"How do I feel today?" An analysis of HRQOL variability among Institutionalized older adults

Roppolo, Mattia; Kunnen, Saskia; Mulasso, Anna; Rabaglietti, Emanuela; van Geert, Paul

Published in:
Nonlinear dynamics psychology and life sciences

Nonlinear Dynamics, Psychology, and Life Sciences, Vol. 20, No. 3, pp. 319-352.

"How do I feel today?" An Analysis of HRQOL Variability Among Institutionalized Older Adults

Mattia Roppolo,[1] *University of Torino, Italy,* ***Saskia Kunnen****, Rijksuniversiteit of Groningen, Netherlands,* ***Anna Mulasso****, University of Torino, Italy,* ***Emanuela Rabaglietti****, University of Torino, Italy, and* ***Paul van Geert****, Rijksuniversiteit of Groningen, Netherlands*

Abstract: *Intra-individual variability is a central topic in Nonlinear Dynamical Systems (NDS) studies of human development, because the theory predicts that particular forms or properties of intra-individual variability will serve as indicators or predictors of transitions, 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 disability 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 disability with validated questionnaires were performed. The intra individual variability on a day-to-day basis was found to be related to HRQOL and disability development. Furthermore, life events as operationalized by extreme values in HRQOL were related to the level of day-to-day HRQOL variability. As predicted by NDS theory, day-to-day variability emerges as an important indicator of levels of and changes in HRQOL and disability and as such, it may be an important indicator of developmental processes in old age.*

Key Words: intra-individual variability, diary method, disability, institutionalized older adults, health related quality of life, perturbation

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

[1] Correspondence address: Mattia Roppolo, Department of Psychology, University of Torino, Via Verdi, 10, 10124 – Torino (IT). E-mail: mattia.roppolo@unito.it

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, Moriarity, Stroup, Ford, and Mokdad (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: (a) the analysis of changes over time, (b) the developmental process, and (c) 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: (a) how HRQOL evolves across the ageing process; (b) which are the characteristics of the developmental trends; (c) how patterns of changes are related to health outcomes, and (d) 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 nonlinear dynamical systems (NDS) approach. Such an approach focuses on processes of change and developmental patterns across time (Kunnen, 2012; Thelen, Ulrich, & Wolff, 1991). The process of change that represents the main objective of NDS studies, is complex and multivariate, and depends on continuous and mutual interactions among environmental, individual and inter-individual characteristics across 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 NDS 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 NDS 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). Shifts and sudden jumps are extremely important in NDS 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).

According to Haken's theory of synergetics (Haken, 2013a, 2013b) increased variability in time serial data may indicate the vicinity to a critical value or bifurcation. Haken states that, when a control parameter (a variable outside the system that can push the complex system into different staes) reaches a specific critical value, the system can become unstable. At a critical point, an order parameter (the macroscopic description of the behavior) may undergo a non-equilibrium phase transition (bifurcation) with symmetry breaking, critical slowing down, critical fluctuations and increased variability. These critical situations are one of the predictors of a transition.

In fact, increased variability was also described as a warning signal in the catastrophe theory (Thom & Zeeman, 1974). In catastrophe theory (specifically the cusp model), the shift described by the system from one stable state to another (and different) state is often associated with an increase in variability. This notion is reported also in the Gilmore's theory (Gilmore, 1981), in which catastrophe flags have been described. One of these flag is the so called "anomalous variance", defined as a large increase in the variability of behavioral variables near a catastrophe (Guastello, 2013; Van der Maas & Molenaar, 1992).

Indicators of variability are increasingly used in various areas of behavioral and developmental 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). Moreover, the analysis of dynamic patterns, discontinuous changes and critical instabilities is a central topic in the study of the psychotherapy effects (Heinzel, Tominschek, & Schiepek, 2014). Heinzel et al. used time series data to describe the fluctuations and sudden gains that occur in treatments of patients with obsessive-compulsive disorders following a cognitive-behavioral group therapy. The usefulness of such an approach lies in the identification of self-organizing patterns of changes due to nonstationary and critical instabilities phases across order transitions. Finally, other studies use catastrophe models to describe the patterns of changes. An interesting application is the one proposed by Guastello et al. (2015) in which the authors analyzed data of cognitive workload and fatigue in N-Back tasks. Their results suggest that the use of a catastrophe model provides a better prediction of cognitive workload and fatigue in N-Back tests than to a linear model. This result suggests that across a cognitive activity both cognitive workload and fatigue show bifurcation and non-linear trends that may be well explicated by catastrophe models.

