Multidimensional model of apathy in older adults using partial least squares—path modeling

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Abstract Apathy defined as a mental state characterized by a lack of goal-directed behavior is prevalent and associated with poor functioning in older adults. The main objective of this study was to identify factors contributing to the distinct dimensions of apathy (cognitive, emotional, and behavioral) in older adults without dementia. One hundred and fifty participants (mean age, 80.42) completed self-rated questionnaires assessing apathy, emotional distress, anticipatory pleasure, motivational systems, physical functioning, quality of life, and cognitive functioning. Data were analyzed using partial least squares variance-based structural equation modeling in order to examine factors contributing to the three different dimensions of apathy in our

sample. Overall, the different facets of apathy were associated with cognitive functioning, anticipatory pleasure, sensitivity to reward, and physical functioning, but the contribution of these different factors to the three dimensions of apathy differed significantly. More specifically, the impact of anticipatory pleasure and physical functioning was stronger for the cognitive than for emotional apathy. Conversely, the impact of sensitivity to reward, although small, was slightly stronger on emotional apathy. Regarding behavioral apathy, again we found similar latent variables except for the cognitive functioning whose impact was not statistically significant. Our results highlight the need to take into account various mechanisms involved in the different facets of apathy in older adults without dementia, including not only cognitive factors but also motivational variables and aspects related to physical disability. Clinical implications are discussed.

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Introduction

Apathy corresponds to a quantitative reduction in goal-directed behavior. It constitutes a major neuropsychiatric symptom following both acquired and neurodegenerative neurological disorders such as stroke (Caeiro et al. 2013), brain injury (Lane-Brown and Tate 2009), Alzheimer's disease (Levenson et al. 2014), or

Parkinson' disease (Pagonabarraga et al. 2015). In these neurologic disorders, apathy has been constantly associated with functional impairments (Jorge et al. 2010; Landes et al. 2001), caregiver burden, anxiety, and depression (Ishii et al. 2009; Lou et al. 2015). Thus, whatever the pathology (Konstantakopoulos et al. 2011), apathy constitutes a fundamental target for pharmacological and psychosocial interventions, because it has a negative impact on rehabilitation effort. However, interventions for this frequent behavioral condition have provided limited evidence of efficacy (Drijgers et al. 2009; Rea et al. 2014). If Marin et al. (1991) originally considered apathy as a motivational disorder, other influential researchers (Stuss et al. 2000; Levy and Dubois 2006) argued that apathy cannot be clinically defined as a lack of motivation, notably because the assessment of motivation is problematic and usually requires inferences based on observations of affect or behavior. While conceptualizations of apathy vary in the terminology these authors use (e.g., intellectual curiosity vs. interest, initiative vs. action initiation), there is general agreement across most definitions for cognitive, behavioral, and emotional components (Njomboro and Deb 2014; Robert et al. 2009). In this context, apathy implicates a constellation of cognitive, behavioral, and affective symptoms including lack of interest in pursuing goal-directed activities, emotional blunting, and lack of initiative (Marin et al. 1991; Mulin et al. 2011; Robert et al. 2002).

In older adults without dementia, clinical apathy is a commonly observed symptom, with a prevalence ranging from 1.4 to 3.1 % (Onyike et al. 2007), increasing with age in otherwise healthy community-dwelling individuals (Brodsky et al. 2010). Similarly to older adults with neurological disorders, apathy in healthy elderly has severe functional consequences (Onyike et al. 2007; Rog et al. 2014) and contributes to perceived reduced quality of life (Groeneweg-Koolhoven et al. 2014). In addition, symptoms of apathy, such as lost of interest, has been shown to be associated with the development of Alzheimer's dementia (Mossaheb et al. 2012) and of mild cognitive impairment in cognitively normal elderly individuals (Grool et al. 2014).

