0)	0	0	0
21	(0,0,0)	0	0	0	(0,0,0)	2	1	1	(0,0,0)	0	0	0
22	(2,0,0)	1	1	0	(3,0,0)	0	0	0	(1,0,0)	0	0	0

Tot.= total
Pos.= positive
Neg.= negative

3.8 Day-to-day variability and perturbations (extreme values)

3.8.1 Variability before and after a perturbation (extreme value)

We compared the variability in the week before the perturbation with the variability in the week after the perturbation. A total of 12 comparisons (four comparisons for each domain), matching distributions of day-to-day variability of positive and negative perturbations, before and after the perturbation, were made with the Monte Carlo method. The results show, as reported in table 6, that in the physical domain variability before the perturbation was statistically higher than variability after the perturbation, both for positive ($p= <.001$) and negative ($p= .033$) perturbations. Variability, near a negative perturbation (defined as the day-to-day variability detected the week before and after the perturbation), was found higher than nearby a positive perturbation, both before ($p= .025$) and after (.001) the peak. These results suggest that before a perturbation, variability was higher and this difference was statistically significant. Furthermore, negative perturbations presented higher variability in comparison with positive perturbations.

In the mental domain, no differences were found, indicating that variability did not change in the vicinity of a perturbation.

Finally, in the social domain variability before a perturbation was higher than after (positive p= .016, negative p= .002). Positive perturbations showed also a higher variability in comparison with the negative ones the week before (p= .042) and the week after, (p= .001) the peak. The results for the social domain confirm the ones found in the physical domain with respect to the higher variability before an extreme value.

Table 6 - Monte Carlo comparisons of daily variability before and after perturbations

Domain	Variability (I)	Variability (J)	p	Variability (I)		Variability (J)	
				Median	SE	Median	SE
Physical	Positive before	Positive after	<.001	.043	.008	.028	.008
	Negative before	Negative after	.033	.050	.013	.043	.009
	Positive before	Negative before	.025	.043	.008	.050	.013
	Positive after	Negative after	.001	.028	.008	.043	.009
Mental	Positive before	Positive after	.666	.050	.008	.047	.009
	Negative before	Negative after	.492	.044	.011	.046	.007
	Positive before	Negative before	.786	.050	.008	.044	.011
	Positive after	Negative after	.691	.047	.009	.044	.007
Social	Positive before	Positive after	.016	.063	.011	.048	.008
	Negative before	Negative after	.002	.049	.011	.013	.010
	Positive before	Negative before	.042	.063	.011	.048	.011
	Positive after	Negative after	.001	.049	.008	.013	.010

Positive before= variability before a positive extreme value
Negative before= variability before a negative extreme value
Positive after= variability after a positive extreme value
Negative after= variability after a negative extreme value
SE= Standard Error

3.8.2 General variability and variability before and after a perturbation (extreme value)

In the physical domain we found that in the week before a perturbation the variability was significantly higher than the average variability for both positive ($p = .003$) and negative ($p < .001$) perturbations. Similar results were found in the mental domain for negative ($p = .038$) and positive ($p = .002$) perturbations. In addition, the variability before a negative perturbation in the mental domain was significantly higher than the variability after the perturbation ($p = .012$). Finally, in the social domain, variability before both a positive and a negative perturbation was higher than variability in the whole period ($p = .001$) and it was significantly lower after a perturbation value ($p = .034$). Data are presented in table 7.

These data demonstrate that in the three domains of HRQOL the variability before a perturbation was higher as compared to the variability of the whole period. This actually means that the perturbation corresponds with a peak in variability during a period of increased variability. It seems that, in various respondents, variability comes in waves, characterized by a peak.

Finally, the variability after a negative perturbation was lower than the variability during the whole period in the mental and social domain.

Table 7 - Monte Carlo comparisons between daily variability near a perturbation and general variability

Domain	Variability (I)	Variability (J)	N	p	Variability (I)		Variability (J)	
					Mean	SD	Mean	SD
Physical	Positive before	General	10	.003	.078	.009	.065	.035
	Negative before	General	7	.000	.120	.014	.073	.042
	Positive after	General	10	.140	.055	.010	.065	.035
	Negative after	General	7	.274	.068	.009	.073	.042
Mental	Positive before	General	10	.002	.091	.014	.073	.033
	Negative before	General	10	.038	.082	.012	.063	.037
	Positive after	General	10	.430	.072	.010	.073	.033
	Negative after	General	10	.012	.045	.007	.063	.037
Social	Positive before	General	7	.001	.117	.013	.084	.039
	Negative before	General	8	.001	.106	.011	.088	.035
	Positive after	General	7	.496	.084	.009	.084	.039
	Negative after	General	8	.034	.065	.011	.088	.035

Positive before= variability before a positive extreme value
Negative before= variability before a negative extreme value
Positive after= variability after a positive extreme value
Negative after= variability after a negative extreme value
General= variability during the whole period
SD= Standard Deviation

3.9 Individual data

In order to get a better insight in the possible patterns and shapes of individual trajectories, directions and time of occurrence of the extreme values, an individual analysis, based on three different subjects, was performed. These subjects were selected because they differed in terms of HRQOL developmental trajectories, and they are representative of a particular type of path (see Figure 2, 3, 4).

The first subject selected is an 83 years old woman, with a high level of cognitive status (MMSE= 30) and a comorbidity health condition. Her HRQOL initial values were: .276 in the physical domain; .469 in the mental domain; and .622 in the social domain. The initial condition indicates that she had a not completely good health condition on the physical side, probably related to the comorbidity situation. Conversely, she had a good HRQOL on the mental and social area. During the 100-day diary based research, she ranged between: .153 and .724 (range .571) in the physical domain; .314 and .749 (range .435) in the mental domain and .267 and .845 (range .578) in the social domain. The last values (day 100) in the three domains were: .349; .648; and .659 respectively in the physical, mental and social domain of HRQOL.

The developmental trajectory (Figure 2) showed strictly connected lines of the three components of HRQOL during the whole period. In fact, correlations among domains were positive and large; specifically: .602 between physical and mental; .543 between physical and social; and .630 between mental and social. These data indicate the interconnections of the three domains in this specific and individual situation.

Day-to-day variability showed medium to high values, near the 10% of the total range (.077 in physical; .093 in mental and .096 in social domain).

The first subject showed lots of extreme values in all the domains: 5 in physical, 3 in mental and 4 in social. The majority of these extreme values (11) were negative. Only in the physical domain, a positive extreme value was found. Furthermore, the extreme values occurred at the same time in the different domains. The first negative extreme value was found in day 25 for the mental and social domain and in day 26 for the physical domain. The second extreme value was in day 37 in social and mental domain, while the third one was in time 83 in the mental domain and 84 in physical domain. Then two extreme values occurred in one domain only, in time 90 in the social area and one in time 100 in the physical domain.

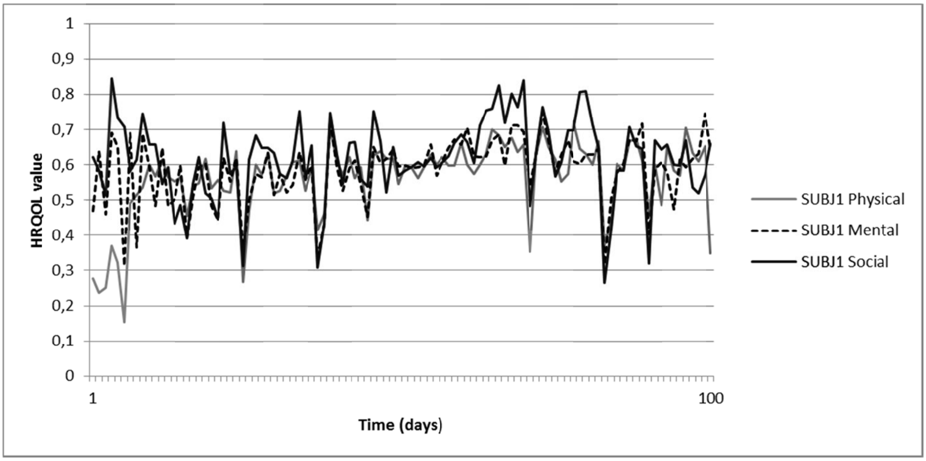

Figure 2 - HRQOL developmental trajectory of three domains over 100 days – subject 1
Time (X axis) is presented as days of observation
HRQOL value (Y axis) is the level of HRQOL on a scale ranging from 0 to 1
Note: subject 1 shows a very instable trajectory, with several extreme values in each of the domains

The second person selected for this analysis of individual trends is an 81 year old woman, with good but not excellent level of cognitive functions (MMSE=26) and the simultaneous presence of five diseases.

The initial condition of the second selected person was as follows: .291 in the physical domain; and .541 in both mental and social domain. Unfortunately, the trend was negative with final conditions (day 100) lower than in baseline for all the domains, specifically: .161; .173 and .136 for physical, mental and social domain respectively. These negative trends can be related to a period of hospitalization (13 days) that occurred during the first part (from day 22) of the research. The range of variations in the 100 days was: .523 in the physical domain (max= .523; min= .000); .713 in the mental domain (max= .756; min= .043); and .455 in the social domain (max= .548; min= .093).

The developmental trend (Figure 3) showed lines correlated with each other; however these correlations were less strong than the ones presented by the first selected subject. Specifically, the three domains were positively correlated; specifically: .246 between physical and mental domain; .350 between physical and social; and .298 between mental and social.

Day-to-variability had medium sizes, near the 5% of the total range (.048 in physical; .056 in mental; and .074 in social domain).

The second subject represents an intermediate condition in terms of extreme values, characterized by 5 extremes data, of which 2 in the physical, 2 in the mental and 1 in the social domain. The direction of these extreme points was positive in the first two domains and negative on the third one. In this case, the first extreme value in the mental domain (detected in time 21) was very close to the extreme values in the physical and social domain (time 22). However, the directions of these extreme values were positive in the physical and mental domains but negative in the social domain. Two single extreme values were found, one in the physical domain on day 36 and one in the mental domain on day 42.

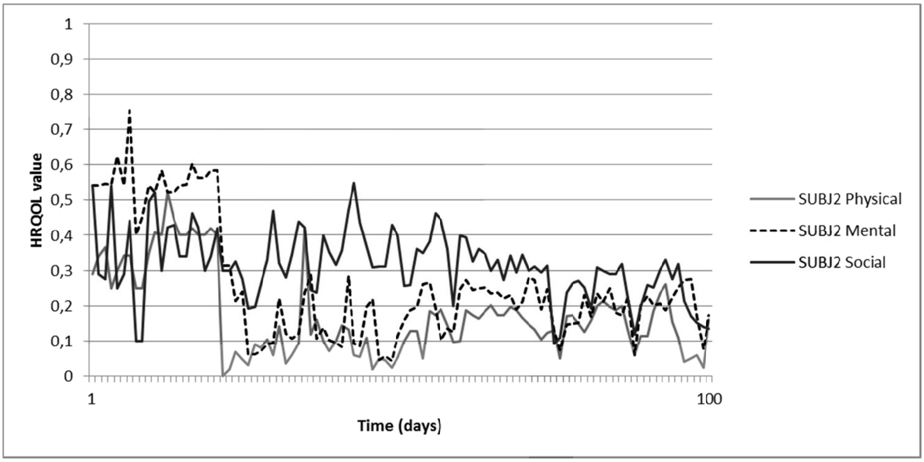

Figure 3 - HRQOL developmental trajectory of three domains over 100 days – subject 2
Time (X axis) is presented as days of observation
HRQOL value (Y axis) is the level of HRQOL on a scale ranging from 0 to 1
Note: subject 2 shows a sudden extreme negative value in days 21 and 22 for all three domains. After the negative extreme value, the social component shows the highest values in comparison with physical and mental domains

Finally, the third selected person, is a 78 years old man, with a good cognitive status (MMSE=29) and two concurrent health problems. His HRQOL initial values were: .367; .572; and .529 respectively in the physical mental and social domain. This condition reflects a good level of HRQOL. The total range of variation during the period of investigation was very low (if compared to the previous two subjects); specifically: .174 (max= .399; min= .216) in the physical domain; .116 (max= .614; min= .498) in the mental domain; and .360 (max= .529; min= .169) in the social domain. Final data (day 100) stated that the levels of the three domains were respectively: .277; .516; and .282 in the physical, mental and social domain.

The trend lines (Figure 4) showed positive but moderate correlations. In fact, the physical and mental domains showed a correlation of .355; the physical and social domains of .204; and the mental and social domains of .309.

The low rate of variations demonstrated by the total range was found also in the analysis of day-to-day variability. In fact, the percentage of variation on a daily basis was found to be close to 3% (.027 in physical; .020 in mental; and .034 in social domain).

