La collana della Scuola di Alta Formazione Dottorale accoglie le migliori tesi di dottorato dell'Università degli Studi di Bergamo, insignite della dignità di stampa e sottoposte a procedura di *blind peer review*.

The results of studies on divergent thinking (DT) skills in the healthy elderly population have often been inconsistent. This study shows that this inconsistency may be due to some theoretical and methodological issues; as a matter of fact, older subjects seem to have the ability to think as divergently as younger subjects, when specific intervening variables are considered. This research also evidences a negative impact of psychological symptoms such as apathy and depression (very frequent in this population) on DT performance of elderly subjects and the possible moderating effects of cognitive reserve. Furthermore, verbal DT appears to be spared even in the prodromal stages of neurodegenerative diseases, while figural DT is already impaired in these patients. It can be argued that, especially verbal DT, with its proven relationship to the CR construct, could be considered a useful target for cognitive enhancement in healthy elderly and for early cognitive stimulation interventions in MCI patients.

Giulia Fusi obtained her Ph.D. in "Human capital formation and labour market relations" (33rd cycle) at the University of Bergamo. She has also achieved a one-year course of Neuropsychological rehabilitation for adults and older adults. Her interests are linked to Clinical Neuropsychology and Cognitive Neuroscience. She is focusing on divergent thinking skills in healthy and pathological aging, and on its link with cognitive reserve, psychological well-being and autobiographical memory.

ISBN: 978-88-97413-59-2
DOI: 10.13122/978-88-97413-59-2

Giulia Fusi

DIVERGENT THINKING IN AGING

39

Collana della Scuola di Alta Formazione Dottorale
- 39 -

Giulia Fusi

DIVERGENT THINKING IN HEALTHY AND PATHOLOGICAL AGING

UNIVERSITÀ DEGLI STUDI DI BERGAMO

2022

Collana della Scuola di Alta Formazione Dottorale

- 39 -

Collana della Scuola di Alta Formazione Dottorale

Diretta da Paolo Cesaretti

Ogni volume è sottoposto a *blind peer review*.

ISSN: 2611-9927

Sito web: https://aisberg.unibg.it/handle/10446/130100

Giulia Fusi

DIVERGENT THINKING IN HEALTHY AND PATHOLOGICAL AGING

Università degli Studi di Bergamo

2022

Divergent thinking in healthy and pathological aging
/ Giulia Fusi. – Bergamo :

Università degli Studi di Bergamo, 2022.
(Collana della Scuola di Alta Formazione Dottorale; 39)

ISBN: 978-88-97413-59-2
DOI: 10.13122/978-88-97413-59-2

Progetto grafico: Servizi Editoriali – Università degli Studi di Bergamo

via Salvecchio, 19
24129 Bergamo
Cod. Fiscale 80004350163
P. IVA 01612800167

https://aisberg.unibg.it/handle/10446/227410

Acknowledgements

I wish to thank the University of Bergamo for having offered me the opportunity to participate to the doctoral program on Human capital formation and labour market relations. I am especially grateful to the professors who supported me in this dissertation as supervisor - prof. Maria Luisa Rusconi - and as co-supervisor - prof. Barbara Colombo for their invaluable human and scientific guidance. I wish to thank also Prof. Sotgiu and Prof. Greco for their precious methodological guidance.

I would like to thank all members of my research group, Maura, Sara and Anna for the constant scientific suggestions, human guidance, support and for becoming more than colleagues, but friends.

I am finally very grateful to Dr. Marina Zanetti for the important clinical insights, for her practical support and for the opportunity to work with her and her patients.

“Odd how the creative power at once

brings the whole universe to order”

Virginia Woolf

Table of contents

Introduction

In the present Ph.D. dissertation, an investigation about divergent thinking (DT) abilities in healthy and pathological aging and related issues such as the impact of psychological symptoms over DT skills, has been conducted. To date, DT is considered as an index of creative potential, over than a cognitive process pivotal for the study of creative cognition. The thesis is divided in three sections which concern (i) the theoretical background; (ii) normal aging and (iii) pathological aging.