Despite growing interest in the diagnosis and the consequence of apathy in normal aging, previous studies have several limits. As discussed above, there is now evidence that apathy can no longer be considered as a unique construct but rather as a multidimensional psychopathological state with different underlying psychological,

biological, or environmental processes. Moreover, apathy in normal aging was analyzed using a categorical approach in which individuals are categorized into two categories, those who are "apathetic" and those who are "not apathetic." Nevertheless, current evidence suggests that neuropsychiatric symptoms are better viewed as a continuum or spectrum ranging from "mild" to "severe" impairments, rather than simple categorical disorders (Arnould et al. 2013). Such a continuous approach allows to better capture the diversity and complexity of the apathetic manifestations, particularly in non-clinical sample at high risk of developing later apathy such as older people (Grool et al. 2014). In addition, the exploration of apathy in normal aging remains mostly descriptive, and in contrast to neurodegenerative or acquired neurological diseases, its underlying components are poorly understood. From a transdiagnostic perspective, several psychological components appear involved in apathy in both neurological diseases and psychiatric disorders, notably cognitive impairments such as executive dysfunctioning (Konstantakopoulos et al. 2011), depression (see Arnould et al. 2013 for a review), sensitivity to reward (Rochat et al. 2013), anticipatory pleasure (Jordan et al. 2013), and global and physical activity (Telenius et al. 2015).

In view of the abovementioned contributing factors to apathy and the consideration of apathy as a multidimensional construct, three comprehensive models were derived (Fig. 1) and tested. Although Fig. 1 presents only the direct effect of the predictor variables on apathy, we also tested the interactions between these variables, that is, both the direct and indirect effects of these variables on apathy. Thus, this study aimed to identify how these factors (i.e., executive functions, depression, anticipatory and consummatory pleasure, sensitivity to reward and punishment, and subjective quality of life) are related to the distinct dimensions of apathy in a sample of cognitively normal older adults. From a clinical perspective, such an approach would guide the development of an individualized treatment of apathetic manifestations that in cognitively normal older adults (Pagonabarraga et al. 2015).

Material

Participants

One hundred and fifty healthy older adults participated in the study. The participants were recruited through

Fig. 1 Examined contributors to apathy

flyers posted in community centers. They were non-institutionalized and were capable of managing their own household. Exclusion criteria for all subjects were a score lower than 26 in the Mini Mental State Examination (MMSE, Folstein et al. 1975), the presence of psychiatry diseases, substance abuse, or dependence as confirmed by the Mini International Neuropsychiatric Interview (MINI). In addition, individuals with the presence or antecedents of neurological disorders (i.e., dementia, delirium, history of head trauma, Parkinson's disease, and multiple sclerosis) and cerebrovascular diseases (i.e., myocardial infarction, angina pectoris, congestive heart failure, peripheral artery disease, stroke, and transient ischemic attack) were also excluded.

All the participants were native French speakers, with normal or corrected-to-normal vision and hearing. Premorbid IQ was assessed by French National Adult Reading Test (fNART; (Mackinnon and Mulligan 2005). Clinical and sociodemographic data are presented in Table 1.

Measures

Apathy

Apathy was quantified using the self-rated Apathy Evaluation Scale (AES), a psychometrically validated instrument in older normal individuals (Marin et al. 1991; Clarke et al. 2007). The 18 items on the scale assess behavioral apathy symptoms (e.g., He/she spends time doing things that interest her/him), emotional apathy symptoms (e.g., When something good happens, he/she gets excited), and cognitive apathy symptoms (e.g., S/he

is interested in things). Each item is rated on a scale from 1 (not at all) to 4 (a lot). Note that the AES has not been validated in French language. In addition, self-reported AES scores may be more sensitive to measure apathy than informant and clinician report when subjects are cognitively normal elderly (Guercio et al. 2015).