Despite the long list of encouraging studies in the behavioral sciences, 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 if studied over time within one individual, it also gives relevant information about individual processes. In particular, we aim 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 indicate that the system may move outside its attractor basin due to either internal dynamics or to outside disturbances. Extreme values give information about instability and perturbations of a system, relevant characteristics in NDS studies. The focus was on institutionalized older adults because: (a) they generally suffer from larger decreases in HRQOL compared to community dwelling older adults (Noro & Aro, 1996); (b) 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); (c) they live in a controlled environment, giving us the possibility to better understand external and random influences; (d) they are generally worried about their health (Wisocki, 1988), and (e) the use of a process based assessment can make them more aware about their health.

The purpose of the current study 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-term 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 potential indicators of 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: (a) is day-to-day variability related to developmental health outcomes (HRQOL and ADL) and trends? (b) Do the day-to-day HRQOL trajectories proceed with a linear/gradual/smooth or jagged path? (c) How do individuals differ with regard to the distribution of extreme values over time and domains? (d) Is day-to-day variability around perturbations (as defined by an extreme value) higher than the average variability in the whole period of investigation?

METHOD

Participants

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

As reported by the medical staff of the residential care facilities, none of the participants presented behavioral and psychological symptoms of dementia (e.g., aggression, agitation, depression, psychosis, repetitive vocalism, wandering).

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).

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
Family condition (N)		
Never married	2	9
Married	4	18
Widow	16	73
Place of birth (N)		
Northern Italy	20	90
Central Italy	1	5
Southern Italy	1	5
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

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.

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.

Measures

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

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).

In addition, 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).

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, which investigates the self-report health status dimension of social status (namely size of the social network) and the FQS, which focuses on the quality of social relations.

The SF-12 represents the short version of the SF-36, and 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). It 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,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: (a) the social domain is a crucial component of HRQOL, especially in an older population; (b) 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.

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 only 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: (a) How long, during the day, have you performed activities requiring some physical effort? (e.g., housework, walking, hobbies, etc.), (b) How would you rate your physical health today? In the mental domain, the questions were: (a) How long, during the day, did you feel in a good mood? (e.g., calm, peaceful, lively, happy, etc.), (b) How would you rate your psychological/mental health today? Finally, in the social domain the following questions were included: (a) How long, during the day, have you performed social activities? (e.g., meetings with relatives and friends, phone calls, card games etc), (b) 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:

$$y = (x - min) / (max - min) \quad (1)$$

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.

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. Descriptive statistics were 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:

1. 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).

2. 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, the assumption was tested 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.

3. 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.

4. 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.

5. 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 extreme value, 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.

6. A Monte Carlo simulation procedure to analyze differences in individual variability the week before and the week after an extreme value (both positive or negative) in the daily data.

7. 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. The Monte Carlo technique is very suitable for unbalanced data because does not assume normality of the distributions. It computes the probability that a result is given by chance alone simulating that chance by means of a series permutations (with or without replacements) from a distribution. The simulated distribution are compared with a given outcome or distribution, in order to test their differences (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 statistical significance of the difference between the two. These analyses offered information about the behavior of the system nearby a critical point (extreme values).

RESULTS

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 consistency, 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 (p = .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 (p = .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 non-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 men, with a chi-square p-value of .006.

HRQOL Monthly Trends

The monthly trend of HRQOL (computed as aggregated changes in the individual data) shows 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 Fig. 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).