Starting from the first section, the first two chapters are dedicated to the theoretical background. More specifically, the first chapter concerns the description of the construct of DT, its evolution and how nowadays it is widely used in experimental research as a measure of creative potential (Lubart, 2013; Mastria et al., 2018; Runco & Acar, 2012). After that, research on cognitive abilities and the neuroanatomical basis related to DT was further explored. Instead, the second chapter is devoted to addressing the effect of the aging processes on brain structure and functioning, considering also the different theoretical models from the cognitive neuroscience literature. In addition, it explores the neural patterns associated with creative cognition in healthy older subjects and the relationship between DT and the construct of cognitive reserve (CR).

The second section includes the two studies on normal aging. More specifically, since we have noticed that the results about DT skills during the lifespan has often been inconsistent, the first study that we have conducted (Study 1, paragraph 3.1.) is a systematic review performed following the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines. This study allowed us to evidence some important findings. Firstly, how the study of DT abilities has historically suffered from some theoretical and methodological problems. Secondly, trying to summarize the 16 selected studies' results, we have also evidenced how older adults seemed to be able to think as divergently as younger subjects if specific intervening variables such as the time constraints or speed of elaboration and working memory capacity are considered. This, in line with the "*Compensation-Related Utilization of Neural Circuits Hypothesis"* (CRUNCH; Reuter-Lorenz & Cappell, 2008) which states that when the task demand increases (i.e., giving them time constraints or a heavy working memory load in the case of DT tasks) older adults can no longer compensate the aging gap and their performance drops.

Further, we hypothesized that another reason for the inconsistency of the studies' results on DT abilities in older adults could also be due to the fact that none of the selected studies have considered the possible negative impact of the variance of psychological symptoms (depression, anxiety and apathy) on DT performances. Psychological symptoms are indeed frequent in the elderly population and have negative effects on cognitive performace, including creative ones. Paragraph 3.2. is dedicated to the description of our experimental studies (Study 2) in which 50 older adults have been evaluated through a DT task (i.e., Abbreviated Torrance Test for Adults) and three questionnaires that specifically assess apathy, depression and anxiety symptoms. The results showed how psychological symptoms such as apathy and depression, can effectively have negative effects on different DT indexes and how this negative correlations might be moderated by other variables, such as the level of education. Interestingly, the results seem to suggests that people with higher level of education and therefore hypothetically higher CR, might be more sheltered from the effect of psychological symptomatology on their cognitive performance.

Finally, the third section is dedicated to pathological aging. The section begins with a brief literature overview (paragraph 4.1.1) that specifically addressed studies that have evaluated DT in patients with different types of dementia, highlighting how the evidence about DT abilities in prodromal or early phase of these diseases are still lacking. Paragraph 4.1.2. is thus devoted to a brief discussion of the characteristics of Mild Cognitive Impairment (MCI) patients who are the subject of the third experimental study. Study 3 (paragraph 4.2.) concerns a preliminary observation of DT skills in 25 patients affected by Mild Cognitive Impairment (MCI) by comparing them to 25 (from a random selection of 50) healthy older participants to observe whether these abilities were spared or altered at this early stage of the disease. The between-group analyses have evidenced spared verbal DT abilities which have opened to some practical implication such as the use of verbal DT in the rehabilitation of these patients to promote CR. On the contrary, the study showed a decline in figural DT, which could be considered by future studies as an early marker of disease. All these results have been finally discussed in terms of future directions and practical implications for both researchers and clinicians.

SECTION 1. THEORETICAL BACKGROUND

Chapter 1. Divergent thinking: construct definition and evolution

In 1950 Joy P. Guilford, president of the American Psychology Association (APA), emphasized the terrible lack of research on creativity, even though this construct could have been fascinating and above all useful in the psychological field. Since then, research on this topic has increased exponentially, from 3 articles written in 1950 to 4669 in 2019 (**see Figure 1**).

