



# Two Sides of the Same Coin: Fluid Intelligence and Crystallized Intelligence as Cognitive Reserve Predictors of Social Cognition and Executive Functions Among Vulnerable Elderly People

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### Specialty section:

This article was submitted to  
Dementia and Neurodegenerative  
Diseases,  
a section of the journal  
Frontiers in Neurology

**Received:** 27 August 2020

**Accepted:** 14 October 2021

**Published:** 19 November 2021

### Citation:

Salas N, Escobar J and Huepe D  
(2021) Two Sides of the Same Coin:  
Fluid Intelligence and Crystallized  
Intelligence as Cognitive Reserve  
Predictors of Social Cognition and  
Executive Functions Among  
Vulnerable Elderly People.  
Front. Neurol. 12:599378.  
doi: 10.3389/fneur.2021.599378

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The concept of cognitive reserve –CR– postulates two forms that prevent cognitive impairment: neural reserve and neural compensation. Both have been primarily linked to the protective role played by genetic factors, educational level, occupation or socioeconomic status. Though it is true that it has been related to executive functions, so far very little attention has been paid to its predictive capacity with other variables more related to social cognition and psychosocial adaptation. Considering socially vulnerable contexts with reduced cultural capital and educational levels, the neural reserve function would be the most relevant and best predictor of aspects related to social cognition and executive functions. We suggest that variables such as fluid and crystallized intelligence influence social cognition and executive functions. This study included a sample of 27 participants over 60 years old from varied contexts of social vulnerability. The procedure included data collection using various cognitive measures. Results show that elderly people with high intelligence—mainly fluid intelligence—have better executive functions, emotional recognition and theory of mind. These results focus on cognitive reserve and its importance because they show that elderly people in vulnerable contexts who strengthen these aspects protect themselves against the deterioration of cognitive skills. This study is the first preliminary research to present a relationship between cognitive reserve and social cognition factors in elderly subjects. Fluid intelligence functions as a highly related factor to protect the performance of executive functions, along with other social-cognitive factors relevant to facilitating the conditions of social adaptation.

**Keywords:** cognitive reserve, fluid intelligence, crystallized intelligence, social cognition, executive functions

## INTRODUCTION

The concept of cognitive reserve –CR– (1, 2) involves two forms of protective actions. The first, known as the neural reserve, states that pre-existing brain networks that are more efficient or have a greater capacity may be less modifiable. On the other hand, it can operate as a neural compensation system where alternative networks can compensate for the disruption of pre-existing pathology networks. Thus, CR has mainly been linked to the protective role of education, occupation, or socio-economic status against cognitive impairment and very little attention has been paid to its moderating role, among other variables like social cognition, since it not only incorporates environmental aspects but also intrinsic body actions [concept differs "brain reserve capacity" - BRC - of (3)]. Epidemiological evidence suggests that individuals with higher fluid intelligence (FI), education, occupational level, or participation in leisure activities have a lower risk of developing Alzheimer's disease (AD) and other neurodegenerative diseases (2). According to the above, we wanted to know which of these components, considered part of the cognitive reserve, better predict social adaptation capabilities. So far, no studies are known to have tested this question. SC and EF refer to the quality of life in terms of social and relational activities, as well as the subjective well-being of an individual in a given context, which, in turn, is a crucial skill for proper development and adaptation in contexts of social vulnerability. This concept includes multiple dimensions such as social behavior, emotional regulation and the development of social habits (4, 5). Psychosocial functioning represents an ecological approach to everyday adaptation and cognitive contexts interrelating cognition and emotion (6). We suggest that variables such as fluid intelligence (FI) and crystallized intelligence (CrI), as part of CR, influence social cognition (SC), emotional recognition (ER), and executive functions (EF) in vulnerable contexts.

### Some Aspects on Elderly Chileans and Vulnerable Contexts

Chile has 2.8 million people 60 years of age and older [16.2% of the total Chilean population; (7)]. According to the Chilean National Health Survey 2009–2010 (8), prevalence of cognitive impairment in this group was 10.4% and it rises rapidly with advancing age (12.8% for people 70–79 years old and 20.9% for 80 years and over). Moreover, this prevalence is much higher among older adults living in contexts of social and economic vulnerability and with low educational levels; 39% had some degree of disability. From a socioeconomic standpoint, 44% of disabled people in Chile belong to low socioeconomic sectors. Older adults account for 44.3% of disabled people, with a high percentage having low levels of education [69.6% according to (9)]. The same trend was seen in the educational level, where prevalence of cognitive impairment was 5.6 times higher among less educated adults than among those with higher educational levels (8). Disability to perform in daily life among the elderly has the same distribution by socioeconomic and educational levels; which means that the poorest and least educated have a higher prevalence of disability to perform in everyday life (9).