Neuropsychological assessment

Working memory

Letter-Number Sequencing Subtest (LNS) of the Wechsler Adult Intelligence Scale-III (Wechsler 1997) The LNS is a measure of verbal working memory (both retention and manipulation of information). Mixed lists of digits and letters were read aloud to the participants who were asked to recall each list in the correct numerical and alphabetical order. The total number of correct trials was summed to create a LNS score. This task correlates strongly with laboratory working memory measures (e.g., operation span) and is a good predictor of fluid intelligence (Shelton et al. 2009).

Inhibition

Hayling Test (Burgess and Shallice 1997) The Hayling test evaluates inhibition and is composed of two sections: the automatic condition and the inhibition condition. Both sections of the test consist of 15 sentences, each missing the last word. In section 1, participants listened to each sentence and were instructed to verbally generate a word that correctly completed the sentence as quickly as possible. In section 2, participants were required to verbally generate a word that did not correctly

Table 1 Descriptive statistics

	Mean	Std. deviation
Age	80.42	8.83
Years of education	9.25	4.11
Premorbid IQ (fNART)	107.36	6.89
Gender (male), <i>N</i> (%)	81 (60.4 %)	
Apathy assessment		
Apathy (AES global score)	24.17	18.08
Cognitive apathy (AES cognitive score)	7.43	6.34
Behavioral apathy (AES behavioral score)	3.87	4.31
Emotional apathy (AES emotional score)	2.38	1.88
Cognitive assessment		
Working memory	8.31	2.59
Inhibition (Hayling Test)	105.95	105.87
Inhibition (Stroop D-KEFS—errors)	3.16	5.14
Inhibition (Stroop D-KEFS—time)	93.49	38.91
Flexibility (Stroop D-KEFS—errors)	4.52	5.02
Flexibility (Stroop D-KEFS—time)	95.84	37.04
Flexibility (TMT D-KEFS)	176.82	126.55
Verbal fluency (semantic)	15.32	4.86
Verbal fluency (phonemic)	11.75	4.26
Clinical assessment		
Depression (BDI-II)	10.49	7.14
Consummatory and anticipatory pleasure	33.86	8.74
Sensitivity to punishment	44.31	9.52
Sensitivity to reward	33.81	7.95
Apathy (AES global score)	24.17	18.08

Cognitive, behavioral, and emotional apathy: Apathy Evaluation Scale; working memory: Letter-Number Sequencing; inhibition: Hayling Test and Stroop D-KEFS condition 3; flexibility: TMT D-KEFS condition 3 and Stroop D-KEFS condition 4; premorbid IQ: fNart; verbal fluency; depression: Beck Depression Inventory; state and trait anxiety: State Trait Anxiety Inventory; anticipatory pleasure: Temporal Experience of Pleasure Scale; sensitivity to reward and to punishment: Sensitivity to Punishment and Reward Questionnaire

complete the sentence and was unconnected to the sentence in every possible way. Outcome measure included mean responses latencies for the section 2.

Inhibition and flexibility

Delis-Kaplan Executive Function System Stroop Test from the Delis-Kaplan Executive Function System (Stroop D-KEFS; Delis et al. 2001) The Stroop D-

KEFS is composed of the three traditional Stroop conditions (color naming, color name reading, interference) as well as a fourth condition in which the subject switches back and forth between naming the dissonant ink colors and reading the conflicting color names. The third and forth conditions were analyzed in the present study (inhibition and flexibility, respectively). Errors and time (in seconds) taken to complete each condition were used as the outcome measures.

Cognitive flexibility

Delis-Kaplan Executive Function System Trail Making Test from the Delis-Kaplan Executive Function System (TMT D-KEFS; Delis et al. 2001) The TMT D-KEFS includes five conditions: the number sequencing task (condition 1) which measures basic numeral processing and requires visual scanning/attentional scanning and motor functions, the letter sequencing task (condition 2) which measures fundamental verbal skill of letter sequencing, the visual scanning task (condition 3) which provides a quick test of visual scanning and visual attention, the motor speed task (condition 4) which assesses psychomotor speed, and the number-letter switching task (condition 5) which measures cognitive flexibility. Errors and time (in seconds) taken to complete each task were used as the outcome measures.