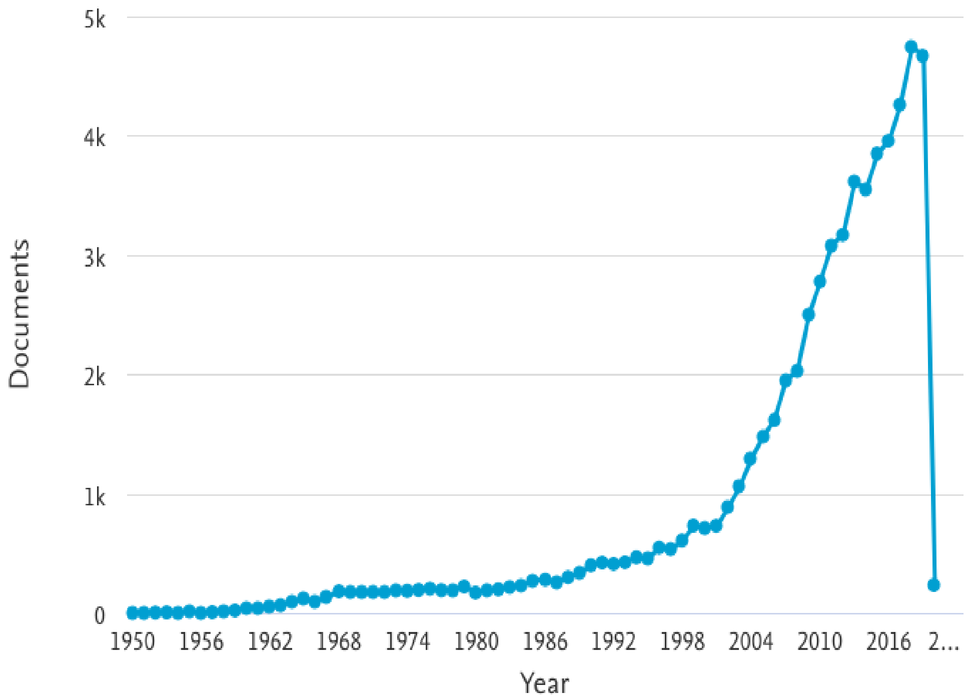

Figure 1: Graphic representation of the great increase of studies on the construct of "creativity" from 1950 to 2019 (Scopus, 01/31/2020).

Notably, even if great accomplishment in this field has been achieved during the last years and especially during the last decade (Fink & Benedek, 2019), one of the constructs used by recent experiment dates back to the 50's; that is the concept of "*Divergent Thinking"* (DT).

Guilford's construct of DT indeed, was first proposed in 1956 within his work "*The Structure Of the Intellect*", which has been updated through the years (SOI model, 1957, 1959, 1988) and has remained an influential concept in the field of creative cognition research until today. Guilford assumed that the best way to explore the human intellect was through a factorial research design; his analysis allowed him to outline a complex model composed by several factors. The two main factors identified were the "*thinking*" and "*memory*" factors (see **Figure 2**).

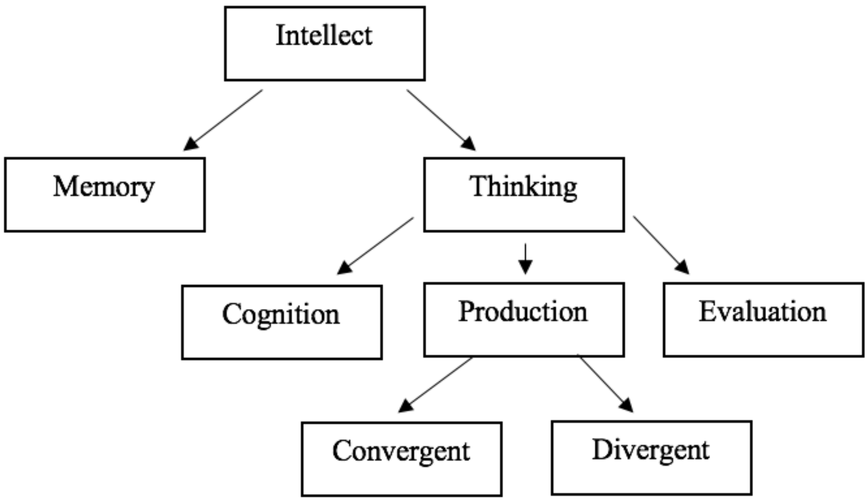

Figure 2: Diagram of the major intellectual structure's factors and their relationships (modified by Guilford, 1957).