There is also a high prevalence of depression in Chile (17.5% according to the latest National Health Survey ENS Chile from 2009 to 2010), especially so among older adults (10) in vulnerable conditions (11). This is relevant, given the association between depression and development of dementia (12), for example. Among diseases associated with cognitive impairment, in Chile Alzheimer's disease is the leading cause of dementia in older adults. Its incidence increases with age (1–2% of the people aged 60 years, 3–5% of people 70, in 15–20% of people 80 years and one-third or half of those over 85). Its clinical course generally begins with failures in recent memory and ends with total dependence (13). Chilean authorities consider factors such as low education and low levels of culture (low-income patients from vulnerable and rural contexts) to be social determinants of this kind of disease (14). Social vulnerability is understood as a set of social characteristics that put a group of people who live in contexts of lower economic resources and at high risk of falling into poverty in a situation of structural, material and personal inequality (15, 16). Typically, these populations have low cultural and educational capital, limited access to goods and services, lower quality of social benefits (health, education, housing), higher levels of social deprivation, more impoverished social environments, and unsafe neighborhoods, effectively lowering the quality of life of their inhabitants compared to the general population (17, 18). For example, it is known that environments of lower social capital or poverty are more likely to be exposed to higher toxins and pollutants, crime and traffic and have fewer chances to participate in physical activities, less access to healthy food, greater likelihood of living in chaotic homes, more violence and lower parental sensitivity (19). Thus, exposure to multiple stressors, that is, various risk factors, has greater side-effects on cognitive abilities than exposure to a single risk (20, 21).

### Cognitive Reserve and Social Cognition as Associated Factors to Psychosocial Adaptation (PSA)

The term psychosocial adaptation (PSA) refers to quality of life in terms of social and relational activities. This concept includes multiple dimensions such as social behavior, emotional regulation, and the development of social habits (4, 5). PSA represents an ecological approach to everyday and cognitive-contextual adaptation, in which cognition and emotion are interrelated (6). Within PSA, social cognition (SC), fluid, and crystallized intelligence (FI; CrI) play a highly significant part, particularly in decision-making, emotional processing, and the way we relate to others (empathy and theory of mind). Research suggests that the prefrontal cortex plays a major role in such adaptability, given its involvement in the flexibility of behavior, executive functions (EF), FI and SC (22, 23). It should be noted that not all EF are related to FI (24–26). Similarly, SC tasks and FI (27, 28) or mental flexibility have been associated with this area (29, 30). Damage or alterations in the frontal lobe have direct implications on these functions, resulting

mainly in maladaptive behaviors. SC includes the ability to make decisions, emotional processing, the ability to understand others' intentions and to develop in the social world (31). Studies in this line have shown that the social context exerts a profound influence on SC (32, 33). Meanwhile, FI has been defined as the ability to think logically and solve problems in new situations, regardless of the acquisition of knowledge. This reflects the ability to reason and think abstractly, in contrast to what is called crystallized intelligence (CrI) (34), which depends on cultural and academic learning. From a neuroanatomical viewpoint, FI has been associated with frontal lobe functions (27). Injuries in this area affect the performance of these cognitive abilities (28, 35) and studies that have measured FI with functional neuroimaging have shown activation of frontal areas (36, 37). FI has been linked as a protective factor for mental health, violent conditions and PSA (38). On the other hand, CrI is known as the ability to use skills, knowledge, and experience (39), relying on accessing information from long-term memory. As McGrew (40) establishes, it "is primarily a store of verbal or language-based declarative (knowing what) and procedural (knowing how) knowledge acquired through the investment of other abilities during formal and informal educational and general life experiences" (p. 5). According to this, CrI is indicated by a person's depth and breadth of general knowledge, vocabulary, and the ability to reason using words and numbers. As such it is also viewed as the product of educational and cultural experience in interaction with FI. One relevant element is that it changes with age (41, 42). For example, research on individuals over the age of 60 showed that many abilities indeed show average decline rates (43–45). Thus, given the description of SC, FI and CrI, this gains relevance as protective factors in aging, in addition to cognitive reserve (CR). In this sense, the CR can be defined as "differences in cognitive processes as a function of lifetime intellectual activities and other environmental factors that explain differential susceptibility to functional impairment in the presence of pathology or other neurological insult" [(46) p. 502]. CR acquires importance since it proposes two forms of protective actions (1, 2). Neural reserve refers to pre-existing brain networks that are more efficient or have a greater capacity but are less susceptible to change. It can also operate like an alternative neural network that compensates for the disruption of pre-existing pathology networks. Despite the fact that CR has mainly been linked to the protective role in everyday activities, as well in education, work, or socio-economic status against cognitive impairment (47), literature on SC shows that very little attention has been paid to its moderating role. It has even been suggested that there is no relationship (48, 49). This is interesting, considering that it incorporates environmental aspects as well as intrinsic body actions [concept differs "brain reserve capacity" (BRC) of (3)]. Epidemiological studies have shown that individuals with higher FI, educational and occupational levels or leisure-related activities have a lower risk of developing AD and other neurodegenerative diseases (2). In the same way, SC has been associated with positive outcomes in aging. On the one hand, factors such as positive