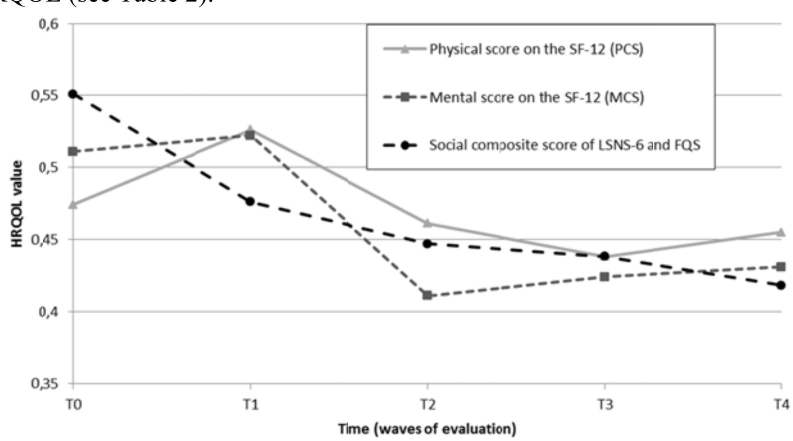

Fig. 1. Average monthly trends of HRQOL over a period of four months. Time (X axis) is presented as waves of evaluation of the monthly measures. HRQOL value (Y axis) is the level of HRQOL on a scale ranging from 0 to 1. Data cover a narrow range between 0.411 to 0.551

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%)

Notes: 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= 2.944 (*df* = 4, *n*= 22, *p* = .567. Statistically significant differences were found for both mental, (χ^2= 14.921 (*df* = 4, *n*= 22, *p* = .005), and social domains (χ^2= 21.215, *df*= 4, *n*= 22, *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 across 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).

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.

Correlation 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. 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, physical domain in T3; max = .712, mental domain in T2).

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 .080 (± .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 $p < .001$. 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.

Correlations between Day-To-Day Variability and Health Development

Results (presented in Table 3) 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 3. 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**

Notes: 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; * $p < .05$; ** $p < .01$

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). 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 of maintaining 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.

Daily Variability, Perturbations and Extreme Values

Variability Before and After a Perturbation (Extreme Value)

We compared the variability in the week before the extreme value with the variability in the week after the extreme value. A total of 12 comparisons (four comparisons for each domain), matching distributions of day-to-day variability of positive and negative extreme values, before and after the extreme value, were made with the Monte Carlo method. The Table 4 shows, that in the physical domain variability before the extreme value was statistically higher than variability after the extreme value, both for positive (p = <.001) and negative (p = .033) extreme values. Variability, near a negative extreme value (defined as the day-to-day variability detected the week before and after the extreme value), was found higher than nearby a positive extreme value, both before (p = .025) and after (p < .001) the peak. These results suggest that before an extreme value, variability was higher and this difference was statistically significant. Furthermore, negative extreme values presented higher variability in comparison with positive extreme values.

Table 4. Monte Carlo comparisons of daily variability before and after perturbations

Domain	*Variability (I)*	*Variability (J)*	*p*	*Variability (I)* *Median*	*Variability (I)* *SE*	*Variability (J)* *Median*	*Variability (J)* *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

Notes: 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

In the mental domain, no differences were found, indicating that variability did not change in the vicinity of an extreme value. Finally, in the social domain variability before an extreme value was higher than after (positive p = .016, negative p = .002). Positive extreme values 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 5. 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

Notes: 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

General Variability Before and After a Perturbation

In the physical domain we found that in the week before an extreme value the variability was significantly higher than the average variability for both positive (p = .003) and negative (p < .001) extreme values. Similar results were found in the mental domain for negative (p = .038) and positive (p = .002) extreme values. In addition, the variability before a negative extreme value in the mental domain was significantly higher than the variability after the extreme value (p = .012). Finally, in the social domain, variability before both a positive and a negative extreme value was higher than variability in the whole period (p = .001) and it was significantly lower after an extreme value (p = .034). Data are presented in Table 5.

These data demonstrate that in the three domains of HRQOL the variability before an extreme value was higher as compared to the variability of the whole period. This actually means that the extreme value corresponds with a peak in variability across 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 extreme value was lower than the variability across the whole period in the mental and social domain.

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 Figs. 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 relatively weak 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 (Fig. 2) showed strictly connected lines of the three components of HRQOL across 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.

Daily 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 many 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.