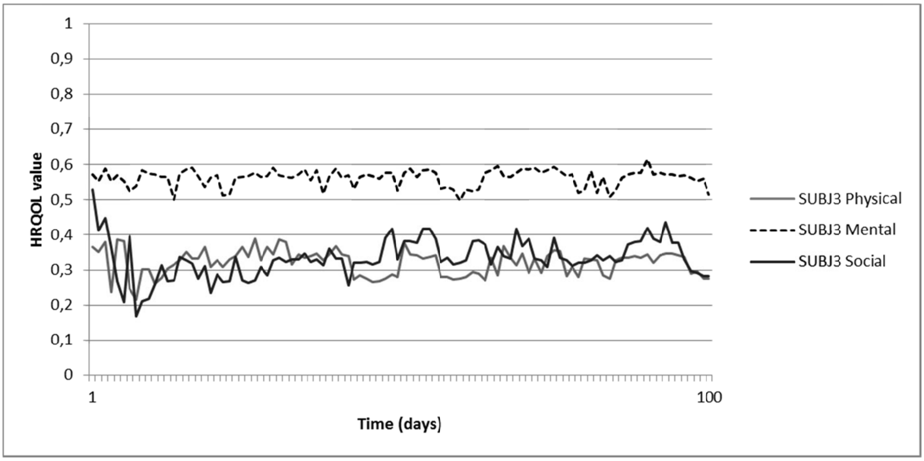

Figure 4 - HRQOL developmental trajectory of three domains over 100 days – subject 3
Time (X axis) is presented as days of observation
HRQOL value (Y axis) is the level of HRQOL on a scale ranging from 0 to 1
Note: subject 3 shows a more stable trend (in comparison with subject 1 and subject 2). The mental domain has consistently higher values than the physical and social domains

4. Discussion

The first research question deals with the relation between day-to-day variability and health outcomes and trends. To answer this question, we performed a correlational analysis of day-to-day variability and data of the last evaluation (day 100). Results show that in the physical and mental domains higher variability was negatively related to the final state measured with validated questionnaires, meaning that individuals with higher daily fluctuations in the self-rating evaluation of these two components had also a lower final state in final assessments. In the same way, higher physical and mental day-to-day variability was associated with a negative trend in the same domain between initial and last measurements. Furthermore, it was found that high day-to-day variability in all of the three components of HRQOL was associated with both a lower level and a higher decrease in ADL, which represents an indicator of daily autonomy of the older adults and is a predictive measure of future health outcomes. These results strongly suggest that day-to-day variability is related to the development of health outcomes and may be seen as indicator of health change in institutionalized older adults. Our data state that subjects with low variability presented also a medium to high initial score. Dynamic Systems theory affirms that too rigid (thus with low variability) and too flexible (thus with high variability) systems are in general not good. However, whether or not this is indeed so depends on the characteristics and types of the systems under study. A possibility may well be that systems that are too rigid are rare in the domain of HRQOL in older adults, because of the reduced physiological reserve (Fried, 2001). On the other hand, our results suggest that stability of HRQOL in the older adult population may be seen as a protective factor, allowing the older adult to maintain an optimally stable health status and perception, as a form of coping to the stressor life events.

The second research question focused on the analysis of the individual day-to-day HRQOL trajectories and the presence of perturbations or peaks in the developmental path. To answer this question, extreme values were established in the individual time serial distribution. We found a total number of 121 extreme values. This suggests that HRQOL on a daily basis did not proceed with linear and smoothed trajectories. It was interesting to find almost 50% of perturbations on the positive side, highlighting the possibility to have strong and unexpected positive perturbations in HRQOL also in institutionalized older adults.

The third research question addressed the issue of how individuals may differ with regard to the distribution of perturbations over time and domains. We found that HRQOL development strongly differed among subjects and that for some subjects perturbations appeared in more domains at the same time, while for other subjects, the extreme value occurred in one domain only. This may have consequences for the general stability of the system. It may well be that subjects with perturbations just in one domain, may suffer from instability just in that domain, with the possibility to maintain stable or hardly changeable levels in the other domains of HRQOL, meaning that in the individual system there is a weak coupling among domains. While subjects with a high number of negative perturbations in all the three domains may have a lower level of stability, and their HRQOL may be more susceptible to changes with strong decrease of the levels in each domain, indicating a strong connection (among domains) in the individual system. The first participant we described showed a very dynamic trend line, with high day-to-day variability, strong connections among the HRQOL components and high number of extreme values. One of the speculations we can offer is that this subject may not have the ability to cope with daily life events in all domains simultaneously, and that a perturbation will have an impact on the whole system. This condition is supported by the fact that, the presence of several perturbations often related in time, indicate a coupled system. This coupling corresponds with a theoretically important property of the dynamic and complex nature of HRQOL. The second subject can be qualitatively described as a person who had a medium level of general day-to-day variability, but who also had a wide range of variation because of a hospitalization period. The correlations between the three domains were weak, and during the whole period of the study there was always a domain (physical in the first phases and social in the latest period) that had a higher level compared with the other two. In sum, as a speculation, this condition may be seen as the individual response to the daily life events, in which one or two domains may be compromised but at least one domain tries to adapt to the perturbations. Finally, the third selected participant, did not show any perturbation in the whole period. This subject may be described as a person who was able to adapt to the daily demands and stressors without having large variations in all three domains. Furthermore, in its stability, this subject showed a generally higher level in the mental domain. Our speculation may indicate a stable and coupled system, in which any external perturbation is assimilated by the system in order to maintain the general trend of HRQOL. These three examples show that clear individual differences exist in the developmental trends, distribution, numbers and co-occurrence of perturbations, in different domains. At the same time, these examples show that individuals do not differ only in terms of HRQOL values, variability and long-term trends, but they differ also in the organization of HRQOL. Furthermore, the analysis of time series data was useful to capture the structure of the individuals HRQOL development and eventually allowed us to see them as examples of subgroups in the whole sample.

These findings about individual differences in presence and occurrence of perturbations, suggest that in the analysis of developmental trajectories and relations among HRQOL domains, the recommended and useful strategy should be the analysis of individual data, with a person-oriented approach. On the contrary, a group-based approach may result in less representative findings, because this approach does not take into account important information about the individual differences in the development of the construct over time.

The fourth and last research question of the study was to analyze the relation between variability and perturbations. We focused on the analysis of day-to-day variability close to extreme values, because variability may show anomalous behavior when the system is close to an instability phase (van der Maas & Molenaar, 1992). Results showed that before a perturbation variability was, in general, higher as compared to variability of that individual after the perturbation or as compared to the whole distribution, especially in case of negative extreme values. That is, variability seems to increase and decrease in the form of waves, at least in a number of subjects. From a Dynamic Systems perspective, variability is seen as consequence of interactions of the complex nature of the system with the environment and with accidental events (Kunnen, 2012). The increase in day-to-day variability may be a sort of indicator of temporary instability in the system that may change or compromise the developmental trend. It suggests that an extreme value may not simply be caused by an external event, but that it is produced by the whole system.

Our study is a first attempt to identify the role of day-to-day variability in individual time serial data of HRQOL in the ageing process, and further studies are needed to clarify and elaborate this role. Nevertheless, this study already gives interesting insights in the nature and the development of HRQOL in late life. In particular, the role of day-to-day variability emerges as an important indicator of final outcomes and developmental trends (change between day 1 and day 100 and occurrence of perturbations).

The role of day-to-day variability, which requires further analysis, may have important applied consequences. First of all, this study demonstrated the feasibility of a daily assessment among institutionalized older adults, with the possibility to capture - with an easily applicable and short instrument - the salient characteristics of HRQOL, suggesting the possibility of a wide use of this kind of assessment in clinical and research settings.

Furthermore, especially in clinical practice, the use of daily measures and variability indicators may be strongly informative about the process acting on a person on a daily basis, capturing dimensions of self-report health-status and experienced-health (Testa & Simonson, 1996). Analysis of daily data and day-to-day variability may have an application mainly in preventive strategies, that is, it may have consequences for analyzing the effectiveness of interventions or changing the activities proposed inside a residential care facility on the basis of the daily assessments. Furthermore, other possibilities may be related to the assessment of the effects of interventions on a daily basis. An example may be the impact of poly-pharmacotherapy on HRQOL. Assessing daily HRQOL may help to detect silent side effects of the drug therapy, by means of the analysis of the day-to-day variability. Another impact is related to healthy ageing policy makers who may use individual HRQOL assessment as the basis to promote, disseminate and test the feasibility of several preventive solutions and activities.

In all these cases the focus is on two important concepts: (i) preventive strategies, necessary in a world that continues to grow increasingly older, and (ii) a person-centered approach, that may have the possibility to intervene on an individual basis, allowing more reliable and better results in terms of compliance to preventive campaigns and the maintenance of health status. Moreover, as stated before, the person-oriented approach emerges here as the more suitable approach for the study of HRQOL time-serial data.

Daily data may be suitable and useful for new research questions and designs. The future steps may be connected to an individualized and preventive approach as cited above. The Dynamic Systems approach is person-oriented (Kunnen, 2012), and in the future, data presented here in an aggregated form will be analyzed also on an individual basis in order to understand personal characteristics in the development of the construct.

Furthermore, from an applied and research point of view, it could be interesting to analyze how different types of preventive interventions influence trajectories of HRQOL.

Despite the long list of possible interesting developments starting from the results presented here, it is necessary to highlight some limitations of the current study. The sample may be seen as a first limitation, because of its small size in comparison with demographic or clinical studies. However, the sample size and the number of observations collected for this paper are generally sufficient for the study of individual characteristics and development. In terms of a dynamic systems approach, the main limitation regards the relatively little attention given here to the analysis of individual data, focusing primarily on group-based analyses. This choice was made because this study represents the first evidence about the usefulness of HRQOL time-serial data in a sample of institutionalized older adults. As such, it may serve as a basis for further and more person-centered investigations.

A second limitation (which can also be seen as an interesting indicator of adaptation to new demands) was related to the consistency and perturbations of the daily measures during the first three weeks. This situation was probably due to a period of adaptability to the diary-based assessments, and in our opinion, it is unrelated with the constructs under study and types of measurements. Data from the first 20 days were excluded from the analysis.

Another limitation was related to the selection of residential care facilities and participants. It was not possible to randomly choose residential care facilities, because we need the voluntary participation of staff and direction members and it was necessary that the involved facilities had a similar weekly plan of activities. In addition, the participants were selected on a voluntary basis, if they met all the inclusion criteria. However, this will always be a problem of real-life research in the social sciences, since it was our intention to study real phenomena in real contexts. This possible methodological limitation does, in our opinion, not have negative implications on data collection and analysis.

Despite these limits, we have good hopes that the results presented here may be informative and innovative, giving to both clinicians and researchers new ideas and points of view about developmental trajectories of HRQOL during the ageing process.

5. References

Adam, E. K., Hawkley, L. C., Kudielka, B. M., & Cacioppo, J. T. (2006). Day-to-day dynamics of experience–cortisol associations in a population-based sample of older adults. *Proceedings of the National Academy of Sciences*, *103*(45), 17058–17063. doi:10.1073/pnas.0605053103

Adamson, H., & Elliott, D. (2005). Quality of life after a critical illness: a review of general ICU studies 1998-2003.

American Psychological Association, A. (n.d.). Ethical Principles of Psychologists and Code of Conduct. *http://www.apa.org*.

Audureau, E., Rican, S., & Coste, J. (2013). Worsening trends and increasing disparities in health-related quality of life: evidence from two French population-based cross-sectional surveys, 1995–2003. *Quality of Life Research*, *22*(1), 13–26. doi:10.1007/s11136-012-0117-7

Bassano, D., & van Geert, P. (2007). Modeling continuity and discontinuity in utterance length: a quantitative approach to changes, transitions and intra-individual variability in early grammatical development. *Dev Sci*, *10*, 588–612. doi:10.1111/j.1467-7687.2007.00629.x

Balboa-Castillo, T., León-Muñoz, L. M., Graciani, A., Rodríguez-Artalejo, F., & Guallar-Castillón, P. (2011). Longitudinal association of physical activity and sedentary behavior during leisure time with health-related quality of life in community-dwelling older adults. *Health and Quality of Life Outcomes*, *9*(1), 47. doi:10.1186/1477-7525-9-47

Boer, A. G. E. M. de, Lanschot, J. J. B. van, Stalmeier, P. F. M., Sandick, J. W. van, Hulscher, J. B. F., Haes, J. C. J. M. de, & Sprangers, M. a. G. (2004). Is a single-item visual analogue scale as valid, reliable and responsive as multi-item scales in measuring quality of life? *Quality of Life Research*, *13*(2), 311–320. doi:10.1023/B:QURE.0000018499.64574.1f

Bowling, A. (2005). Just one question: If one question works, why ask several? *Journal of Epidemiology and Community Health*, *59*(5), 342–345. doi:10.1136/jech.2004.021204

Bratteby, L.-E., Sandhagen, B., Fan, H., & Samuelson, G. (1997). A 7-day activity diary for assessment of daily energy expenditure validated by the doubly labelled water method in adolescents. *European Journal of Clinical Nutrition*, *51*(9), 585–591. doi:10.1038/sj.ejcn.1600449

Brosschot, J. F., Van Dijk, E., & Thayer, J. F. (2007). Daily worry is related to low heart rate variability during waking and the subsequent nocturnal sleep period. *International Journal of Psychophysiology*, *63*(1), 39–47. doi:10.1016/j.ijpsycho.2006.07.016

Crosby, R. D., Kolotkin, R. L., & Williams, G. R. (2003). Defining clinically meaningful change in health-related quality of life. *Journal of Clinical Epidemiology*, *56*(5), 395–407. doi:10.1016/S0895-4356(03)00044-1

Curran, S. L., Beacham, A. O., & Andrykowski, M. A. (2004). Ecological Momentary Assessment of Fatigue Following Breast Cancer Treatment. *Journal of Behavioral Medicine*, *27*(5), 425–444. doi:10.1023/B:JOBM.0000047608.03692.0c

DeSalvo, K. B., Fisher, W. P., Tran, K., Bloser, N., Merrill, W., & Peabody, J. (2006). Assessing Measurement Properties of Two Single-item General Health Measures. *Quality of Life Research*, *15*(2), 191–201. doi:10.1007/s11136-005-0887-2

Dominick, K., Ahern, F., Gold, C., & Heller, D. (2002). Relationship of health-related quality of life to health care utilization and mortality among older adults. *Aging Clinical and Experimental Research*, *14*(6), 499–508.