Verbal fluency

Validated French adaptations of phonemic and semantic fluency tasks were administered (Cardebat et al. 1990) In the phonemic task, participants were allowed 2 min to generate as many words beginning with the letter P as possible. In the semantic task, they had to generate as many names of animals as possible for 2 min.

Affective variable

Depression

Twenty-one-item Beck Depression Inventory-II (BDI-II; Beck et al. 1996) The BDI-II measures the severity of self-reported depression and addresses all nine of the diagnostic criteria for a major depressive episode that are listed in the DSM-IV-TR. It is scored by summing the highest ratings for each of the 21 symptoms. Each

symptom is rated on a four-point scale ranging from 0 to 3, and total scores can range from 0 to 63.

Emotional and motivational assessment

Anticipatory and consummatory pleasure

Temporal Experience of Pleasure Scale (TEPS; Gard et al. 2006; Favrod et al. 2009 for the French version) Anhedonia has been characterized as comprising both anticipatory and consummatory pleasure deficits. Anticipatory anhedonia refers to the inability to generate a desire for a future reward (“wanting”), whereas consummatory anhedonia is the inability to experience pleasure upon receipt of a reward (“liking”). The TEPS measures momentary pleasure and anticipation of pleasure in future activities. It is an 18-item self-report measure of anticipatory (10 items) and consummatory (8 items) pleasure. The mean theoretical range of the two scales goes from 1 to 6; higher scores indicate more pleasure.

Sensitivity to punishment and reward

Sensitivity to Punishment and Reward Questionnaire short version (SPSRQ; Torrubia et al. 2001) The SPSRQ is a self-report measure assessing a participant’s appetitive (SR) and aversive (SP) motivational system functioning levels in adolescent and adult populations. The French short version of the SPSRQ (Lardi et al. 2008) is comprised of 35 items, similar to that developed by O’Connor et al. (2004), of which 17 assess SR and 18 assess SP. The participants have to evaluate whether these items fit their personality on a four-point Likert scale, with 1 = totally true and 4 = totally wrong, with responses being summated to form SR and SP scores.

Quality of life

SF-36 Quality of Life Questionnaire (Ware and Sherbourne 1992) The SF-36 is a widely used questionnaire for measuring self-reported physical and mental health status. This comprehensive short form with only 36 questions yields an eight-scale health profile (physical functioning, role physical, bodily pain, general health, vitality, social functioning, role emotion, and mental health) as well as summary measures of health-related quality of life. In the present study, we focused

on the physical functioning, bodily pain, and mental health subscores.

Procedure

The participants were tested individually in a quiet environment. The participants completed all measures in one session. Prior to the study, all the procedures were explained to the participants and their written consent was obtained. During the interview, clinical cardiovascular diseases were defined as self-report of the following: myocardial infarction, angina pectoris, congestive heart failure, peripheral artery disease, stroke, and transient ischemic attack. Then, the participants completed the MMS, followed by the neurocognitive evaluation and after the different questionnaires. Each participant completed the questionnaires in a varied sequence, as the order was counterbalanced. The study was carried out according to the code of ethics of the World Medical Association (declaration of Helsinki). The University of Montpellier 3 Institutional Review Board approved this study and all subjects provided informed consent.

Statistical analysis

The data were analyzed using partial least squares variance-based structural equation modeling (PLS-SEM) in order to model for simultaneous relationships among multiple constructs. PLS-SEM has a number of advantages over other techniques including first-generation techniques and covariance-based SEM. For instance, PLS-SEM is an exploratory technique based on an ordinary least squares regression method, which used the available data to estimate the path relationships in complex models. Moreover, PLS-SEM makes practically no assumptions about data distribution and works efficiently with small sample sizes and complex models (Hair et al. 2014).