life events and social support, have proven to influence and increase survival rates in patients with dementia compared to subjects living in poor conditions (50). Similarly, Fratiglioni et al. (51) have found that the construction of social networks with poor or limited support increased the risk of dementia by 60% and that there is a link between variables such as isolation, feelings of social isolation, educational level, among other lifestyles, that accelerate or delay the occurrence dementia (52, 53). These can be seen as protective factors, but with an active role (1) based on neural networks. On the other hand, evidence from epidemiological research suggests that higher FI, high educational and occupational levels (better jobs), being active in leisure activities or larger social networks, have a lower risk of developing, for example, Alzheimer's disease (AD) or dementia (54, 55). Therefore, we understand that people with better social adaptability, given their greater social cognition, will be more resistant to neurodegenerative diseases, either due to the existence of a more functional network or a larger brain capacity to involve alternative networks. There are known risks factors for neurodegenerative diseases such as genetic or medical conditions, other neurological pathologies, or brain injuries. Nevertheless, the role of social variables have been studied less formally and are less understood, especially considering only individual factors (56). One possible hypothesis about the relationship between CR and FI is that other protective social and cultural factors could modulate the adaptation process, benefiting from the social and cognitive conditions that people possess, such as social support and social networks, demographic aspects, educational level, among others. Although the concepts of CR, CrI and FI differ in important respects, they are complementary as opposed to competing. Accordingly, the study of social factors as predictors of the delay or acceleration of neurodegenerative diseases is essential and we sought to fill a gap in previous research by conducting a study to find the relationship between fluid intelligence (FI) and crystallized intelligence (CrI), and as complementary factor with cognitive reserve (CR), as well as their relationship to social cognition (SC), emotional recognition (ER) and executive function (EF) in older adults in socially vulnerable contexts. In addition, we want to go into greater depth and answer the question of which of these two types variables (FI or CrI) better predicts social adaptive capacity. We suggest that FI and CrI, are associated with aspects of SC, such as emotional recognition and theory of mind (ToM), in addition to EF; and could strength cognitive process that are crucial for CR. All these aspects could influence the processes of social adaptation and thus the possibility to the adjustment of the elderly in vulnerable contexts. CR is often estimated using proxy variables for lifetime exposures and cognitive activity: years of education, measures of crystallized intelligence, such as vocabulary or knowledge, literacy level, number of intellectually stimulating leisure activities, degree of occupational complexity, and socioeconomic status are all commonly used to create an estimate of CR (1). According to the above, FI and CrI are variables that we propose to use as a synthetic way to explain a broader construct of CR (since both variables are components of CR).

## METHODS

### Participants

All twenty-seven participants in this study were in healthy conditions, over 60 years old ( $M = 66.44$ ,  $SD = 6.59$ ; 55.6% male) and recruited from contexts of social vulnerability. Given that they come from contexts of high social risk (poverty and insecurity), they are participants who are very difficult access. They come from families currently participating in a Chilean Social Security Program—CSPP—implemented by the Chilean Ministry of Social Development. All participants signed an informed consent, following the protocol of the Declaration of Helsinki. Participation was voluntary, protecting participants' anonymity. The following exclusion criteria were considered: individuals with visual and/or hearing impairment that prevents them from performing the various tasks and measurements in the study; and a psychiatric or neurological background representing an impediment to the evaluation of the protocol, assessed in an initial interview.