European Commission. (2012). *Active ageing and solidarity between generations. A statistical portrait of the European Union 2012* (Vol. 1). Luxembourg: Office for Official Publ. of the European Communities.

Everard, K. M., Lach, H. W., Fisher, E. B., & Baum, M. C. (2000). Relationship of Activity and Social Support to the Functional Health of Older Adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *55*(4), S208–S212. doi:10.1093/geronb/55.4.S208

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state": A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, *12*(3), 189–198. doi:10.1016/0022-3956(75)90026-6

Fried, L. P., Tangen, C. M., Walston, J., Newman, A. B., Hirsch, C., Gottdiener, J., Seeman, T., Tracy, R., Kop, W. J., Burke, G., McBurnie, M. A. (2001). Frailty in Older Adults Evidence for a Phenotype. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *56*(3), M146–M157. doi:10.1093/gerona/56.3.M146

Gandek, B., Ware, J. E., Aaronson, N. K., Apolone, G., Bjorner, J. B., Brazier, J. E., Bullinger, M., Kaasa, S., Leplege, A., Prieto, L., Sullivan, M. (1998). Cross-Validation of Item Selection and Scoring for the SF-12 Health Survey in Nine Countries: Results from the IQOLA Project. *Journal of Clinical Epidemiology*, *51*(11), 1171–1178. doi:10.1016/S0895-4356(98)00109-7

Haas, B. K. (1999). A Multidisciplinary Concept Analysis of Quality of Life. *Western Journal of Nursing Research*, *21*(6), 728–742. doi:10.1177/01939459922044153

Hawthorne, G. (2006). Measuring Social Isolation in Older Adults: Development and Initial Validation of the Friendship Scale. *Social Indicators Research*, *77*(3), 521–548. doi:10.1007/s11205-005-7746-y

Hawthorne, G., & Griffith, P. (2000). *The Friendship Scale: Development and properties* (working paper).

Hickey, D. A., Barker, M., McGee, H., & O'Boyle, C. (2005). Measuring health-related quality of life in older patient populations. *PharmacoEconomics*, *23*(10), 971–993. doi:10.2165/00019053-200523100-00002

Hiratsuka, T., & Kida, K. (1993). Quality of life measurements using a linear analog scale for elderly patients with chronic lung disease. *Internal Medicine (Tokyo, Japan)*, *32*(11), 832–836.

Hollenstein, T., Granic, I., Stoolmiller, M., & Snyder, J. (2004). Rigidity in Parent—Child Interactions and the Development of Externalizing and Internalizing Behavior in Early Childhood. *Journal of Abnormal Child Psychology*, *32*(6), 595–607. doi:10.1023/B:JACP.0000047209.37650.41

Hopman, W. M., Harrison, M. B., Coo, H., Friedberg, E., Buchanan, M., & VanDenKerkhof, E. G. (2009). Associations between chronic disease, age and physical and mental health status. *Chronic Diseases in Canada*, *29*(3), 108–116.

Idler, E. L., & Benyamini, Y. (1997). Self-Rated Health and Mortality: A Review of Twenty-Seven Community Studies. *Journal of Health and Social Behavior*, *38*(1), 21–37. doi:10.2307/2955359

Jenkinson, C., Layte, R., Jenkinson, D., Lawrence, K., Petersen, S., Paice, C., & Stradling, J. (1997). A shorter form health survey: can the SF-12 replicate results from the SF-36 in longitudinal studies? *Journal of Public Health*, *19*(2), 179–186.

Jones, M. B. (1977). Health status indexes: The trade-off between quantity and quality of life. *Socio-Economic Planning Sciences*, *11*(6), 301–305. doi:10.1016/0038-0121(77)90015-5

Katsura, H., Yamada, K., & Kida, K. (2003). Usefulness of a Linear Analog Scale Questionnaire to Measure Health-Related Quality of Life in Elderly Patients with Chronic Obstructive Pulmonary Disease. *Journal of the American Geriatrics Society*, *51*(8), 1131–1135. doi:10.1046/j.1532-5415.2003.51363.x

Kirchengast, S., & Haslinger, B. (2008). Gender differences in health-related quality of life among healthy aged and old-aged austrians: Cross-sectional analysis. *Gender Medicine*, *5*(3), 270–278. doi:10.1016/j.genm.2008.07.001

Kroenke, C. H., Kubzansky, L. D., Adler, N., & Kawachi, I. (2008). Prospective Change in Health-Related Quality of Life and Subsequent Mortality Among Middle-Aged and Older Women. *American Journal of Public Health*, *98*(11), 2085–2091. doi:10.2105/AJPH.2007.114041

Kunnen, S. E. (2012). *A Dynamic Systems Approach of Adolescent Development*. Psychology Press.

Kunnen, S. E., & Bosma, H. A. (2000). Development of meaning making: A dynamic systems approach. *New Ideas in Psychology*, *18*(1), 57–82. doi:10.1016/S0732-118X(99)00037-9

Li, F., Fisher, K. J., Harmer, P., Irbe, D., Tearse, R. G., & Weimer, C. (2004). Tai Chi and Self-Rated Quality of Sleep and Daytime Sleepiness in Older Adults: A Randomized Controlled Trial. *Journal of the American Geriatrics Society*, *52*(6), 892–900. doi:10.1111/j.1532-5415.2004.52255.x

Lichtwarck-Aschoff, A., Kunnen, S. E., & van Geert, P. L. C. (2009). Here we go again: A dynamic systems perspective on emotional rigidity across parent–adolescent conflicts. *Developmental Psychology*, *45*(5), 1364–1375. doi:10.1037/a0016713

Lima, M. G., Barros, M. B. de A., César, C. L. G., Goldbaum, M., Carandina, L., & Ciconelli, R. M. (2009). Impact of chronic disease on quality of life among the elderly in the state of São Paulo, Brazil: a population-based study. *Impacto de Las Enfermedades Crónicas En La Calidad de Vida de Los Adultos Mayores En El Estado de São Paulo, Brasil: Estudio Poblacional.*, *25*(4), 314–321.

Lubben, J., Blozik, E., Gillmann, G., Iliffe, S., von Renteln Kruse, W., Beck, J. C., & Stuck, A. E. (2006). Performance of an Abbreviated Version of the Lubben Social Network Scale Among Three European Community-Dwelling Older Adult Populations. *The Gerontologist*, *46*(4), 503–513. doi:10.1093/geront/46.4.503

Lubben, J. E. (1988). Assessing social networks among elderly populations. *Family & Community Health: The Journal of Health Promotion & Maintenance*, *11*(3), 42–52.

Maimon, O. Z., & Rokach, L. (2005). *Data mining and knowledge discovery handbook*. New York: Springer.

Meerding, W. J., Bonneux, L., Polder, J. J., Koopmanschap, M. A., & van der Maas, P. J. (1998). Demographic and epidemiological determinants of healthcare costs in

Netherlands: cost of illness study. *BMJ*, *317*(7151), 111–115. doi:10.1136/bmj.317.7151.111

Nezlek, J. B., Richardson, D. S., Green, L. R., & Schatten-Jones, E. C. (2002). Psychological well-being and day-to-day social interaction among older adults. *Personal Relationships*, *9*(1), 57–71. doi:10.1111/1475-6811.00004

Nishiyama, O., Taniguchi, H., Kondoh, Y., Nishimura, K., Suzuki, R., Takagi, K., & Yamaki, K. (2000). The effectiveness of the Visual Analogue Scale 8 in measuring health-related quality of life for COPD patients. *Respiratory Medicine*, *94*(12), 1192–1199. doi:10.1053/rmed.2000.0950

Noro, A., & Aro, S. (1996). Health-related quality of life among the least dependent institutional elderly compared with the non-institutional elderly population. *Quality of Life Research*, *5*(3), 355–366. doi:10.1007/BF00433920

Nunnally, J. C. (1978). *Psychometric theory* (2d ed.). New York: McGraw-Hill.

Otero-Rodríguez, A., León-Muñoz, L. M., Balboa-Castillo, T., Banegas, J. R., Rodríguez-Artalejo, F., & Guallar-Castillón, P. (2010). Change in health-related quality of life as a predictor of mortality in the older adults. *Quality of Life Research*, *19*(1), 15–23. doi:10.1007/s11136-009-9561-4

Ozcan, A., Donat, H., Gelecek, N., Ozdirenc, M., & Karadibak, D. (2005). The relationship between risk factors for falling and the quality of life in older adults. *BMC Public Health*, *5*(1), 90. doi:10.1186/1471-2458-5-90

Peters, M. L., Sorbi, M. J., Kruise, D. A., Kerssens, J. J., Verhaak, P. F. ., & Bensing, J. M. (2000). Electronic diary assessment of pain, disability and psychological adaptation in patients differing in duration of pain. *Pain*, *84*(2–3), 181–192. doi:10.1016/S0304-3959(99)00206-7

Piek, J. P. (2002). The role of variability in early motor development. *Infant Behavior and Development*, *25*(4), 452–465. doi:10.1016/S0163-6383(02)00145-5

Resnick, B., & Nahm, E. S. (2001). Reliability and Validity Testing of the Revised 12-Item Short-Form Health Survey in Older Adults. *Journal of Nursing Measurement*, *9*(2), 151–161.

Rockwood, K., Howlett, S. E., MacKnight, C., Beattie, B. L., Bergman, H., Hébert, R., Hogan, D. B., Wolfson, C., McDowell, I. (2004). Prevalence, Attributes, and Outcomes of Fitness and Frailty in Community-Dwelling Older Adults: Report From the Canadian Study of Health and Aging. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *59*(12), 1310–1317. doi:10.1093/gerona/59.12.1310

Romero-Ortuno, R., O'Shea, D., & Kenny, R. A. (2011). The SHARE frailty instrument for primary care predicts incident disability in a European population-based sample. *Quality in Primary Care*, *19*(5), 301–309.

Romero-Ortuno, R., Walsh, C. D., Lawlor, B. A., & Kenny, R. A. (2010). A Frailty Instrument for primary care: findings from the Survey of Health, Ageing and Retirement in Europe (SHARE). *BMC Geriatrics*, *10*(1), 57. doi:10.1186/1471-2318-10-57

Savelsbergh, G. J. P., van der Maas, H., & van Geert, P. (1999). *Non-linear developmental processes*. Royal Netherlands Academy of Arts and Sciences.

Siegler, R. S. (1994). Cognitive Variability: A Key to Understanding Cognitive Development. *Current Directions in Psychological Science*, *3*(1), 1–5. doi:10.2307/20182248

Siegler, R. S. (2007). Cognitive variability. *Developmental Science*, *10*(1), 104–109. doi:10.1111/j.1467-7687.2007.00571.x

Sillanpää, E., Häkkinen, K., Holviala, J., & Häkkinen, A. (2012). Combined Strength and Endurance Training Improves Health-Related Quality of Life in Healthy Middle-Aged and Older Adults. *International Journal of Sports Medicine*, *33*(12), 981–986. doi:10.1055/s-0032-1311589

Singh, J. A., Nelson, D. B., Fink, H. A., & Nichol, K. L. (2005). Health-related quality of life predicts future health care utilization and mortality in veterans with self-reported physician-diagnosed arthritis: The veterans arthritis quality of life study. *Seminars in Arthritis and Rheumatism*, *34*(5), 755–765. doi:10.1016/j.semarthrit.2004.08.001

Sloan, J. A., Loprinzi, C. L., Kuross, S. A., Miser, A. W., O'Fallon, J. R., Mahoney, M. R., Vaught, N. L. (1998). Randomized comparison of four tools measuring overall quality of life in patients with advanced cancer. *Journal of Clinical Oncology*, *16*(11), 3662–3673.

Sprenkle, M. D., Niewoehner, D. E., Nelson, D. B., & Nichol, K. L. (2004). THe veterans short form 36 questionnaire is predictive of mortality and health-care utilization in a population of veterans with a self-reported diagnosis of asthma or copd*. *CHEST Journal*, *126*(1), 81–89. doi:10.1378/chest.126.1.81

Testa, M. A., & Simonson, D. C. (1996). Assessment of Quality-of-Life Outcomes. *New England Journal of Medicine*, *334*(13), 835–840. doi:10.1056/NEJM199603283341306

Thelen, E. (1996). *A Dynamic Systems Approach to the Development of Cognition and Action*. MIT Press.