The *memory factor* concerned different memory abilities with different type of content and things to be remembered (such as rote memory, auditory or visual memory and so on). Instead, the *thinking factor* has a three-fold division in cognition, production and evaluation factors. Particularly:

1. *Cognition* (or discovery ability) factor concerns the ability of becoming aware of mental items and tasks in which subjects has to comprehend, recognize or discover something;
2. *Production* factors have to do with the production of some end result and could be divided again in two factors, that are divergent or convergent thinking;
3. *Evaluation* factor is related to the skills involved in assessing the goodness, suitability or effectiveness of the thinking processes' results; it is defined as a "judgmental step".

Going deeper into the production factor, it is possible to observe two different types of tasks that lead, consequently, to two different ways of thinking. On the one hand, "*Convergent Thinking*" (CT) is usually employed when a unique and correct solution is required: thinking is therefore channeled or controlled in the direction of that specific answer. On the other hand, "*Divergent Thinking*" (DT) is essential when an open-ended problem is presented to the examinee. This type of problem requires more than one solution, the thinking process in not channeled, rather, conversely, involves an actual divergence of thought, with the exploration of a variety of directions, conceptual spaces, possibilities and novel possible associative paths (Acar & Runco, 2014, 2015; Guilford, 1957).

It is interesting to note that, in the same article, Guilford also advanced the idea that some components can be recognized as indices of creative responses, and these would be the indices of fluidity, flexibility and originality (Guilford, 1957). Hence, most of the DT tasks developed over the years (e.g., Torrance Test of Creative Thinking, the Alternative Uses Task or Wallach and Kogan, just to mention the most-widely used) tend to look and measure these qualities during ideas production. *Fluency* is described as the ability to produce a great number of ideas meeting certain requirements; *flexibility* is usually defined as the ability to switch from a semantic category to another or the ability that leads to ideas that employ a variety of conceptual categories; *originality*, is usually described as the ability to give unusual, un-common, or clever responses, or to make remote associations or connections; finally, also *elaboration* was proposed in some of the instruments and these index is related to the ability to embellish an idea through details.

Even if early research has sometimes confused the concept of DT with a direct assessment of creative ability (Piffer, 2012), it is now clear that DT is not a synonymous of creativity (Runco, 2004, 2008; Runco & Jaeger, 2012). Consequently, nowadays it is recognized as one of the most important proxies of creative thinking, essentially a measure of "*creative potential*" (Lubart, 2013; Mastria et al., 2018; Runco & Acar, 2012). Notably, the first to advance this idea could be considered Wallach, in 1970, who described DT tasks as a predictor rather than a criterion of creative performance. Accordingly, DT tasks are considered as estimates of the potential for creative problem solving and for creative achievements (Runco & Jaeger, 2012). Some studies have already highlights how DT seems to predict creative achievement above other important variables such as intelligence (Kim, 2008) or "Openness to Experience" personality trait (Jauk et al., 2014; Vartanian et al., 2018b).

The DT assessment has a long tradition and has been employed in many different contexts (Forthmann et al., 2019) representing the most widely-used assessment for creative potential (Runco et al., 2017). Therefore, the concept of DT was and still is attractive for several reasons: the first reason could be that it is believed to trigger cognitive processes leading to creative responses (Barbot et al., 2019) and the generation of original ideas (Runco et al., 2017). Secondarily, DT tasks are essentially easy to be administered and above all, can be easily adapted to the strict constraints of neuroimaging and neurophysiological research protocol; almost 51% creativity assessments in neuroscience research employed DT tasks according to Benedek et al. (2019).