## MEASURES AND PROCEDURE

The procedure included direct telephone contact, with the help CSPP agencies, and data collection by members of the program, who had been previously trained in the measures taken. A house for neighborhood meetings (local area) was the setting for data collection and the interview considered a research assistant to complete the instruments. The study protocol included: Executive functions (EF), measured with INECO Frontal Screening –IFS– (57, 58), a brief tool that evaluates EF through different domains: programming tasks Motorboat; conflictual instructions, inhibitory verbal control, abstraction, back span of digits for working memory space, and Go / No Go testing. It is a very sensitive instrument and has been tested in patients with frontal and neuropsychiatric disorders and injuries. To measure Fluid and crystallized intelligence (FI and CrI), we used the Wechsler Adult Intelligence Scale III (WAIS-III) (59) and ran two subtests, progressive matrices and vocabulary. We obtained a total score for each subtest from each scale. The progressive matrices represent FI and from vocabulary test, we calculated CrI. Additionally, years of education also was used as a proxy for CrI (as a second variable) and Theory of Mind (ToM) was measured with Reading the Mind in the Eyes Test (60, 61). This battery evaluates ToM, through 28 pictures of faces of

people where only the area around the eyes is visible;. Emotional recognition was tested with the Mini-Sea (62). This instrument is built around two subtests: (a) a facial emotion recognition test (from Ekman pictures; scored from 0 to 15) in which participants must identify which emotion is being expressed; and (b) a shortened version of the Faux Pas recognition test (63) to evaluate emotional recognition. Inhibitory verbal control was measured because it could be linked to emotional regulation and adaptation (64, 65). For that purpose, we used the Hayling Test (66), consisting in two parts: (a) concentrated attention, verbal initiation, processing speed and the strategy of a well-succeeded search for automated words; and (b) EF components, such as verbal inhibition and planning (the individual must inhibit the content of the sentence).

### Statistical Analysis

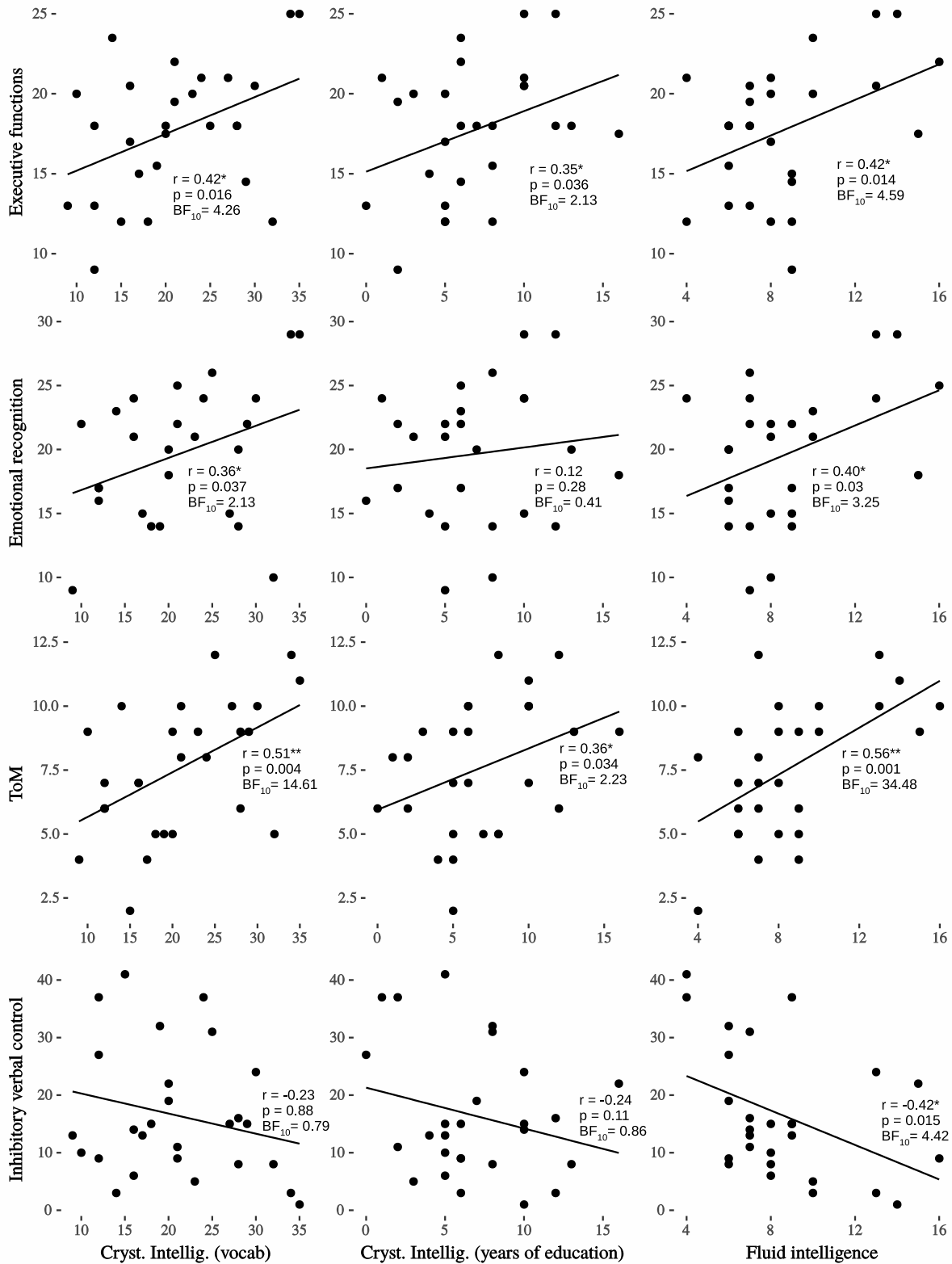
We obtained descriptive statistics (central trend and dispersion measurements) and subsequently calculated Pearson's correlation coefficients to evaluate the independency between variables. A Kolgomorov-Smirnov Test was conducted to test for normal distribution. We worked with  $p$  level of  $< 0.05$  (two-tailed) to confirm bivariate correlations. In addition, we quantified the evidence to support the alternative hypothesis by computing a Bayes factor for the specific effect of crystallized and fluid intelligence on: (a) EF score; (b) total emotional recognition score; (c) ToM; and (d) inhibitory verbal control. Bayes factor analysis for each prediction will yield very strong evidence to support the alternative expected effect on main interest variables when  $BF_{10} > 30$  and  $\leq 100$ ; strong when  $BF_{10} > 10$  and  $\leq 30$ ; and moderate evidence if it is between  $BF_{10} > 3$  and  $BF \leq 10$  [assuming a uniform distribution of priors; see (67, 68)].