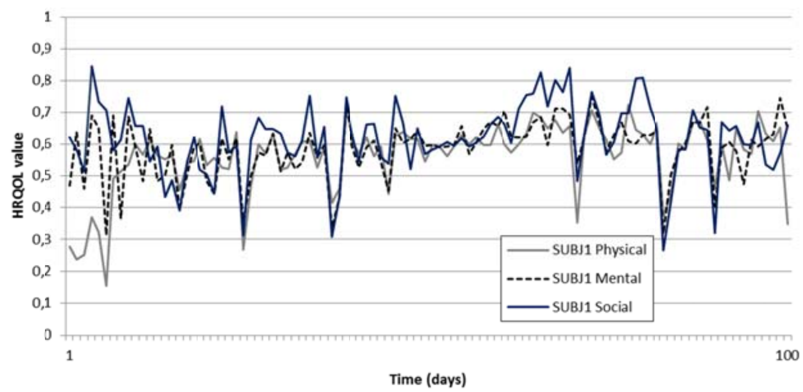

Fig. 2. HRQOL developmental trajectory of three domains over 100 days – subject 1. Time (X axis) is presented as days of observation; HRQOL value (Y axis) is the level of HRQOL on a scale ranging from 0 to ; Note: subject 1 shows a very instable trajectory, with several extreme values in each of the 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 (Fig. 3) showed trajectories 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. Daily 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 always negative. 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). Two single extreme values were found, one in the physical domain on day 36 and one in the mental domain on day 42.

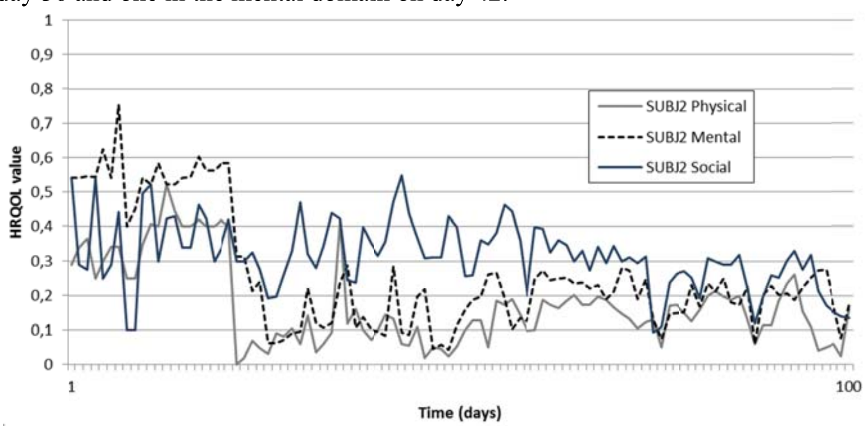

Fig. 3. HRQOL developmental trajectory of three domains over 100 days – subject 2. Time (X axis) is presented as days of observation; HRQOL value (Y axis) is the level of HRQOL on a scale ranging from 0 to 1; subject 2 shows a sudden extreme negative value in days 21 and 22 for all three domains. After 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 across 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 (Fig. 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).

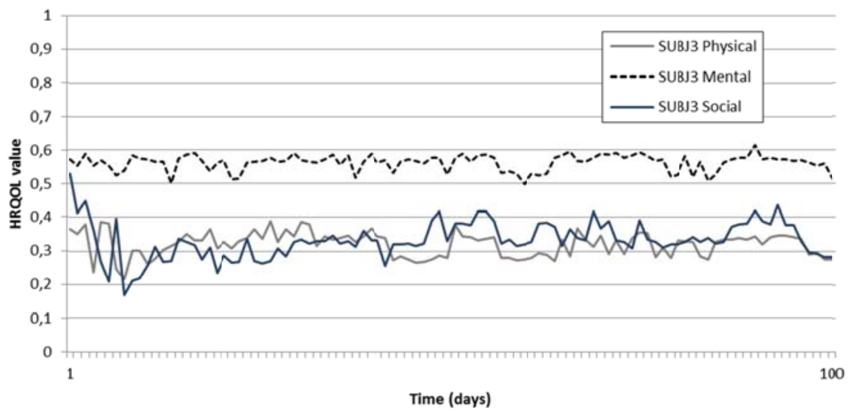

Fig. 4. HRQOL developmental trajectory of three domains over 100 days – subject 3. Time (X axis) is presented as days of observation; HRQOL value (Y axis) is the level of HRQOL on a scale ranging from 0 to 1; subject 3 shows a more stable trend (in comparison with subject 1 and subject 2). The mental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