PLS-SEM first tests the relationship among latent variables (LVs). Latent variables are used to measure a phenomenon that is abstract and complex concepts. We can measure this phenomenon indirectly using a set of different indicators that represent a single aspect of the larger concept. The latent variable combines several items to measure a single concept and thus can be considered a more accurate measure since it is more likely to represent the most relevant aspects of the concept. Secondly, it provides a measurement model and a structural model (Haenlein and Kaplan 2004).

Smart PLS statistical software was used for the data analysis (Ringle et al. 2005).

All variables were included in the PLS-SEM analysis as explanatory variables.

PLS-SEM was performed taking into account the variables presented in the Fig. 1, but we also evaluated the indirect effect of some latent variables on apathy. First, all variables were included as possible apathy predictors. Only indicators, LVs, and paths that reached the significance level of 0.05 were retained in the model after Bootstrapping analysis. Moreover, indicators were only retained if (1) the indicator loadings (indicator reliability) were higher than 0.6, (2) the composite reliability (internal consistency reliability) was higher than 0.6, and (3) the average variance extracted (convergent validity) was higher than 0.5. The discriminant validity (cross-loadings) was also checked.

Regarding the structural model, the confidence intervals of the PLS-SEM coefficients were obtained by cross-validation, and the Q2 index was calculated to measure the predictive power of the model. The best predictive model was obtained by maximizing the Q2.

Results

Sociodemographic, cognitive, and clinical data

Mean and standard deviation for the variables included in the models are presented in Table 1. It includes all sociodemographic measures, cognitive evaluation, and other clinical data (e.g., depression).

PLS-SEM analysis

We computed a model for each type of apathy: cognitive, emotional, and behavioral.

Model 1: cognitive apathy

Measurement model Reliability results and discriminant validity measures are given in Table 2. Measures of internal consistency and reliability, as indexed by the composite reliability, range from 0.734 to 0.936, exceeding the recommended threshold value of 0.70 (Bagozzi and Yi 1988). Similarly, the average variance extracted (AVE) exceeds 0.50 for each measure (Fornell and Larcker 1981).

Variances extracted (shown in the matrix diagonals) are greater in all cases than the off-diagonal elements in their corresponding row and column, supporting discriminant validity at the LV level. In order to test the convergent validity, we extracted the factor and the cross-loadings for all indicators to their respective LV (see supplementary data). Each item's factor loading is significant ($p < 0.05$) and higher than 0.67 (Chin 2010).

Structural model The structural model results are displayed in Fig. 2. The model is statistically significant, $t = 8.371$, $p < 0.001$, with R^2 equals to 0.51. All beta paths are statistically significant ($p < 0.05$; see supplementary files). Cognitive functioning, sensibility to reward, anticipatory pleasure, gender, age, and perceived physical functioning have a direct and significant influence on cognitive apathy. The indirect impact of age on cognitive apathy was also significant, $\beta = 0.113$, $p = 0.003$, $R^2 = 0.14$, $p = 0.048$.

The effect size (F^2) of each path is displayed in Table 3. Finally, the model predictive power was examined by calculating the Q^2 index of cognitive apathy ($Q^2 = 0.25$). The result indicated that the model predictive power exceed the recommended threshold value ($Q^2 > 0$), indicating an adequate predictive validity (Haenlein and Kaplan 2004).

Model 2: emotional apathy

Measurement model Like in the previous model, reliability results and discriminant validity measures are given in Table 2. The measures of internal consistency (composite reliability) exceed the recommended threshold value of 0.70 (Bagozzi and Yi 1988). Likewise, the AVE exceeds 0.50 for each measure (Fornell and Larcker 1981). The square roots of the AVE (shown in the matrix diagonals) are greater than the off-diagonal elements in their corresponding row and column in all cases, supporting discriminant validity at the LV level. Regarding the convergent validity for the emotional apathy model (see supplementary data), each item's factor loading was significant ($p < 0.05$) and higher than 0.65.