1.1. Cognitive processes involved in creative cognition

During the last decades, an increasing body of research around DT has been focused on the discovering and understanding of the cognitive basis and processes involved in creative cognition. Basically, the question that researchers are trying to solve is: if creative thinking is based on normal cognition, what are the processes that intervene and integrate to generate new, original and useful ideas?

To address this issue, some authors have started from the study of basic mechanisms and normal brain functioning. What they have highlighted is the fact that there are three basic brain mechanisms that allow us, as humans, to respond to environmental request in a quickly and efficient way: the choice of the path of least resistance, the repetition suppression effect, and the ability of our brain to form pattern representations. One of the first observations about these basic brain mechanisms is that during normal cognition we tend to choose "*the path of least resistance*" (Eagleman & Brandt, 2017; Hagura et al., 2017). According to the studies, this mechanism leads us to choose the answer that is available faster or that suits the environment best, allowing us to react and make choices as quickly as possible.

Another basic brain mechanism is the "*Repetition suppression*" (RS) effect, that is defined as a diminished neural activation as consequence of the repeated presentation of a stimulus (Henson, 2003; Henson & Rugg, 2003). For the sake of our survival, we have indeed a great ability to quickly adapt to the environment and, consequently, to react more rapidly and efficiently to frequent and usual situations. The adaptation to the new incoming information assures us to make predictions about the environment and to respond with efficient and automatic behaviors to previously encountered stimuli (Eagleman & Brandt, 2017).

Finally, a third mechanism is the human ability to form mental representations and to perform what is called "*pattern recognition*". Indeed, when someone encounters an object for the first time, a mental representation that catches all the main characteristics and properties of this object is formed and stored in forms of a mental representation so that, when we encounter a new object with the same characteristics, we have only to reactivate the pattern previously stored in our brains to know what this object is and to understand its properties.

Summing up, all these basic brain mechanisms help us to deal quickly and efficiently with information or problems that we have already encountered in the environment and to respond, accordingly, in an automatic way. As a result, initial responses to stimuli will usually not be the most creative, as we are programmed to find the quickest, automatic, response. Accordingly, several research have highlighted that responses' originality increases during the performance of a DT tasks (i.e. "*time on task effect*"; Acar & Runco, 2014; Barbot, 2018; Beaty & Silvia, 2012; Heinonen et al., 2016; Wang et al., 2017).

Indeed, sometimes, these automatic responses are not enough to deal with environmental requests. Specifically, during DT tasks people are required to move away, or suppress these automatic responses to find novel and original answers. These basic brain mechanisms have helped researchers to formulate hypotheses and experiments which have tried to explain how the brain faces novel problems and which cognitive functions come into play when a creative response is generated instead of an automatic one. Different cognitive functions have been reported to be correlated or connected with DT. In the next paragraphs, an overview of these cognitive functions will be addressed separately, even if the interplay of all these functions has always to be considered.

1.1.1. Memory: the role of episodic and semantic information

When a novel or original response is required by a task or by environmental conditions, the first cognitive function that has to be considered is surely memory and the role of previously acquired knowledge. Almost every researcher in the field agrees on the fact that nothing is created from scratch: established knowledge and concepts or representations deposited in our memory archives are surely the starting point for every idea, normal or creative that is. These notions have been supported both by behavioral and neuroimaging research showing that DT relies on episodic as well as on semantic memory (Abraham & Bubic, 2015; Leon et al., 2014; Beaty et al., 2020).