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. NDS theory affirms that too rigid (thus with low variability) and too flexible (thus with high variability) systems are in general not good, in the sense that they are not adaptive enough. However, the criteria for "too rigid" and "too flexible" depend on the characteristics and types of the systems under study. In fact, research in younger age groups shows that especially lack of variability may be non-optimal for example with regard to the effects of interventions and the quality of functioning (Lichtwarck-Aschoff, Hasselman, Cox, Pepler, & Granic, 2012; Lichtwarck-Aschoff, Kunnen, & van Geert, 2009). It is possible that systems that are too rigid (with completely stable trajectories) 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 smooth trajectories. It was interesting to find almost 50% of extreme values on the positive side, highlighting the possibility to have strong and unexpected positive extreme values 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 extreme values over time and domains. We found that HRQOL development strongly differed among subjects and that for some subjects extreme values 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 across 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. This is a form of negative feedback where a decline in two of the domains is in fact compensated by either an increase or increased stabilization forces in the other domain, in order to shield the system from being drawn in a negative spiral. Finally, the third selected participant, did not show any extreme value 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 extreme values, 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 extreme values, 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 an extreme value variability was, in general, higher as compared to variability of that individual after the extreme value 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 NDS 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. These results seem to be in accordance with Haken's theory of synergetics, in which critical fluctuation indicates that an attractor (stable state) is attenuated in the vicinity of a critical event (perturbation). Moreover, in general, variability before a perturbation was found to be higher than variability after the perturbation. This finding may suggest that the system, after the extreme value, has resettled in a novel stable state (attractor) after the critical event.

It is to notice that in our study day-to-day variability was computed as the absolute difference between two subsequent data points in the individual series. An individual general level of variability was calculated as the average day-to-day variability. This procedure allowed to study the temporal dependency of measurements over time. In future and person oriented approach it will be possible to measure changes across time in the day-to-day variability for a better explanation of the developmental trends.

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. Another potential impact is related to healthy ageing policy makers who may use individual HRQOL assessments 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: (a) preventive strategies, necessary in a world that continues to grow increasingly older, and (b) a person-centered dynamical 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-centered dynamical 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 NDS 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 NDS 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 a dynamic, person-centered approach to 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 across 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, first, we need the voluntary participation of staff and direction members and, second, 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, the selective as of the sample 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.

Fourthly, we used ARIMA as a simple method to find exceptional values. A disadvantage of ARIMA analysis is that is based on linear assumptions. More advanced methods, allowing for nonlinear developmental trends, might reveal slightly different exceptional values. But for the current purposes, the widely available ARIMA analysis seems to be a sufficient first approximation.

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 across the ageing process.

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,* 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. Australian Critical Care, 18*(2), 50-60.

American Psychological Association, A. (n.d.). *Ethical principles of psychologists and code of conduct.* Retrieved October 9, 2013, from http://www.apa.org/ethics/code/index.aspx

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,* 13–26. doi: 10.1007/s11136-012-0117-7

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,* 47. doi: 10.1186/1477-7525-9-47

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. *Developmental Science, 10*, 588–612. doi: 10.1111/j.1467-7687.2007.00629.x

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,* 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*, 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*, 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*, 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*, 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*, 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*, 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*, 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 Publications 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*, 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,* 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., … McBurnie, M. A. (2001). Frailty in Older Adults Evidence for a Phenotype. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 56*, 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., … 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,* 1171–1178. doi: 10.1016/S0895-4356(98)00109-7

Gilmore, R. (1981). *Catastrophe theory for scientists and engineers*. New York: Wiley.

Guastello, S. (2013). Catastrophe theory and its applications to I/O psychology. In J. M. Cortina & R. S. Landis (Eds.), *Frontiers of methodology in organizational research* (pp. 29–61). New York: Routledge.