Structural model The results show that the structural model is statistically significant, $t = 6.710$, $p < 0.001$, with R^2 equals to 0.41. All beta paths are statistically significant ($p < 0.05$; see supplementary files). Cognitive functioning, sensibility to reward,

Table 2 Assessment of the measurement model and discriminant validity of variable constructs

	Composite reliability	AVE	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Model 1: cognitive apathy									
Age	1.000	1.000	1.000						
Anticipatory pleasure	0.875	0.636	-0.304	0.798					
Cognitive apathy	0.889	0.536	0.495	-0.456	0.732				
Cognitive function	0.741	0.580	0.159	0.061	0.282	0.762			
Gender	1.000	1.000	0.098	-0.008	-0.123	0.018	1.000		
Physical functioning	0.935	0.594	-0.384	0.068	-0.499	-0.411	-0.032	0.770	
Reward	0.816	0.596	-0.258	0.055	-0.320	-0.015	0.046	0.246	0.772
Model 2: emotional apathy									
Anticipatory pleasure	0.873	0.633	0.796						
Cognitive apathy	0.742	0.576	0.066	0.759					
Cognitive function	0.789	0.53	-0.344	0.318	0.808				
Physical functioning	0.936	0.597	0.070	-0.419	-0.464	0.772			
Reward	0.79	0.557	0.061	-0.036	-0.355	0.234	0.747		
Model 3: behavioral apathy									
Age	1.000	1.000	1.000						
Anticipatory pleasure	0.874	0.635	-0.294	0.797					
Behavioral apathy	0.891	0.620	0.316	-0.42	0.788				
Gender	1.000	1.000	0.095	-0.001	-0.201	1.000			
Physical functioning	0.934	0.589	-0.396	0.08	-0.286	-0.039	0.768		
Reward	0.829	0.714	0.18	-0.071	0.219	0.116	0.106	0.845	

AVE average variance extracted

anticipatory pleasure, and perceived physical functioning have a significant influence on emotional apathy (Fig. 3).

The effect size (F^2) of each path is displayed in Table 3. The model predictive power (Q^2 index) of emotional apathy is equal to 0.22. The result indicated that the model predictive power exceeds the recommended threshold value ($Q^2 > 0$), indicating an adequate predictive validity (Haenlein and Kaplan 2004).

Model 3: behavioral apathy

Measurement model As for the previous models, measures of internal consistency (composite reliability) and the AVE exceed the recommended threshold value of 0.70 (Bagozzi and Yi 1988) and 0.50, (Fornell and Larcker 1981) respectively (Table 2). The discriminant validity at the LV level is also supported by the square roots of the AVE (shown in the matrix diagonals).

Fig. 2 Structural model results (model 1)

Table 3 Effect sizes of the structural model paths

Paths	F^2	Magnitude of the effect
Model 1: cognitive apathy		
Age on physical functioning	0.173	Moderate
Age on cognitive apathy	0.077	Low
Anticipatory pleasure on cognitive apathy	0.266	Moderate to high
Cognitive function on cognitive apathy	0.039	Low
Gender on behavioral apathy	0.049	Low
Reward on cognitive apathy	0.050	Low
Physical functioning on cognitive apathy	0.131	Moderate
Model 2: emotional apathy		
Anticipatory pleasure on emotional apathy	0.171	Moderate
Cognitive function on emotional apathy	0.058	Low
Reward on emotional apathy	0.106	Low to moderate
Physical functioning on emotional apathy	0.112	Moderate
Model 3: behavioral apathy		
Age on physical functioning	0.186	Moderate
Anticipatory pleasure on behavioral apathy	0.218	Moderate
Gender on behavioral apathy	0.088	Low
Reward on behavioral apathy	0.093	Low
Physical functioning on behavioral apathy	0.127	Low to moderate

Greater values were observed in all cases compared to the off-diagonal elements in their corresponding row and column. Regarding the convergent validity for the behavioral apathy model (see supplementary data), each item's factor loading was significant ($p < 0.05$) and higher than 0.65.