Thelen, E., Ulrich, B. D., & Wolff, P. H. (1991). Hidden Skills: A Dynamic Systems Analysis of Treadmill Stepping during the First Year. *Monographs of the Society for Research in Child Development*, *56*(1), i–103. doi:10.2307/1166099

Tsai, S.-Y., Chi, L.-Y., Lee, C., & Chou, P. (2007). Health-related quality of life as a predictor of mortality among community-dwelling older persons. *European Journal of Epidemiology*, *22*(1), 19–26. doi:10.1007/s10654-006-9092-z

Van der Maas, H. L., & Molenaar, P. C. (1992). Stagewise cognitive development: An application of catastrophe theory. *Psychological Review*, *99*(3), 395–417. doi:10.1037/0033-295X.99.3.395

Van Dijk, M., & van Geert, P. (2007). Wobbles, humps and sudden jumps: a case study of continuity, discontinuity and variability in early language development. *Infant and Child Development*, *16*(1), 7–33. doi:10.1002/icd.506

Van Geert, P., & van Dijk, M. (2002). Focus on variability: New tools to study intra-individual variability in developmental data. *Infant Behavior and Development*, *25*(4), 340–374. doi:10.1016/S0163-6383(02)00140-6

Verspoor, M., Lowie, W., & Van Dijk, M. (2008). Variability in Second Language Development From a Dynamic Systems Perspective. *The Modern Language Journal*, *92*(2), 214–231. doi:10.1111/j.1540-4781.2008.00715.x

Walker, A. (2005). A European perspective on quality of life in old age. *European Journal of Ageing*, *2*(1), 2–12. doi:10.1007/s10433-005-0500-0

Wallace, M., & Shelkey, M. (2007). Katz Index of Independence in Activities of Daily Living (ADL). *Urologic Nursing*, *27*(1), 93–94.

Wisocki, P. A. (1988). Worry as a phenomenon relevant to the elderly. *Behavior Therapy*, *19*(3), 369–379. doi:10.1016/S0005-7894(88)80009-1

Wolinsky, F. D., Unverzagt, F. W., Smith, D. M., Jones, R., Wright, E., & Tennstedt, S. L. (2006). The Effects of the ACTIVE Cognitive Training Trial on Clinically Relevant Declines in Health-Related Quality of Life. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *61*(5), S281–S287.

Yang, Z., Norton, E. C., & Stearns, S. C. (2003). Longevity and Health Care Expenditures The Real Reasons Older People Spend More. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *58*(1), S2–S10. doi:10.1093/geronb/58.1.S2

Zack, M. M., Moriarty, D. G., Stroup, D. F., Ford, E. S., & Mokdad, A. H. (2004). Worsening trends in adult health-related quality of life and self-rated health—United States, 1993–2001. *Public Health Reports*, *119*(5), 493–505. doi:10.1016/j.phr.2004.07.007

Zubritsky, C., Abbott, K. M., Hirschman, K. B., Bowles, K. H., Foust, J. B., & Naylor, M. D. (2013). Health-related Quality of Life: Expanding a Conceptual Framework to Include

Older Adults Who Receive Long-term Services and Supports. *The Gerontologist*, *53*(2), 205–210. doi:10.1093/geront/gns093

CHAPTER 5

SUMMARY AND GENERAL DISCUSSION

1. Introduction

The main aim of the present thesis was the conceptualization and development of Health Related Quality of Life (HRQOL) in older adults, applying a Dynamic Systems perspective.

The general idea for this thesis arose from personal work experiences and empirical observations. Questions and issues that emerged from these observations did not find answers in the scientific literature on HRQOL among older adults. Specifically, current literature did not report results and information about the development of HRQOL in this target group.

However, it is known that HRQOL in later life is an important indicator for both effectiveness of interventions (among others: Balboa-Castillo, León-Muñoz, Graciani, Rodríguez-Artalejo, & Guallar-Castillón, 2011; Hopman et al., 2009; Lima et al., 2009; Sillanpää, Häkkinen, Holviala, & Häkkinen, 2012) and negative health outcomes (among others: Dominick, Ahern, Gold, & Heller, 2002; Singh, Nelson, Fink, & Nichol, 2005; Tsai, Chi, Lee, & Chou, 2007). For this reason, a systematic analysis of developmental trends may bring new insights, ideas and solutions contributing to maintaining, for as long as possible, a good health status in the aged population.

The major limitations found in literature were related to:

(i) conceptual models, that are too numerous (Aaronson, 1993; Berzon, Hays, & Shumaker, 1993; Ware & Dewey, 2000; Wilson & Cleary, 1995), with repercussions in diversity and low comparability of instruments; in general such models apply a direct and causal approach, based on the biomedical model (Ferrans, Zerwic, Wilbur, & Larson, 2005; Wilson & Cleary, 1995), neglecting the possibility of interconnections and non-deterministic relationships;

(ii) measurement strategies that generally focus on long time periods or apply cross-sectional or transversal research designs (among others: Chan et al., 2009; Hopman et al., 2009; Kempen, Ormel, Brilman, & Relyveld, 1997; Lam & Lauder, 2000; Lima et al., 2009; Visser et al., 2009), with the impossibility to study and provide in-depth insights into short term changes and relations between different time scales.

The current study tried to fill these gaps. From a conceptual point of view we developed a model that integrates both the biopsychosocial (Engel, 1977) and the Dynamic Systems perspectives. The conceptual model was delineated starting from the WHO definition of health (WHO, 1948), and takes into account the development of the construct, with the interconnections among domains, the role of time, and random influences. The characteristics of a Dynamic Systems approach and their applications in similar studies on various research fields (among others: Kunnen & Bosma, 2000; Steenbeek & van Geert, 2005; Thelen, Ulrich, & Wolff, 1991; van Geert, 1993) were analyzed in order to understand the consistency of HRQOL in a Dynamic Systems setting.

From an empirical point of view, the present work adopted a short-term level assessment of HRQOL in older adults, using a daily diary-based assessment. The day-to-day data were used to depict developmental trajectories, to analyze relations with different time levels and to describe the usefulness of variability indicators in relations to final outcomes and trends. The use of such an empirical approach derived from previous research in the analysis of Dynamic Systems behaviors in the field of social sciences and developmental psychology.

This thesis contributes to the specific body of literature mainly because it aims to expand the knowledge of HRQOL, conceptualizing and analyzing it as a system that develops over time with the typical characteristics of Dynamic Systems.

The use of a developmental view was particularly suitable in respect to the aims of this thesis. Development is a central topic in Dynamic Systems, and it is seen as the path described by the relevant dimensions of the system measured on different time points. Developmental processes are one of the main fields of applications, theory and model building for Dynamic Systems (Kunnen, 2012).

One of the most challenging aspects, in the application of a Dynamic Systems approach and in shaping models and theory, is the need to clearly define domains, characteristics, properties and functions of the system (Kunnen, 2012; van Geert & Steenbeek, 2005). To do so, the components of the systems have to be selected. Then, it is necessary to define their characteristics, influences and relations. Finally, the role of changes (i.e., their representation by means of equations) over time must to be set.

The use and application of a Dynamic Systems perspective in the study and analysis of HRQOL was the guideline for the whole thesis, and it was applied to conceptualize and measure this construct.

The point of departure of this thesis was, on the one hand, curiosity about the ways of changes in health status and perceptions among older adults, with the aim to understand how these changes may arise; and on the other hand, the need to find a way to evaluate and enhance health promotion activities and interventions.

The general aim of the thesis was the application of a Dynamic Systems approach to HRQOL that resulted in an expansion of the current conceptualization of the construct, including a deep analysis of the HRQOL dynamic trends and characteristics over time in older adults.

To achieve the general objectives, the thesis was structured in three scientific articles, ranging from a conceptual to an empirical analysis. Specifically, the three central chapters of the thesis were about:

(i) the formulation and operationalization of a HRQOL Dynamic Systems conceptual model,

(ii) the translation of the conceptual model into a mathematical one and its validation procedures,

(iii) the empirical assessments of dynamic characteristics in a sample of institutionalized older adults.

In this final chapter, the main characteristics, findings and methodological issues of the three papers will be summarized. Finally, an analysis of strengths, weakness, opportunities and threats of the thesis will be discussed in the last paragraph.

2. Conceptual model

The first stage in the analysis of HRQOL among older adults as a dynamic system was the development of a conceptual model. This model had to meet specific requirements, namely: (i) the use of a biopsychosocial approach, (ii) the identification of HRQOL as system that needs to be studied as a whole, (iii) the application of developmental view, (iv) the use of terminology adopted by WHO in the identification of domains, (v) the use of a double assessment for each component, in order to capture both self-report health-status and experienced-health. Moreover, the Dynamic Systems conceptual model was developed in order to fill a number of gaps and limitations, such as: (i) the high diversity among existent conceptual models (Ferrans et al., 2005), (ii) the lack of uniformity in terminology and model components (Ferrans et al., 2005), (iii) the application of direct and causal relationships (Berzon et al., 1993; Wilson & Cleary, 1995).

The model depicted in the first article tried to encounter all these issues, meeting also the major characteristics of Dynamic Systems. To do so, it was necessary to think and hypothesize the mechanisms and relations among phenomena under study in a new way.

The first article of this thesis represents an answer to the many scholars (among others: Adamson & Elliott, 2005; Haas, 1999; Hickey, Barker, McGee, & O'Boyle, 2005; Zubritsky et al., 2013) who defined HRQOL as a dynamic construct, but without any further specification or explanation of its dynamic characteristics. The conceptual model matched Dynamic Systems requirements with HRQOL characteristics and theory.

The model described development of HRQOL as follows. The stable individual parameters act directly on the three main components of the model (physical, mental and social domain). This means that higher age, morbidity and presence of negative health behaviors affect each HRQOL domain directly and in a negative way. The influence of the individual characteristics is replicated again and again in the model due to the iterative nature of the model itself. In this sense, the model is able to take into account the influence of individual conditions in each time point. The three domains of HRQOL are fully connected, because each component is related to the other ones and to itself, in the next time point. This choice implies the dependence between two subsequent data points, highlighting the iterative nature of the model, and the inter-relations among domains, meaning that the modifications in the state of one domain influence also the other two. It was decided to specify the connections among domains in each successive data point, because this allowed us to reckon with the effect of change that had taken place in each preceding data point. This procedure is consistent with the idea that the change of each domain may be more informative and more explicative of the whole development, as also reported in the article of Idler & Benyamini (1997).

Finally, in each data point each domain is directly related to a random influence that can be seen as the sum of the accidental life events that act, change or even reverse the trend of HRQOL.

In summary, every time point of each domain is function of: (i) the stable individual parameters, (ii) the previous level in the same domain, and (iii) the change rate of the other two domains, and (iv) the random influences.

The conceptual model introduced some innovative aspects regarding, (i) the adoption of a developmental view, with the conceptualization of time dependency and iterative behaviors; (ii) the mutual influence of the domains, as an emergent higher structure, created by changes and interconnections among the system's components; and, (iii) the use of a stochastic component, useful to consider also unpredictable life events.

For a conceptual model to be really useful, it needs a practical and empirical translation. For this reason, in the first article, the conceptual model has been operationalized, describing measurement methods for the components of the model, in order to obtain a direct and applied view of the concepts inserted in the model.

The operational translation of the conceptual model was the first step in the direction of an empirical analysis of the model. The first article serves as a basis for the development and validation of the HRQOL quantitative model, this model was described in the second article and in the third paper we describe a time serial analysis of HRQOL among institutionalized older adults.

3. Mathematical model

The mathematical model was conceived and built to test and validate theoretical assumptions of the conceptual model, comparing simulated and empirical data, and to depict HRQOL developmental trajectories for specific persons in specific conditions.

The first step taken was the translation of the conceptual model into a quantitative form. This work was done by numerically quantifying the components of the model, by developing an equation that describes how for each component the value changes between one iteration and the next. The basic equation used in the model was the logistic growth equation, previously described as suitable in the analysis of living systems development (Kunnen, 2012; Kunnen & Bosma, 2000; van Geert, 1994).

Once the changes between one iteration and the next were translated in a quantitative form, the iterated calculation of the equations of the mathematical model produced developmental trends for each HRQOL domain. The trend lines depend on stable individual parameters, control parameters, random influences and iterative process.

In the calibration procedure, developmental trajectories have been compared with theoretical expectations. This analysis was necessary to obtain a first impression about the theoretical plausibility of the trajectories. Furthermore, it was necessary to analyze the limits (intended as parameter ranges) in which the model produces plausible developmental patterns. These comparisons showed that the model produced theoretically plausible trajectories.

The final step was the validation procedure, carried out by comparing empirical and simulated results in several ways. Data showed a good fit between the outcomes produced by the model and the empirical ones. Moreover, multiple comparisons of different clusters between empirical and simulated data showed overlapping results. These findings highlighted that the model was able to replicate the final state of the empirical results.

Our results stated that the conceptual speculations made in the theoretical model were correct, giving new insights about HRQOL structure and mechanisms of changes in late life. The combination of the conceptual and the mathematical models was the first step in the direction of a dynamic and complex definition of HRQOL. The validated model offers a better understanding of processes of changes in the construct under study, giving to HRQOL a combination of dynamic and biopsychosocial properties, expressed in the form of connections and quantitative relations.