Guastello, S. J., Reiter, K., Malon, M., Timm, P., Shircel, A., & Shaline, J. (2015). Catastrophe models for cognitive workload and fatigue in N-back tasks. *Nonlinear Dynamics, Psychology, and Life Sciences, 19*, 173–200.

Haas, B. K. (1999). A multidisciplinary concept analysis of quality of life. *Western Journal of Nursing Research, 21*, 728–742. doi: 10.1177/01939459922044153

Haken, H. (2013a). *Principles of brain functioning: A synergetic approach to brain activity, behavior and cognition*. New York: Springer Science & Business Media.

Haken, H. (2013b). Synergetics: Introduction and advanced topics. New York: Springer Science & Business Media.

Hawthorne, G. (2006). Measuring social isolation in older adults: Development and initial validation of the friendship scale. *Social Indicators Research, 77,* 521–548. doi: 10.1007/s11205-005-7746-y

Hawthorne, G. & Griffith, P. (2000). *The friendship scale: Development and properties*. Centre for Health Program Evaluation (Working Paper 114). Retrieved from http://arrow4.lib.monash.edu.au:8080/vital/access/manager/Repository/monash:2605

Heinzel, S., Tominschek, I., & Schiepek, G. (2014). Dynamic patterns in psychotherapy--discontinuous changes and critical instabilities during the treatment of obsessive compulsive disorder. *Nonlinear Dynamics, Psychology, and Life Sciences, 18*, 155–176.

Hickey, D. A., Barker, M., McGee, H., & O'Boyle, C. (2005). Measuring health-related quality of life in older patient populations. *PharmacoEconomics, 23*, 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*, 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*, 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*, 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*, 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*, 179–186.

Jones, M. B. (1977). Health status indexes: The trade-off between quantity and quality of life. *Socio-Economic Planning Sciences, 11*, 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*, 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*, 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*, 2085–2091. doi: 10.2105/AJPH.2007.114041

Kunnen, S. E. (2012). *A dynamic systems approach of adolescent development*. New York: Psychology Press.

Kunnen, S. E., & 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

Lichtwarck-Aschoff, A., Hasselman, F., Cox, R., Pepler, D., & Granic, I. (2012). A characteristic destabilization profile in parent-child interactions associated with treatment efficacy for aggressive children. *Nonlinear Dynamics, Psychology, and Life Sciences, 16*, 353–379.

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*, 1364–1375. doi: 10.1037/a0016713

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*, 892–900. doi: 10.1111/j.1532-5415.2004.52255.x

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*, 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*, 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,* 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*, 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*, 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*, 355–366. doi: 10.1007/BF00433920
Nunnally, J. C. (1978). *Psychometric theory* (2nd 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,* 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*, 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*, 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*, 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,* 151–161.
Rockwood, K., Howlett, S. E., MacKnight, C., Beattie, B. L., Bergman, H., Hébert, R., … 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,* 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*, 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*:57. doi: 10.1186/1471-2318-10-57
Savelsbergh, G. J. P., van der Maas, H., & van Geert, P. (Eds., 1999). *Non-linear developmental processes*. Amsterdam: 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,* 1–5. doi: 10.2307/20182248

Siegler, R. S. (2007). Cognitive variability. *Developmental Science, 10*, 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*, 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*, 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*, 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*, 81–89. doi: 10.1378/chest.126.1.81

Thelen, E. (1996). *A dynamic systems approach to the development of cognition and action*. Cambridge, MA: 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*, i–103. doi: 10.2307/1166099

Thom, R., & Zeeman, E. C. (1974). Catastrophe theory: Its present state and future perspectives. In A. Manning (Ed.), *Dynamical Systems-Warwick 1974, Lecture Notes in Mathematics* (vol 468. pp. 366-372). Berlin: Springer-Verlag.

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*, 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*, 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*, 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*, 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*, 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,* 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,* 93–94.

Wisocki, P. A. (1988). Worry as a phenomenon relevant to the elderly. *Behavior Therapy, 19*, 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*, 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*, 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*, 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,* 205–210. doi: 10.1093/geront/gns093.