Structural model The results showed that the structural model is statistically significant, $t = 3.499$, $p < 0.0001$,

Fig. 3 Structural model results (model 2)

with R^2 equals to 0.32. All beta paths are statistically significant ($p < 0.05$; see supplementary files). The indirect impact of age on behavioral apathy was also significant, $\beta = 0.115$, $p = 0.003$, $R^2 = 0.149$, $p = 0.036$. Sensibility to reward, anticipatory pleasure, and perceived physical functioning have a significant influence on behavioral apathy.

The effect size (F^2) of each path is displayed in Table 3. The model predictive power (Q^2 index) of behavioral apathy is 0.20. The result indicated that the model predictive power exceeds the recommended threshold value ($Q^2 > 0$), indicating an adequate predictive validity (Haenlein and Kaplan 2004) (Fig. 4).

Discussion

Apathy is one of the most frequent behavioral symptoms in acquired and neurodegenerative neurological disorders, but has been poorly studied in normal aging. Apathy is often associated with poor quality of life and reduced daily functioning in healthy older adults (Moonen et al. 2015; Okura et al. 2010). Moreover, there is evidence suggesting that apathy in older normal adults may constitute a risk

Fig. 4 Structural model results (model 3)

factor of neurodegenerative diseases (Donovan et al. 2015; Grool et al. 2014). Capitalizing on recent multidimensional models of apathy, the main aim of the present study was to investigate different factors that may be associated with cognitive, emotional, and behavioral apathy in older adults using PLS-SEM analysis. In order to achieve this aim, we tested three different models, one for each type of apathy.

Overall, we observed that similar variables impact on cognitive and emotional apathy, namely anticipatory pleasure, sensitivity to reward, cognitive functioning, and physical functioning. Nevertheless, we also observed that the impact of anticipatory pleasure (moderate to high effect size; $F^2 = 0.316$) and physical functioning (moderate effect size; $F^2 = 0.221$) were stronger for the cognitive than emotional apathy. Conversely, the impact of reward, although small, was slightly stronger on emotional apathy (low to moderate effect size; $F^2 = 0.106$). Regarding behavioral apathy, again we found similar LV except for the cognitive functioning whose impact was not statistically significant. Although similar LVs impact on behavioral apathy, it is important to notice that different factors loaded in the reward LV (see supplementary data). While three factors (Does the possibility of social advantage move you to action even if this involves not playing fair?; do you often give preference to those activities that imply an immediate gain?; do you sometimes do things for quick gains?) loaded in the reward LV for the cognitive and emotional apathy model, only two loaded in the reward LV for the behavioral apathy model (Do you often have trouble resisting the temptation of doing forbidden things?; do you like displaying your physical abilities even though this may involve danger?) suggesting that different

items might impact on the sensitivity to reward depending on the type of apathy. While the models for the cognitive and emotional apathy explained 49 and 41 % of their variance, respectively, the model for the behavioral apathy explained only 28 % suggesting that there are other variables that should be considered in further studies. For instance, it has been suggested that low self-esteem could prevent individuals from enrolling in valued activities to protect oneself from threat (Arnould et al. 2013). Moreover, the predictive power was especially lower for this model ($Q^2 = 0.15$).

Our results thus replicate and extend the associations found in previous studies in healthy older adults between apathy and cognitive functioning (Onyike et al. 2007), more specifically executive function. This result is not surprising as executive dysfunction has been involved in apathetic manifestations in Parkinson's disease (Pagonabarraga et al. 2015), Alzheimer's disease (Landes et al. 2001), and schizophrenia (Konstantakopoulos et al. 2011). Disturbance in executive functioning could lead to lack of cognitive flexibility, notably difficulties in modifying intentions according to the environmental demands, which in turn lead healthy older adults to drop their current action increasing apathy. These findings shed new light on the specificity of this association. Indeed, if cognition function was a predictor of emotional and cognitive apathy, this association was not found with behavioral apathy. Thus, it corroborates the view that apathy is not a unitary construct, but rather depends on different types of mechanisms.