Furthermore, since the model demonstrated its ability to capture and simulate empirical data in a satisfactory way, it can be used for further and wider applications and analyses. Examples of these further applications may be the analyses of:

(i) simulated and empirical daily HRQOL trajectories, in order to test differences in different types of people and conditions;

(ii) the impact of different simulated processes acting on a person (e.g., diseases, interventions etc.), rating their effects on the whole systems or on each domain (physical, mental and social);

(iii) a large set of initial values identifying the ones that, on average, produce negative trends, and using the model as a preliminary screening tool, in order to prevent or intervene as soon as possible to avoid health decline;

(iv) the role of time (expressed as autocorrelation in the time series data), starting from different combinations of initial values, identifying patterns of individual data that tend to have higher fluctuations in time;

(v) the role of interconnections among domains, starting from different combinations of initial values, identifying patterns of individual HRQOL data that tend to have higher or lower correspondence in the level of different domains;

(vi) the role of day-to-day variability starting from different combinations of initial values, identifying patterns of individual data that tend to have the worst developmental trends.

All these possible solutions may be useful in research as well as clinical settings. From a research point of view, a valid simulation tool is useful to test hypotheses and create new research designs and questions. From the clinical point of view, the model can be helpful to detect people at risk to develop negative HRQOL trends and to hypothesize solutions or changes in the patients' health management.

Finally, it is necessary to specify again that the aim of the model presented in the second paper, which was to confirm theoretical assumptions. It does not allow for prediction of individual trajectories in a deterministic way. In fact, the stochastic nature of the model does not imply deterministic speculations. However, the analysis of several developmental trajectories can be useful to hypothesize general characteristics of trends and compute risk scores related to different types of subjects.

Finally, the mathematical model does not pretend to be the final and definitive model of HRQOL specifically designed for older adults, and surely further updates and revisions may be made. In our opinion, the models represent an innovative first step in the discovery of the dynamic and complex nature of HRQOL.

4. Day-to-day trends of HRQOL

After the first two articles, the thesis proceeded with an empirical, longitudinal study. This step aimed to test the possible dynamic development of HRQOL among institutionalized older adults in a real and clinical setting.

Specifically, the role of day-to-day variability on trends and health outcomes was the focus of the third paper. Variability in time serial data is a central topic in Dynamic Systems studies, because it may be strongly informative about the characteristics of a system and can have an effect on the developmental trajectories (Thelen, 1996; Thelen et al., 1991; van Geert & van Dijk, 2002).

Daily data were assessed in a sample of institutionalized older adults with the use of short and easy diary-based questionnaires, structured on the basis of the conceptual model. A typical aspect of this study was the daily assessment of HRQOL among older adults and it is important to first describe some characteristics of the evaluation procedure.

One of the greatest results achieved during the research project was the high level of compliance during the empirical assessments. In fact, the final level of drop out and missing values was very low and due to reasons not directly related to the project itself. The reasons for the low attrition were attributed to: (i) the inclusion criteria that allowed to select participants without cognitive problems and with a good residual functioning, (ii) the small sample size, that allowed a better relationship between staff and participants, (iii) the role of research staff who reminded the respondents to fill out the questions on a daily basis. Despite this list of favorable aspects, we were not sure a priori about the response rate to daily evaluations, mainly because in such a sample, it was unusual to test and analyze daily self-report characteristics.

However, opinions and qualitative information collected during the course of the project provide additional explanations for the high rate of completed responses. In fact, most of the participants interviewed about the feasibility of the diary completion and their related feelings, answer that, in general, they did not have a problem in filling out the questionnaires. Moreover, they reported us that the use of daily questions forced them to think about the day just passed, and to reason on the activities performed and their related perceptions. Most of the participants were satisfied about this personal reasoning process that helped them to summarize each day and to really be focused and honest with themselves about the health conditions. In some cases, participants reported, after the completion of some weeks of the diary, experiences such as: *"I never realized that my overall health is not so bad. The use of the questionnaires gave me the possibility to think about it. I am still able to walk autonomously, my mind is still lucid and curious and my* *family and my grandsons gave me a lot of support and happiness"*. In our opinion, this qualitative information was as important as the quantitative data reported in this thesis. Moreover, this qualitative information may give important insights about the possibility that perceptions of health may be modified or strengthened by the use of the questionnaire itself, maybe as a result of a sort of metacognitive processes taking place in the respondents. This consideration, which may have practical implications, can be studied and analyzed in further research.

It is necessary to remark that, in this project, qualitative data have not been collected in a standardized way, but they nevertheless offer a starting point for discussion. However, since in most of the cases, collected comments were meaningful for a better comprehension of the reactions to the daily questionnaires, it would be good to rate specifically also these aspects in a next phase of the study.

Finally, as reported in the third paper it also necessary to state that, the use of daily diary-based evaluation was a great change and required effort by participants, and in fact, results in the first weeks were not found sufficiently reliable. However, also this result was relevant information for further analysis, and provided suggestions about the necessary time span for the adaptation to a new demand. Furthermore, the lower reliability in the first few days may be related to perturbations or adaptations to the new demands. From a dynamic systems point of view, the lower reliability does not correspond with less meaningful or less realistic data. In fact, the perturbation or low accordance between the self-report health status and experienced-health components of the daily questions could be part of the developmental process and may be studied in further research. Theoretically, it may be that the first measures are the most genuine ones, while later measures are shaped by the memory and the habits of filling in the list. However, based on the reports of perturbations and adjustment difficulties, we have decided that it is highly likely that the low reliability is the result of perturbations that are not related to the process we want to measure.

In addition to the good compliance (low attrition) of the daily assessments on a quantitative and qualitative side, the third paper reported also some interesting results. First of all, our study demonstrated how just a brief and easy Visual Analogic Scale-based HRQOL questionnaire was able to capture the salient characteristics of the construct, with positive and significant correlations with validated instruments. Moreover, the role of variability was investigated, and significant results were found in relations with the final health outcomes level, long-term trends of HRQOL, and indicators of instability (perturbations) of the system.

In addition to the role of variability in daily data, the use of a Dynamic Systems approach can be useful to detect: (i) the role of time by means of the autocorrelation in the domains of HRQL, (ii) the interconnections among HRQOL components, (iii) the role of life events in the development of the construct, (iv) the impact and characteristics of transitional phases during time, and (v) the role of individual characteristics on the dynamic trajectories and on all the above mentioned aspects. This long list of possibilities suggests a wide variety of things to do in the future and ways to analyze and explore dynamics characteristics of HRQOL.

We believe that one of the main and more intriguing features of the thesis is the analysis of individual trajectories, their relationships with personal characteristics and their comparisons with different subjects. The person-oriented approach is typical of Dynamic Systems (Kunnen, 2012), and in my opinion, it may fit perfectly with the aim and approach pursued by this thesis. Each person is a system, connected and related to the external world, but with specific and unique properties, abilities and ways to react and respond to the thousands of internal and external inputs received each day. Furthermore, it is our aim to reach an individual-based analysis of needs and requests as soon as possible. This study represents a necessary step in the way to achieve, finally, an individualized preventive and health promotion approach.

From this statement, the utility of our data for applied solutions can be quite considerable. The discovery of dynamic trends and the central role of day-to-day variability may be used in several contexts in order to enhance the quality of the proposed services and the life of individuals.

Residential care facilities can be seen as the best setting where the current and classical approaches can be modified and integrated with new and more detailed assessment and intervention strategies. An example of a possible application can be the daily evaluation and analysis of HRQOL inside a residential care facility with a subsequent adaptation of the proposed activities in relation to the real needs of the older adults. This application would imply a more tailor-made plan of activities, with the aim to respond to individual needs and enhance healthy life as much as possible. However, this is just an example of possible applied solutions that in general may be oriented to a better understanding of the impact of different processes in a longitudinal way and to the subsequent introduction or modification of solutions and strategies.

In the case of third paper, the analyses made were, mainly, on a group level, and this was done because it was the first analysis of such longitudinal and time serial data. It is our aim to perform a more detailed and individualized approach in the near future. Specifically: (i)the comparison between individual starting values and trends; (ii) the dynamics between self-report health status and experienced-health measurements of HRQOL on the individual level; (iii) the role of variability in the individual trends and the developmental path; (iv) the intra-individual correlations between the domains in different states of the process (e.g., nearby an extreme value and during a stable state); (v) the role of daily life events in the developmental trends and variability, are aspects that may be investigated, starting from the results and suggestions that arose from this thesis.

The results achieved represent an innovative step in the study of HRQOL, but certainly need to be explored and integrated with a wider data collection, including older adults with different characteristics (e.g., community dwelling, dependent in ADL etc.). Furthermore, longer research periods may provide more information, at least about long term changes, with the possibility to infer the first results obtained here on a longer time scale. Finally, medical and epidemiological indicators can be integrated in the data collection and analysis, in order to obtain a translation and comparison between indicators of HRQOL and medical health markers.

5. Limitations of this thesis

In the development of the mathematical model (paper 2), we had to make decisions concerning the values of the parameters. Because there is no empirical evidence concerning these values, we had to base these decisions on educated guesses and theoretical reasoning. In future analyses, once we have gained more knowledge about the behavior of the model and its fit to different types of empirical findings, it may be necessary to reconsider the choices we made. In order to be as clear and transparent as possible, in the calibration procedure and in the first step of the validation, we decided to test a set of values for this parameters (- .1; .1). Since we found a good fit of the model within this range, it was decided to use the combination of values that created simulated results that were as close as possible to the median value of the empirical data. Despite this methodological precaution, the selection of parameters appears to result in suboptimal choices of individual characteristics growth rates. In order to avoid this limitation, a possible solution in future analyses, is the empirical evaluation of the weight and size that changes in individual conditions have on the three domains of HRQOL.

A second limitation is related to the empirical data of the second paper. Specifically, as reported in the article, the number of missing values largely affected the final sample size. We decided to use, at this stage, data from participants who completed both the evaluation sessions and the whole battery of tests. This choice was made to maintain reliable and real data as much as possible, and because in a dynamic systems approach, common methods for replacement of missing values are considered as invalid, because they are often based on averages, thereby ignoring the variability that is the topic of interest. From what we learned in the third article, the best way to maintain the adherence and to reduce as much as possible the number of missing values, is to personally involve subjects in the process of measurements, making them the first and principal actors of the study, and avoiding the feeling of being just a "lab rat".

Finally, the empirical study counts just two data points (initial and final), and surely, a higher number of data points would have been better to analyze developmental trends and to compare simulated and empirical data. A stronger comparability analysis between empirical and simulated data is urgently needed, in order to analyze similarities in short time scales rather than on the long-term time scales.

The third article presents limitations regarding participants and measures. On the participant side, a first limitation is the voluntary participation. This condition implicitly selected older adults with specific characteristics, such as a higher motivation to participate, a special awareness about their health status, a general good physical and mental health condition, and finally availability to be interviewed several times. In future studies it will be necessary to extend the group from which participants are recruited, including also older adults with lower health conditions and motivation. It is also recommended that new and less invasive assessment tools must be designed, and that the frequency of filling out the questionnaires should be reduced to just twice or three times a week. Specifically, innovative and ICT-based tools are already available to assess a plethora of individual characteristics and variables that may be useful to measure in a transparent and non-invasive way the core variables of HRQOL.

The broadening of the sample characteristics will allow a better and clearer idea about the role of individual conditions on the development of HRQOL. A second limitation is related to the participants is the sample. Currently, a little and (more or less) homogeneous group of older adults participated in the study. This condition was necessary in a first stage of our study, that it was seen as a sort of pilot study. Taking into account the great number of data points and the objectives of the study, the number of participants was adequate, and helped us to address the respondents in a much more individualized and personal way. Furthermore, since finding older adults voluntarily participating in a time serial research design with a daily assessment was difficult, the resulting sample size necessarily remained rather small. However, in the future, it will be necessary to focus on different groups (e.g., normative older-adults, hospitalized patients), in order to reach different target populations and to achieve wider, more relevant and more representative results. To do so and to overcome limitations and enrollment difficulties, some adjustments must be made (e.g., higher number of staff members involved, new and less invasive way of assessment, rewards for participation etc.) but such adjustments would by necessity require more time, more resources and more researchers.

As far as the measurements are concerned, the diary-based VAS questionnaire may need more thorough validation and standardization, although the items were selected carefully for their face validity by two HRQOL researchers. The questions used comply with our conceptual requests and the first data analysis of convergent validity demonstrated satisfactory and significant correlations between daily measures and standardized questionnaires. Moreover, other non-validated and very short instruments have been used to rate HRQOL (Boer et al., 2004, Bowling, 2005; DeSalvo et al., 2006; Sloan et al., 1998). Nevertheless, a more powerful validity analysis of daily measures will be necessary, in order to give greater credibility and strength to the reported results.

Finally, this research aimed to explore the dynamic nature of HRQOL and eventually to create hypotheses for future and more applied studies. This thesis was the first step of a, hopefully, long series of studies and publications on the Dynamic Systems approach to the ageing process. The above-mentioned limitations can be interpreted in the light of this novelty in the approach and to the lack of theories and similar studies in the field of interest.