## RESULTS

Descriptive statistics are shown in **Table 1**, where one can see that almost all the scores for each test are above the median point of the maximum obtained for its scale (with de exception of inhibitory verbal control and CrI). In **Figure 1**, Cognitive reserve (CR) variables –FI and CrI—show associations with social and cognitive variables. The most important effect found was between FI and ToM ( $r = 0.56$ ,  $p < 0.01$ ;  $BF_{10} = 34.48$ , very strong evidence) and next with executive functions ( $r = 0.42$ ,  $p < 0.05$ ;  $BF_{10} = 4.59$ , moderate evidence), inhibitory verbal control ( $r = 0.42$ ,  $p < 0.05$ ;  $BF_{10} = 4.42$ , moderate evidence)

**TABLE 1** | Mean, standard deviations, median and minimum-maximum for each interest variable.

	Executive function	Emotional recog.	ToM	Inhibitory verbal control	Crystallized intell (years education)	Crystallized intell (vocab.)	Fluid intelli.
Mean	17.72	19.65	7.593	16.44	6.852	21.00	8.593
Std. deviation	4.163	5.321	2.606	11.28	3.870	7.514	3.153
Median	18.00	20.50	8.00	14.00	6.00	20.00	8.00
Minimum	9.00	9.00	2.00	1.00	0.00	9.00	4.00
Maximum	25.00	29.00	12.00	41.00	16.00	35.00	16.00



**FIGURE 1 |** Regression line, Pearson's r and Bayesian factor between crystallized and fluid intelligence on interest variables. Very strong evidence between fluid intelligence and ToM; moderate evidence with executive functions, inhibitory verbal control and emotional recognition; strong evidence between crystallized intelligence (vocabulary) and ToM; moderate evidence between crystallized intelligence (vocabulary) and executive functions; \* $p < 0.05$ ; \*\* $p < 0.01$ .