Another key finding of this study was the association between anticipatory pleasure and apathy. This result extends previous findings in Parkinson's disease (Jordan et al. 2013) and schizophrenia (Favrod et al. 2010) linking

between anticipatory pleasure and goal-directed behaviors. Thus, difficulties in predicting enjoyment in the future negatively influence motivation to seek out a desired end in older healthy adults (Freitas et al. 2002a).

In addition, we also found that sensitivity to reward was a significant predictor of apathy in our sample. The Behavioral Activation System was conceived by Gray and McNaughton (2000) as a theoretical construct to describe the physiological mechanisms underlying individual responsiveness to cues of reward and the positive effect derived from engaging in reinforcing behaviors. Consequently, it is not surprising that older individuals with low reward sensitivity have a reduced tendency to engage in effortful goal-directed behaviors. Our results corroborate previous evidence from stroke patients with fronto-striatal lesions and extend it to normal aging suggesting that reward insensitivity constitutes a key component of apathy (Rochat et al. 2013).

Finally, we found that self-reported physical functioning was a key determinant of the different dimensions of apathy in our sample. This result is in line with previous studies (Okura et al. 2010) that have shown that apathy could be strongly associated with functional limitations in older adults with no dementia. This finding also highlights a bidirectional direction between apathy and functional impairment (i.e., physical functioning) as it has been shown that apathy can have a significant negative effect on physical functioning (Tang et al. 2013; Yao et al. 2015). Overall, our results suggest that some variables such as physical or cognitive functioning could be both consequences and causes of apathy, leading to the maintenance of vicious circles. This possible dynamic interplay of apathy, cognition, and physical functioning impairments suggests the need of a multilevel intervention in apathy reduction programming to promote mental and physical health of older adults.

Limitations

Some limitations of the present study must be highlighted. The estimation of the prevalence of cerebrovascular diseases was based only on self-report and may have underestimated the prevalence of cardiovascular diseases. For example, lower blood pressure (Moonen et al. 2015) or cardiovascular disease and cardiovascular risk factors (Ligthart et al. 2012) have also been shown to be involved in increased apathy in normal aging, even if cardiovascular risk factors per se are more indirectly correlated with

apathy than silent cerebrovascular disease (Yao et al. 2015). Similarly, pharmacological treatments were not assessed despite the evidence that some agents such as antidepressants (Barnhart et al. 2004; Fava et al. 2006) can induce apathy syndrome. Despite the fact that all patients with a major depressive disorder were excluded, we could not totally exclude that some patients received antidepressant treatments. Finally, more robust physiological and objective measures should be used in future studies to fully understand the development and contribution of physical factors to apathy.

Conclusions and future developments

From a clinical perspective, our results support the multidimensional model of apathy. Although similar factors impact on the different types of apathy, this impact was not the same especially regarding the behavioral apathy. This study points toward the importance of the development and implementation of non-pharmacological interventions such as promotion physical activity (Telenius et al. 2015), cognitive remediation interventions, and anticipatory pleasure skills training (Favrod et al. 2010) to reduce apathy in healthy older adults.

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Authors' contributions Stéphane Raffard designed the research. Stéphane Raffard, Catherine Bortolon, Mariana Burca, and Delphine Capdevielle performed the research. Catherine Bortolon analyzed the data. Stéphane Raffard, Catherine Bortolon, Mariana Burca, Delphine Capdevielle, and Marie-Christine Gely-Nargeot wrote the paper.

Compliance with ethical standards The study was carried out according to the code of ethics of the World Medical Association (declaration of Helsinki). The University of Montpellier 3 Institutional Review Board approved this study and all subjects provided informed consent.

Conflict of interest All authors declared that there are no conflicts of interest in relation to the subject of this study.

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