6. Conclusion

This thesis follows a structure that proceeds progressively from a conceptual to an empirical analysis. In our opinion, this was the better way to proceed and to unravel the dynamic nature and development of HRQOL among older adults on different levels. Each paper is the direct consequence of the previous one, adding new and more concrete insights. Each of the three main chapters of this thesis introduced innovative elements but, in our opinion, it is the whole picture that emerges by doing so, that represents the main strength of the thesis, allowing for the creation of a theoretical framework, extending the current body of literature and the development of new conceptual and applicative solutions and research designs.

A second strength of this thesis is the application of the Dynamic Systems theory and approach in the ageing process. The Dynamic Systems approach enabled us to focus on change processes and mechanisms that drive these processes. In sum, the application of the Dynamic Systems approach is not just a method of conceptualization and analysis, but becomes an iterative process itself, in which theory and empirical results are mutually and repeatedly connected and by doing so influence each other.

Finally, a third strength of the thesis is due to the future perspectives it presents. Europe is continuously and progressively growing old (Giannakouris, 2008), and within this context it is fundamental to find innovative, effective and low cost solutions to tackle ageing process and ageing-related health problems. The topic of healthy ageing becomes central in the whole western world, because it can contribute to providing better solutions for the reduction of individual and societal costs, and the maintenance of an optimal health status in the ageing population (Fries et al., 1993). However, before creating an effective and valid health promotion strategy, it is necessary to know how the health-related constructs develop over time, which are the relevant characteristics in the developmental changes and how different persons behave over time. This thesis creates the basis for this knowledge, shedding new lights on the dynamic and complex nature of HRQOL. For these reasons our research fits perfectly with the requests and needs of an aged population.

7. Epilogue

At the end of this work, I come back to my "original" and initial questions about the lack of causality between stimuli and outcomes, among older adults or within the same subject but in different times. Clearly, this thesis does not give us answers about the effectiveness of interventions or about the different effects that an intervention has on different persons or in different times. Nevertheless, the study we did can provide a basis for finding answers to those questions, and also provided us with an interpretative key of mechanisms and phenomena that may act on an individual level on different time scales, producing non-deterministic, non-linear outcomes.

However, if some questions and doubts start to find an answer, the study of HRQOL as a dynamic system and the analysis of individual developmental trajectories can generate new insights and hypotheses that we would like to answer in the near future.

In this sense, the application of Dynamic Systems approach was fruitful, because it allowed us to discover new and innovative characteristics of the ageing process and create new research and applied perspectives.

Development, changes and variability are, in my opinion, the central aspects that need to be studied and addressed in the next few years, in order to promote healthy behavior and prevent health decline in the ageing process.

“La cosa più durevolmente e veramente piacevole è la varietà delle cose, non per altro se non perché nessuna cosa è durevolmente e veramente piacevole”. (Giacomo Leopardi, 1817)

"The most lasting and truly enjoyable thing is the variety of things, for no other reason than because nothing is lasting and very pleasant." (Giacomo Leopardi, 1817)

8. References

Adamson, H., & Elliott, D. (2005). Quality of life after a critical illness: a review of general ICU studies 1998-2003.

Balboa-Castillo, T., León-Muñoz, L. M., Graciani, A., Rodríguez-Artalejo, F., & Guallar-Castillón, P. (2011). Longitudinal association of physical activity and sedentary behavior during leisure time with health-related quality of life in community-dwelling older adults. *Health and Quality of Life Outcomes*, *9*(1), 47. doi:10.1186/1477-7525-9-47

Berzon, R., Hays, R. D., & Shumaker, S. A. (1993). International use, application and performance of health-related quality of life instruments. *Quality of Life Research*, *2*(6), 367–368. doi:10.1007/BF00422214

Boer, A. G. E. M. de, Lanschot, J. J. B. van, Stalmeier, P. F. M., Sandick, J. W. van, Hulscher, J. B. F., Haes, J. C. J. M. de, & Sprangers, M. a. G. (2004). Is a single-item visual analogue scale as valid, reliable and responsive as multi-item scales in measuring quality of life? *Quality of Life Research*, *13*(2), 311–320. doi:10.1023/B:QURE.0000018499.64574.1f

Bowling, A. (2005). Just one question: If one question works, why ask several? *Journal of Epidemiology and Community Health*, *59*(5), 342–345. doi:10.1136/jech.2004.021204

Chan, S. W., Chiu, H. F., Chien, W., Goggins, W., Thompson, D., & Hong, B. (2009). Predictors of change in health-related quality of life among older people with depression: a longitudinal study. *International Psychogeriatrics*, *21*(06), 1171–1179. doi:10.1017/S1041610209990950

DeSalvo, K. B., Fisher, W. P., Tran, K., Bloser, N., Merrill, W., & Peabody, J. (2006). Assessing Measurement Properties of Two Single-item General Health Measures. *Quality of Life Research*, *15*(2), 191–201. doi:10.1007/s11136-005-0887-2

Dominick, K., Ahern, F., Gold, C., & Heller, D. (2002). Relationship of health-related quality of life to health care utilization and mortality among older adults. *Aging clinical and experimental research*, *14*(6), 499–508.

Engel, G. L. (1977). The need for a new medical model: a challenge for biomedicine. *Science*, *196*(4286), 129–136. doi:10.1126/science.847460

Ferrans, C. E., Zerwic, J. J., Wilbur, J. E., & Larson, J. L. (2005). Conceptual Model of Health-Related Quality of Life. *Journal of Nursing Scholarship*, *37*(4), 336–342. doi:10.1111/j.1547-5069.2005.00058.x

Fries, J. F., Koop, C. E., Beadle, C. E., Cooper, P. P., England, M. J., Greaves, R. F., Sokolov, J. J., Wright, D. (1993). Reducing Health Care Costs by Reducing the Need and

Demand for Medical Services. *New England Journal of Medicine*, *329*(5), 321–325. doi:10.1056/NEJM199307293290506

Haas, B. K. (1999). A Multidisciplinary Concept Analysis of Quality of Life. *Western Journal of Nursing Research*, *21*(6), 728–742. doi:10.1177/01939459922044153

Hickey, D. A., Barker, M., McGee, H., & O'Boyle, C. (2005). Measuring health-related quality of life in older patient populations. *PharmacoEconomics*, *23*(10), 971–993. doi:10.2165/00019053-200523100-00002

Hopman, W. M., Harrison, M. B., Coo, H., Friedberg, E., Buchanan, M., & VanDenKerkhof, E. G. (2009). Associations between chronic disease, age and physical and mental health status. *Chronic diseases in Canada*, *29*(3), 108–116.

Idler, E. L., & Benyamini, Y. (1997). Self-Rated Health and Mortality: A Review of Twenty-Seven Community Studies. *Journal of Health and Social Behavior*, *38*(1), 21–37. doi:10.2307/2955359

Kempen, G. I., Ormel, J., Brilman, E. I., & Relyveld, J. (1997). Adaptive responses among Dutch elderly: the impact of eight chronic medical conditions on health-related quality of life. *American Journal of Public Health*, *87*(1), 38–44. doi:10.2105/AJPH.87.1.38

Kunnen, S. E. (2012). *A Dynamic Systems Approach of Adolescent Development*. Psychology Press.

Kunnen, S. E., & Bosma, H. A. (2000). Development of meaning making: A dynamic systems approach. *New Ideas in Psychology*, *18*(1), 57–82. doi:10.1016/S0732-118X(99)00037-9

Lam, C. L., & Lauder, I. J. (2000). The impact of chronic diseases on the health-related quality of life (HRQOL) of Chinese patients in primary care. *Family Practice*, *17*(2), 159–166. doi:10.1093/fampra/17.2.159

Lima, M. G., Barros, M. B. de A., César, C. L. G., Goldbaum, M., Carandina, L., & Ciconelli, R. M. (2009a). Health related quality of life among the elderly: a population-based study using SF-36 survey. *Cadernos de Saúde Pública*, *25*(10), 2159–2167. doi:10.1590/S0102-311X2009001000007

Lima, M. G., Barros, M. B. de A., César, C. L. G., Goldbaum, M., Carandina, L., & Ciconelli, R. M. (2009b). Impact of chronic disease on quality of life among the elderly in the state of São Paulo, Brazil: a population-based study. *Impacto de las enfermedades crónicas en la calidad de vida de los adultos mayores en el estado de São Paulo, Brasil: estudio poblacional.*, *25*(4), 314–321.

Sillanpää, E., Häkkinen, K., Holviala, J., & Häkkinen, A. (2012). Combined Strength and Endurance Training Improves Health-Related Quality of Life in Healthy Middle-Aged and Older Adults. *International Journal of Sports Medicine*, *33*(12), 981–986. doi:10.1055/s-0032-1311589

Singh, J. A., Nelson, D. B., Fink, H. A., & Nichol, K. L. (2005). Health-related quality of life predicts future health care utilization and mortality in veterans with self-reported physician-diagnosed arthritis: The veterans arthritis quality of life study. *Seminars in Arthritis and Rheumatism*, *34*(5), 755–765. doi:10.1016/j.semarthrit.2004.08.001

Sloan, J. A., Loprinzi, C. L., Kuross, S. A., Miser, A. W., O'Fallon, J. R., Mahoney, M. R., Heid, I. M., Bretscher, M. E., Vaught, N. L. (1998). Randomized comparison of four tools measuring overall quality of life in patients with advanced cancer. *Journal of Clinical Oncology*, *16*(11), 3662–3673.

Steenbeek, H., & van Geert, P. (2005). A dynamic systems model of dyadic interaction during play of two children. *European Journal of Developmental Psychology*, *2*(2), 105–145. doi:10.1080/17405620544000020

Steenbeek, H., & Van Geert, P. (2008). An empirical validation of a dynamic systems model of interaction: do children of different sociometric statuses differ in their dyadic play? *Developmental Science*, *11*(2), 253–281. doi:10.1111/j.1467-7687.2007.00655.x

Thelen, E. (1996). *A Dynamic Systems Approach to the Development of Cognition and Action*. MIT Press.

Thelen, E., Ulrich, B. D., & Wolff, P. H. (1991). Hidden Skills: A Dynamic Systems Analysis of Treadmill Stepping during the First Year. *Monographs of the Society for Research in Child Development*, *56*(1), i–103. doi:10.2307/1166099

Tsai, S.-Y., Chi, L.-Y., Lee, C., & Chou, P. (2007). Health-related quality of life as a predictor of mortality among community-dwelling older persons. *European Journal of Epidemiology*, *22*(1), 19–26. doi:10.1007/s10654-006-9092-z

Van Geert, P. (1994). *Dynamic systems of development: change between complexity and chaos*. New York: Harvester Wheatsheaf.

Van Geert, P., & Steenbeek, H. (2005). Explaining after by before: Basic aspects of a dynamic systems approach to the study of development. *Developmental Review*, *25*(3–4), 408–442. doi:10.1016/j.dr.2005.10.003

Van Geert, P., & van Dijk, M. (2002). Focus on variability: New tools to study intra-individual variability in developmental data. *Infant Behavior and Development*, *25*(4), 340–374. doi:10.1016/S0163-6383(02)00140-6

Visser, M., Verbaan, D., van Rooden, S., Marinus, J., van Hilten, J., & Stiggelbout, A. (2009). A Longitudinal Evaluation of Health-Related Quality of Life of Patients with Parkinson's Disease. *Value in Health*, *12*(2), 392–396. doi:10.1111/j.1524-4733.2008.00430.x

Walker, S. R. (1993). *Quality of Life Assessment: Key Issues in the 1990s*. Springer.

Ware, J., E., & Dewey, J. (2000). Health status and outcome assessment tools. *Int Electronic J Health Education*, *3*(3), 138–148.

Wilson, I., & Cleary, P. (1995). Linking clinical variables with health-related quality of life: A conceptual model of patient outcomes. *JAMA*, *273*(1), 59–65. doi:10.1001/jama.1995.03520250075037

Zubritsky, C., Abbott, K. M., Hirschman, K. B., Bowles, K. H., Foust, J. B., & Naylor, M. D. (2013). Health-related Quality of Life: Expanding a Conceptual Framework to Include Older Adults Who Receive Long-term Services and Supports. *The Gerontologist*, *53*(2), 205–210. doi:10.1093/geront/gns093

SHORT SUMMARY

This thesis deals with the construct of Health Related Quality of Life (HRQOL) in older adults, applying a Dynamic Systems perspective. The focus is on the older adult population because, as demonstrated by the Eurostat data presented in the thesis, Europe is facing a demographic revolution. In fact, the slowdown of the birth and the fertility rates together with the increase of the number of older adults will generate a change in the population pyramid (Pollack, 2005), characterized by a thinning of the pyramid's basis (infants and children) and a huge enlargement of the peak (Giannakouris, 2008).

The ageing of the population is an interesting and challenging topic in many areas of research (e.g. medicine, psychology, sociology, etc.) because the ageing process may have consequences at many different levels.