and emotional recognition ( $r = 0.40$ ,  $p < 0.05$ ;  $BF_{10} = 3.25$ , moderate evidence). On the other hand, and taking the Bayes factor into account, only crystallized intelligence (vocabulary) was significantly associated with ToM ( $r = 0.51$ ,  $p < 0.01$ ;  $BF_{10} = 14.61$ , strong evidence) and executive functions ( $r = 0.42$ ,  $p < 0.05$ ;  $BF_{10} = 4.26$ , moderate evidence). On the other hand, it is known that fluid intelligence and age are variables typically that have been inversely associated (15, 41, 69, 70). Before age 50 ability such as processing speed, memory, and reasoning begins to decline (71). To control the effect of the age, we calculate partial correlation for each variable of the interest, adjusting for age. Outcomes show that all correlations remained statistically significant (one-tailed): FI – FE,  $r = 0.41$ ,  $p = 0.019$ ; FI – ToM,  $r = 0.56$ ,  $p = 0.001$ ; FI – Emotional recognition,  $r = 0.35$ ,  $p = 0.043$ ; and inhibitory verbal control,  $r = -0.40$ ,  $p = 0.021$ .

## CONCLUSION AND FUTURE DIRECTIONS

This study shows that elderly individuals living in vulnerable contexts in Chile and with high intelligence -mainly fluid intelligence- have better executive functions, emotional recognition and theory of mind (ToM). This is the first preliminary research to present a relationship between cognitive reserve (CR), social cognition (SC) and executive function (EF) in elderly subjects who live in vulnerable contexts. As seen in the results, FI functions as a factor highly related to the improvement of EF shown by the subjects measured, along with other SC factors relevant in the probability of enhanced psychosocial adaptation (PSA). These results focus on cognitive reserve (IF and CrI connected to SC) and their possible protective effects in vulnerable contexts. We can say that older people in vulnerable contexts who strengthen these aspects (through CR) protect the deterioration of some cognitive and social abilities (72–74). Social interactions that promote the resolution of everyday situations (that is, FI) allow the brain to continue with the demands it has become accustomed to since birth. The exercise of cognitive aspects and the use of cognitive functions such as attention, memory and planning to solve day-to-day dilemmas function as protective factors in vulnerable contexts. This could also be because these contexts present multiple challenges that are approached from social and cognitive abilities and which generate greater social adaptation. Furthermore, social contact skills are essential for collaborative work and the joint construction of learning (75). Elderly people who adapt and continue learning use CR as a key element. This study invites us to review social and health policies regarding the promotion of programs for the elderly that favor autonomy and continuity in decision-making by the elderly. Activities that favor the continuity of establishing relationships with others, which allow elderly people to face the resolution of daily dilemmas, seem to be key and should be informed to those health professionals who attend to them.

Further studies that relate cultural and social factors associated with neurodegenerative diseases are needed, but not just as mere descriptors. On the other hand, SC should be increasingly considered in research on neurodegenerative diseases, not only as

a potential early marker, but also as a key factor to understanding how it can moderate and slow the disease manifests itself on a day-to-day basis. Fluid intelligence must be revealed in its protective role, especially from its educational potential, in the sense that learning instances in the elderly should be highly promoted. The same way, SC and EF appear to be relevant factors to improving adaptive capacities, particularly in vulnerable contexts. There is a need to methodologically bridge the study of PSA skills between external individual characteristics (social and cultural factors) and internal (genetic or hereditary predisposition) based on the concept of “CR,” upon an active (neural networks) point of view.

Regarding the limitations of the present study, we can mention the small sample and the need for additional measurements to evaluate social adaptation. However, given the difficulty of access, and despite the small number of participants, it was still possible to robustly demonstrate the expected effects. In favor of this argument, other research types have been published with sample sizes similar to the present study (76–78). On the other hand, social adaptation was also considered through the protocol study that considered inclusion criteria associated with a population normally adapted to daily life.

In conclusion, this study has researched the positive effectiveness that CR has on SC and EF from an ecological perspective. Our results show that FI is the most relevant variable for predicting how elderly people adapt and function in their social environments.

## DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Universidad Adolfo Ibáñez, Chile. The patients/participants provided their written informed consent to participate in this study.

## AUTHOR CONTRIBUTIONS

NS and DH participated in the development of the study, in data collection and analysis, in writing and editing the manuscript, and in giving final approval. JE worked on editing the language and made important contributions to the manuscript and made final comments. All authors contributed to the article and approved the submitted version.

## FUNDING

This work was supported by grants from National Scientific and Technological Research Commission (ANID/FONDECYT Regular No. 1201486 to DH and ANID/FONDECYT Iniciación No. 11190565 to JE). The funders had no role in the decision to publish, or preparation of the manuscript.

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