In general, we can state that the ageing process in the individual person is characterized by a loss of homeostasis (defined as the capacity of a system to maintain internal stability despite external fluctuations) and a reduced ability to respond to the external requests (Weinert & Timiras, 2003). These phenomena cause an increase in the incidence of diseases and finally cause death. Within this context, a huge debate has started about finding the best and most cost-saving preventive strategies that ensure the maintenance of a good health status of the elderly. These preventive strategies may address: (i) the individual level, with the reduction of the unhealthy life expectancy, an increase of the autonomy and a consequent reduction of institutionalization rate; and (ii) the societal level, with a decrease of direct (i.e., hospitalization) and indirect (i.e., loss of quality of life) costs in association with an increase of healthy and active population.

The targets of these strategies all concern HRQOL, a central topic in the study of ageing process. HRQOL refers to physical, mental, and social domains of health. These are seen as distinct areas that are influenced by a person's experiences, beliefs, expectations, and perceptions (Testa & Simonson, 1996). As compared to the broad concept of Quality of Life (QOL), HRQOL narrows the focus to the effects of health, illness, and treatment, and excludes aspects of QOL that are not related to health, such as cultural, political, or societal attributes (Ferrans, Zerwic, Wilbur, & Larson, 2005). HRQOL is a person-centered concept that can be described as a differentiated and complex system consisting of (i) perceptions of physical and psychological-emotional health; (ii) level of independence; (iii) social roles; (iv) relationships; (v) context; and (vi) environmental and working interactions (Testa & Simonson, 1996).

Despite the important role of HRQOL as an outcome and predictor measure, currently, there are still some gaps in the conceptualization and measurement of the construct. From a conceptual point of view, lots of conceptual models have been developed resulting in a high number of instruments, with a low coherence between them.

Furthermore, the most frequently adopted conceptual models are based on a biomedical approach (Wilson & Cleary, 1995), whereas an approach based on the biopsychosocial model may result in a more complete comprehension of the construct. With regard to the application of the construct in research, studies that address the development of HRQOL over time and the developmental relation between the different domains are lacking.

Research into these topics is highly relevant, because knowledge of the developmental process and of the relations between the domains will result in a better understanding of the nature of HRQOL, and in interesting applications in the area of health promotion and prevention of negative health outcomes during the ageing process.

The general aim of the thesis was to study the development of HRQOL from a Dynamic Systems approach in order to get insight in the developmental trajectories and their characteristics, and to analyze developmental trends in older adults. To achieve this general aim, the thesis was divided in three articles (chapters 2-3-4), that deal with the conceptualization, measurement and application of HRQOL with a dynamic systems approach respectively.

The first stage in the analysis of HRQOL among older adults as a dynamic system was the development of a conceptual model. In the thesis specific requirements for this model have been elaborated, namely: (i) the use of a biopsychosocial approach, (ii) the identification of HRQOL as a system that needs to be studied as a whole, (iii) the application of a developmental view, (iv) the use of terminology adopted by the WHO definition of health in the identification of domains, and, finally, (v) for each domain two components should be distinguished in order to capture both the self-report health-status and the experienced-health. Moreover, the conceptual Dynamic Systems model was developed in order to overcome some limitations and fill a number of gaps in the existing literature, such as: (i) the high diversity among current conceptual models (Ferrans et al., 2005), (ii) the lack of uniformity in terminology and model components (Ferrans et al., 2005), (iii) the common conceptualization of relationships as linear and causal (Berzon et al., 1993; Wilson & Cleary, 1995). The model that is developed in the first article tries to fulfil all these requirements, meeting also the major characteristics of Dynamic Systems.

The model describes development of HRQOL as an iterative process. The stable individual parameters act directly on the three main components of the model (being the physical, mental and social domain). This means that higher age, morbidity and presence of negative health behaviors affect each HRQOL domain directly and in a negative way. The influence of the individual characteristics is replicated again and again in the model due to the iterative nature of the model. In this sense, the model is able to take into account the influence of individual conditions in each time point. The three domains of HRQOL are fully connected, because each domain is related to the other ones and to itself, in the next time point. This implies that modifications in the state of one domain may influence also the other two.

The conceptual model that is described in this first article serves as a basis for the development and validation of the HRQOL quantitative model that is described in the second article. In the third paper we describe a time serial analysis of HRQOL among institutionalized older adults.

The mathematical model was conceived and built in order to test and validate theoretical assumptions of the conceptual model, comparing simulated and empirical data, and to depict HRQOL developmental trajectories for specific persons in specific conditions.

The first step taken was the translation of the conceptual model into a mathematical model. Here, we quantified the relations between the components of the model by developing an equation that describes how for each component the value changes between one iteration and the next.

The second step was the calibration procedure, in which simulated developmental trajectories have been compared with theoretical expectations. This analysis was necessary to obtain a first impression about the theoretical plausibility of the trajectories. The tests showed that the model produced theoretically plausible trajectories. The final step was the validation procedure, carried out by comparing empirical and simulated results in several ways. Data showed a good fit between the outcomes produced by the model and the empirical ones, and thus confirmed that the model was able to replicate empirical results.

Our results suggest that the conceptual assumptions that were made in the conceptual model were correct. This gives new insights about HRQOL structure and mechanisms of change in late life. The combination of the conceptual and the mathematical models was the first step in the direction of a dynamic and complex definition of HRQOL. The validated model offers a better understanding, than the existing conceptual models, of processes of changes in the construct under study in individuals. It represents HRQOL as a combination of dynamic and biopsychosocial properties, which are expressed in the form of connections and quantitative relations.

The third part of the thesis consists of an empirical, longitudinal study aimed to test the dynamic development of HRQOL among institutionalized older adults in a real and clinical setting.

Specifically, we focused on the role of HRQOL day-to-day variability on trends and health outcomes. Daily data were assessed in a sample of institutionalized older adults with the use of short and easy diary-based questionnaires, structured on the basis of the HRQOL conceptual model.

This study demonstrated that HRQOL day-to-day variability was related with the final health outcomes level, long-term trends (over 90 days) of HRQOL, and indicators of instability (perturbations) of the system, in the sample of institutionalized participants.

Analysis of the role of variability in daily data is just one of the many possible uses of a Dynamic Systems approach. Other research questions may concern: (i) the role of time by means of the autocorrelation in the domains of HRQL, (ii) the intra-individual interconnections among HRQOL domains, (iii) the role of life events in the developmental trajectories, (iv) the impact and characteristics of transitional phases, and (v) the role of individual characteristics in the dynamic trajectories and in all the above mentioned aspects. This list suggests a wide variety of new questions that can be asked and methods that can be used to analyze and explore dynamic characteristics of HRQOL.

The results in this thesis represent an innovative step in the study of HRQOL, but more research is needed, using a broader sample (for example including older adults with different characteristics such community dwelling, dependent in ADL etc.). Furthermore, research should cover longer periods and thus provide more information about long term changes, with the possibility to extend the first results obtained in the present set of studies to a longer time scale. Finally, medical and epidemiological indicators can be integrated in the data collection and analysis, in order to obtain a translation and comparison between indicators of HRQOL and medical health markers.

Finally, we may conclude that HRQOL can well be conceptualized and studied as a dynamic system. A dynamic systems approach may stimulate the change from a mechanistic to a systems view, allowing to focus on change processes and mechanisms that drive these processes, and on identifying characteristics and indicators of different individual developmental trends. This procedure may result in the development of new person-centered preventive strategies that contribute to the achievement of active and healthy ageing.

References

Berzon, R., Hays, R. D., & Shumaker, S. A. (1993). International Use, Application and Performance of Health-Related Quality-of-Life Instruments - Preface. *Quality of Life Research*, *2*, 367–368. doi:10.1007/Bf00422214

Ferrans, C. E., Zerwic, J. J., Wilbur, J. E., & Larson, J. L. (2005). Conceptual Model of Health-Related Quality of Life. *Journal of Nursing Scholarship*, *37*(4), 336–342. doi:10.1111/j.1547-5069.2005.00058.x

Giannakouris, K. (2008). Population and social conditions. Ageing characteristics the demographic perspectives of the European societies. Eurostat, Statistic in focus.

Pollack, M. E. (2005). Intelligent Technology for an Aging Population: The Use of AI to Assist Elders with Cognitive Impairment. *AI Magazine*, *26*(2), 9. doi:10.1609/aimag.v26i2.1810

Testa, M. A., & Simonson, D. C. (1996). Assessment of Quality-of-Life Outcomes. *New England Journal of Medicine*, *334*(13), 835–840. doi:10.1056/NEJM199603283341306

Weinert, B. T., & Timiras, P. S. (2003). Invited Review: Theories of aging. *Journal of Applied Physiology*, *95*(4), 1706–1716. doi:10.1152/japplphysiol.00288.2003

Wilson, I., & Cleary, P. (1995). Linking clinical variables with health-related quality of life: A conceptual model of patient outcomes. *JAMA*, *273*(1), 59–65. doi:10.1001/jama.1995.03520250075037

SAMENVATTING

Het onderwerp van deze these is de Health Related Quality of Life (HRQOL) in ouderen, bestudeerd vanuit een dynamisch systeem perspectief. Voor de doelgroep ouderen is gekozen omdat Europa het toneel is van een demografische revolutie, zoals te zien in de Eurostat data die worden gepresenteerd in de these. De afname van de geboorte- en de vruchtbaarheidsratio, samen met de toename van de populatie ouderen, veroorzaakt een verandering in de populatiepiramide (Pollack, 2005), waarbij de basis versmalt en de top verbreedt (Giannakouris, 2008).

De verouderende bevolking is een interessant en uitdagend onderwerp in veel onderzoeksgebieden (zoals in de geneeskunde, psychologie, sociologie, enzovoorts) omdat de veroudering effecten heeft op veel verschillende niveaus. In het algemeen kan worden gesteld dat de veroudering gepaard gaat met een verlies van homeostase (gedefinieerd als het vermogen van een systeem om stabiel te blijven ongeacht externe fluctuaties) en de afname van het vermogen om te reageren op externe uitdagingen (Weinert & Timiras, 2003). Dit leidt tot een toename van het aantal ziektes en uiteindelijk tot de dood. De relatieve toename van het aantal ouderen heeft daarom geleid tot een intensief debat over de beste, en de meest kosten-effectieve strategieën om ouderen zo lang mogelijk een goede gezondheid te bieden. Deze strategieën richten zich op 1) het individuele niveau, door de reductie van het verwachte aantal levensjaren met slechte gezondheid, het stimuleren van de autonomie en het verminderen van institutionalisering, 2) op maatschappelijk niveau, door de afname van de directe en indirecte kosten van veroudering. Deze doelen hebben allen betrekking op het construct Health Related Quality of Life. Dit construct is een centraal begrip in het onderzoek naar veroudering. Het verwijst naar gezondheid in zowel het fysieke, mentale als sociale domein. Deze drie domeinen worden gezien als afzonderlijke gebieden, die allen worden beïnvloed door de ervaringen, verwachtingen, percepties en opvattingen van de persoon (Testa & Simonson, 1996). Het construct HRQOL is specifieker dan het construct Quality of Life (QOL), omdat het eveneens focust op ziekte, gezondheid en behandelingen, maar niet-gezondheidsgerelateerde aspecten uitsluit. Hieronder vallen bijvoorbeeld culturele, politieke en maatschappelijke aspecten (Ferrans, Zerwie, Wilbur & Larson, 2005). Het construct HRQOL is een zogenaamd person-centered construct, dit is een construct dat zich richt op de persoon als geheel, en niet op een afzonderlijk kenmerk. Het kan worden beschreven als een gedifferentieerd en gecompliceerd systeem, bestaande uit verschillende onderdelen: i) de perceptie van de eigen fysieke en psycho-sociale gezondheid, ii) de mate van onafhankelijkheid, iii) de sociale rollen, iv) sociale relaties, v) de brede context, en vi) de omgevings- en arbeidsinteracties (Testa & Simonson, 1996).

Hoewel HRQOL een belangrijk construct is dat in onderzoek veel gebruikt wordt als uitkomstmaat en als predictor, bestaan er nog onduidelijkheden in de conceptualisering en de operationalisatie van het construct. Ten aanzien van de conceptualisering zijn er veel verschillende modellen ontwikkeld, resulterend in een groot aantal verschillende meetmethoden met een geringe onderlinge coherentie. Bovendien zijn de meest gebruikte modellen gebaseerd op een biomedische benadering (Wilson & Cleary, 1995), terwijl een biopsychosociaal model betere mogelijkheden biedt voor het conceptualiseren van het construct. Wat betreft de toepassing van het construct in onderzoek blijkt dat onderzoek naar de ontwikkeling van HRQOL over de tijd ontbreekt, evenals onderzoek naar de manier waarop deze ontwikkeling in de verschillende domeinen met elkaar samenhangt. Onderzoek naar deze onderwerpen is van groot belang, omdat kennis van de ontwikkeling van HRQOL en van de relatie tussen de verschillende gebieden zal leiden tot een beter inzicht in de HRQOL, en kan leiden tot zinvolle toepassingen op het gebied van gezondheidsbevordering en het voorkomen van negatieve gezondheidsuitkomsten tijdens het proces van ouder worden.

Het algemene doel van deze these is daarom het onderzoeken van de ontwikkeling van de HRQOL vanuit een dynamisch systeem perspectief, en meer specifiek, om inzicht te verkrijgen in de kenmerken van de ontwikkelingstrajecten van HRQOL bij oudere volwassenen. Op basis van dit algemene doel zijn in de these drie artikelen opgenomen, die achtereenvolgens de conceptualisatie, het kwantificeren, en het toepassen van een dynamisch systeem model beschrijven. De eerste stap in deze analyse van HRQOL ontwikkeling bij ouderen was het ontwikkelen van een conceptueel dynamisch systeem model. In de these zijn een aantal eisen uitgewerkt waaraan dit model moet voldoen: i) het moet gebaseerd zijn op een biopsychosociaal model, ii) het moet HRQOL conceptualiseren als een complex systeem dat als een geheel kan worden bestudeerd, iii) het moet uitgaan van een ontwikkelingsperspectief, iv) het moet aansluiten bij de gangbare terminologie zoals die is geformuleerd in de WHO definitie van gezondheid in verschillende domeinen, v) de verschillende domeinen moeten worden onderscheiden in twee componenten zodat de objectieve situatie en de subjectieve perceptie afzonderlijk zijn opgenomen.

Het dynamische conceptuele model is bovendien ontwikkeld met als doel om een aantal bestaande lacunes en beperkingen te ondervangen, zoals i) de grote diversiteit in bestaande conceptuele modellen, ii) de afwezigheid van uniformiteit in terminologie en componenten van het model (Ferrans et al., 2005), iii) het conceptualiseren van relaties als eenvoudige lineaire causaliteiten (Berzon et al., 1993; Wilson & Cleary, 1995). Het model dat wordt ontwikkeld in het eerste artikel beoogt al deze tekortkomingen te ondervangen en te voldoen aan de hier beschreven eisen.

Dit model beschrijft de ontwikkeling van HRQOL als een iteratief model. Het model onderscheidt het fysieke, psychologische en sociale domein, en beschrijft de ontwikkeling van in deze drie domeinen, beginnend vanuit een zogenaamde “initiële conditie”. Dit betekent dat factoren zoals hogere leeftijd, morbiditeit, en de aanwezigheid van negatieve gezondheidskenmerken de ontwikkeling van ieder van de drie domeinen vanaf het begin beïnvloeden. Het iteratieve karakter betekent dat de uitkomst van iedere ontwikkelingsstap dient als startpunt voor de volgende stap ofwel iteratie. Hierdoor kunnen invloeden vanaf het begin van het model doorwerken in de volgende stappen. Ook invloeden die optreden in latere fasen van de gemodelleerde ontwikkeling worden op deze manier opgenomen in het systeem. De drie domeinen van HRQOL zijn volledig met elkaar verbonden omdat de nieuwe toestand in ieder domein wordt bepaald door de eigen vorige toestand, en de vorige toestand van beide andere domeinen. Hierdoor kunnen veranderingen in één domein leiden tot veranderingen in de beide andere domeinen. Het conceptuele model dat is ontwikkeld in het eerste artikel dient als basis voor de ontwikkeling en de validatie van een kwantitatief dynamisch systeem model in het tweede artikel. In het derde artikel de uitkomsten van dit model worden gebruikt in de analyse van tijdseries van HRQOL metingen bij geïnstitutionaliseerde ouderen.

Het kwantitatieve dynamische systeemmodel is ontwikkeld om de theoretische assumpties, gedaan in het conceptuele model, te valideren door het vergelijken van door het model gesimuleerde data met empirische data van personen in verschillende condities. De eerste stap in de ontwikkeling van het kwantitatieve model was het kwantificeren van de relaties tussen de verschillende componenten in het model. Hiertoe worden vergelijkingen ontwikkeld voor de verschillende componenten die beschrijven hoe de waarde van de component verandert tussen iedere iteratie en de volgende. De volgende stap is de calibratie. Hierin worden gesimuleerde ontwikkelingstrajecten vergeleken met theoretische verwachtingen. Deze stap is nodig om een eerste indruk te krijgen van de plausibiliteit van de gegenereerde trajecten. In deze stap bleek dat de gesimuleerde trajecten theoretisch plausibel waren. De laatste stap bestond uit de validatieprocedure, door middel van het vergelijken - op verschillende manieren - van empirische en gesimuleerde uitkomsten. Hieruit bleek een goede fit tussen de gesimuleerde en empirische data. De uitkomsten toonden aan dat het model in staat is om empirische resultaten te repliceren.

Deze uitkomsten suggereren dat de conceptuele assumpties die zijn gemaakt in het conceptuele model correct waren. Dit geeft nieuwe inzichten in de structuur van

HRQOL en in de veranderingsmechanismen in ouderen. Deze combinatie van een conceptueel en een kwantitatief model vormt een eerste stap in de richting van een dynamische en complexe definitie van HRQOL. Het gevalideerde model beschrijft HRQOL als een combinatie van biopsychosociale kenmerken die iteratief en dynamisch met elkaar interacteren, en dit model biedt beter inzicht in de processen die ten grondslag liggen aan veranderingen in de HRQOL in individuele ouderen.

Het derde onderdeel van deze these bevat een empirische longitudinale studie naar de dynamische ontwikkeling van HRQOL in geïnstitutionaliseerde ouderen in een klinische setting. De focus of dit onderzoek was de invloed van dagelijkse variabiliteit in HRQOL op ontwikkelingstrends en gezondheidsuitkomsten. Dagelijks werden gegevens verzameld van een groep geïnstitutionaliseerde ouderen door middel van korte eenvoudige vragenlijsten, die waren gestructureerd met het conceptuele HRQOL model als uitgangspunt. In dit onderzoek demonstreerden we dat in deze doelgroep de dagelijkse variabiliteit gerelateerd is aan gezondheidsuitkomsten 90 dagen later, aan trends tijdens deze periode, en aan indicatoren van instabiliteit, geoperationaliseerd als extreme waarden van het systeem.

De analyses van de rol van variabiliteit zijn slechts één mogelijkheid van een dynamische systeemaanpak. Andere onderzoeksvragen kunnen betrekking hebben op i) de rol van tijd in de autocorrelaties binnen de verschillende domeinen en ii) de intra-individuele correlaties tussen de domeinen, iii) de invloed van life events op het ontwikkelingsverloop, iv) de impact van transities, en v) de rol van persoonlijke kenmerken in het verloop van de individuele trajecten en in de bovengenoemde relaties. Deze opsomming geeft een indruk van de mogelijke vragen en analysemethodes waarmee de dynamische karakteristieken van HRQOL kunnen worden onderzocht. Hoewel de resultaten in dit proefschrift nieuwe inzichten bieden in de ontwikkeling van HRQOL is er veel meer onderzoek nodig, met andere onderzoeksgroepen, zoals thuiswonende ouderen, en meer behoeftige ouderen. Daarnaast is er een langer durend onderzoek nodig dan de nu gebruikte 90 dagen om ontwikkelingen te onderzoeken over de langere termijn. Bovendien kunnen medische en epidemiologische indicatoren worden opgenomen in het onderzoek, om op deze manier inzicht te krijgen in de relatie tussen HRQOL en indicatoren van gezondheid.

Samengevat kan worden geconcludeerd dat HRQOL goed kan worden geconceptualiseerd en onderzocht als dynamisch systeem. De dynamische systeembenadering kan bijdragen aan de ontwikkeling van een minder statische en mechanistische benadering die ruimte biedt voor het onderzoeken van veranderingsprocessen, van mechanismen die aan deze processen te grondslag liggen, en van indicatoren van verschillen in individuele ontwikkelingstrajecten. Dit kan bijdragen aan de ontwikkeling van nieuwe person-centered strategieën voor het bevorderen van actief en gezond ouder worden.

References

Berzon, R., Hays, R. D., & Shumaker, S. A. (1993). International Use, Application and Performance of Health-Related Quality-of-Life Instruments - Preface. *Quality of Life Research*, *2*, 367–368. doi:10.1007/Bf00422214

Ferrans, C. E., Zerwic, J. J., Wilbur, J. E., & Larson, J. L. (2005). Conceptual Model of Health-Related Quality of Life. *Journal of Nursing Scholarship*, *37*(4), 336–342. doi:10.1111/j.1547-5069.2005.00058.x

Giannakouris, K. (2008). Population and social conditions. Ageing characteristics the demographic perspectives of the European societies. Eurostat, Statistic in focus.

Pollack, M. E. (2005). Intelligent Technology for an Aging Population: The Use of AI to Assist Elders with Cognitive Impairment. *AI Magazine*, *26*(2), 9. doi:10.1609/aimag.v26i2.1810

Testa, M. A., & Simonson, D. C. (1996). Assessment of Quality-of-Life Outcomes. *New England Journal of Medicine*, *334*(13), 835–840. doi:10.1056/NEJM199603283341306

Weinert, B. T., & Timiras, P. S. (2003). Invited Review: Theories of aging. *Journal of Applied Physiology*, *95*(4), 1706–1716. doi:10.1152/japplphysiol.00288.2003

Wilson, I., & Cleary, P. (1995). Linking clinical variables with health-related quality of life: A conceptual model of patient outcomes. *JAMA*, *273*(1), 59–65. doi:10.1001/jama.1995.03520250075037

APPENDICES

ABOUT THE AUTHOR

Mattia Roppolo was born in Torino (IT) in 1985, and he grew up in the small mountain-village of Salbertrand. In 2004, after obtaining his Scientific Baccalaureate, he moved to Torino and he started study Movement and Sport Sciences at the University of Torino. After his Master Degree (magna cum laude) in Adapted Physical Activity, he started his research career, with the supervision of his mentor prof.ssa Silvia Ciairano. He firstly received a research grant “Master dei Talenti della Società Civile” from the Fondazione Giovanni Goria and Fondazione CRT. Within this year, he studied the physical, psychological and social adjustments in women with Multiple Sclerosis who attended a specifically designed physical intervention program. In the meanwhile, he started to work in residential care facilities as trainer for the older adults. In 2011 he began his PhD course in Developmental Psychology, working firstly on the research project ACT ON AGEING. Starting from this project, he developed his curiosity about the complex and dynamics process of ageing. He focused for his thesis on the construct of Health Related Quality of Life among the older adults and he received the joint supervision thesis between the University of Torino and Rijksuniversiteit of Groningen. His main research interest is the analysis of the complex nature of health components and their development during the life course as preventive strategy to avoid or delay ageing-related health outcomes. Currently, he received a grant from Department of Psychology, University of Torino funded by Piedmont Region and the ‘‘Fondo Europeo di Sviluppo Regionale (POR–FESR)’’ for the project ‘‘Sistema di allerta integrato delle fragilità emergenti” and he is studying the developmental trajectories of frailty among community dwelling older adults. He is member of the “European Innovation Partnership on Active and Healthy Ageing” in the working group on “Frailty and Functional Decline”, led by the European Commission. He was awarded by the Italian Ministry of research and education within the call “Smart Cities and Communities and Social Innovation” for the project “A social innovation to evaluate and to prevent frailty in elderly population”.

Mattia was a good mountain-runner athlete. He was Italian champion of mountain running and finished 11th at the Mountain Running World Championship in 2004. Currently he is an amateur runner and trainer for long-distance athletes. He loves sports and competitions and he like to transmit his passion for an active and healthy life to all the people who are around him.

Mattia is married to Anna who is also his collegue. Simone is their little son.

ACKNOWLEDGENMENTS

My interests in research, preventive strategies and complexity have been transmitted me from my mentor prof.ssa Silvia Ciairano. Her unexpected and premature death left me a great sadness, but her enthusiasm and innovative mind will always be with me. My first “grazie” is for Silvia, to whom this thesis is dedicated.

A special thanks is given to my promoters. Dr. Emanuela Rabaglietti, Dr. Saskia Kunnen and Prof. Paul van Geert. Without your teaching, help and support I wouldn’t be able to conclude such an interesting but very difficult and demanding PhD. All of you gave me precious examples on how to perform in the best way a scientific work and how to cope and react to the very frustrating and complicated situations we encounter during the last years. Your support helped me to become a better researcher and a better person.

I wish to thank the members of the assessment committee Prof. Fabio Lucidi, Prof. Peter de Jonge, Prof. Robbert Sanderman and Prof. Elena Marta Rizzi. Many thanks to the time and effort you spent reading my thesis, giving me your honest opinion.

The person who I will never stop thanking is Anna. Anna, you are my colleague, my friend, my wife, and the mother of our amazing Simone. You are always by my side, and you are the only one who constantly help me and push me to reach our (work and life) objectives. Nothing would be the same without you. Thanks. My son Simone with his big smiles and sly look is able to make each day unpredictable, interesting and special. Simone, you made my life full of joy (and even full of responsibilities). Thank you.

I want to thank my family, my mom Mimi, my father Mario, my brother Nicolò. They always believe in me and this is a source of support and confidence that helps me every day. Thanks to my grandparents Linda, Ireneo and Wanda. Thanks to Marisa and Domenico. Your help and support in the everyday activities is fundamental.

Finally, I would like to thank all the PhD students and staff members of the Department of Developmental Psychology at the University of Groningen. You helped me a lot during the months spent in Groningen. It was pleasure to join you.

Thanks very much to all of you and to all the other people who I did not mention here, for your help, support and friendship.

Thank you!

Mattia Roppolo

Torino, September 14, 2015