As concern episodic memory, Gilhooly and colleagues in 2007 were the first to propose a link between this specific cognitive function and DT. They administered an Alternative Uses Task (AUT), in which a word representing a simple object (i.e., brick, bottle of water, and so on) is given to participants and they are requested to produce as many alternatives uses as possible (possibly creative or original) of this specific object. Interestingly, through a thinking-aloud procedure they highlighted that initial responses were based on a strategy that imply the retrieval of information from long-term memory (LTM) of pre-known uses. Only later, different strategies could be observed to produce original responses (e.g., property-use generation, imagined disassembly, scanning broad use). These, also in line with the previously mentioned “time on task effect”. Subsequent experiments have tried to prove this connection. Sheldon and colleagues (2011), for example, highlighted how processes underlying episodic memory, in particular those enabling the retrieval of detail and episodic simulation, may contribute to open-ended problems such as DT ones. This was confirmed by the studies performed by Madore and colleagues (2015, 2016) in which they have proved the positive effects of an "episodic-specificity induction" (ESI) on DT performances. More specifically, in this experiment, after the observation of a video during the “ESI” condition, participants were asked questions about the specific contents of the video with different probes that boosts the number of accurate details: the goal was to help participants recall an experience event in an episodically specific way. Interestingly, participants who have received this episodic induction, compared to a control group, exhibited a selective boost on a DT task (i.e., AUT); these experiments have provided direct evidence that episodic memory was involved in DT.

It is also worth noting that it’s been many years since some authors agree on the fact that memory is a reconstructive process (Schacter et al., 1998). Consequently, some studies have advanced the idea that DT is strongly associated with future episodic thinking (Addis et al., 2014) and that DT and future simulation are governed by the same underlying mechanism. This “constructive” mechanism (Beaty et al., 2018b) might involve the ability to form associations between distinct memory representations and therefore requires the intervention of executive functions that have to act on these associations (Roberts & Addis, 2018). According to these proposals, a recent study has proved that the generation of new and old original ideas showed similar brain activation patterns (Benedek et al., 2018). The study is of particular interest because the authors highlighted a new subdivision of the generated idea during an AUT, that is: i) the generation of new uses, ii) the recall of original uses, and ii) the recall of common uses. This division is based on previous literature findings that have suggested how highly common, prototypical ideas are likely to be recalled from semantic memory, whereas previously experienced original object uses are more likely obtained from searches in episodic memory, which contains autobiographic details on where and how this unusual object use was encountered (Addis et al., 2016; Gilhooly et al., 2007). Summing up the study results, the authors found that the generation of new versus recalled original object uses involved both common and distinct brain processes. They evidenced how the two activities shared a bilateral activation of the parahippocampal cortex and of the medial prefrontal cortex (mPFC) and they proposed that these activations might reflect memory-related processes supporting episodic simulations (Mullally & Maguire, 2014; Schacter et al., 2012). However, creating a novel and original use goes beyond memory: new ideas involved a specific cluster of activations in the left supramarginal gyrus (SMG) and postcentral gyrus. The authors proposed that this could mean that creating novel ideas may imply higher demands on multimodal integration and controlled mental simulation to support the creative act.

As concern the relationship between semantic processes and DT, it could be stated that this has not been thoroughly investigated until now (Jung & Vartanian, 2018), but also that it is one of the increasingly addressed topics in the DT experimental field. Semantic memory is the stores of concepts and facts, regardless of time or context, and is responsible for the storage of semantic categories (Budson & Price, 2005; McRae & Jones, 2013; Vallar & Papagno, 2018). The specific nature of semantic memory remains an open issue in cognitive research (McRae & Jones, 2013). However, the role of semantic distance in creative cognition is utilized by experimental research through the idea that the farther one moves from a concept in a semantic space, the more there will be the possibility to generate an original and creative idea. As it has already mentioned in paragraph 1.1., people usually follow a path of least resistance, choosing the fastest and automatic response; this implies that when a person try to create a novel idea and to be creative, has to try to “overcome knowledge constraints” that refers to the ability to override the influence imposed by semantic knowledge structure (Abraham et al., 2012). These ideas have been confirmed in recent studies which have found that high creative individuals are faster in generating associative responses between distant concepts and provide higher percentages of unique associative responses (Kenett et al., 2014). Furthermore, it was proposed that creative individuals may have more associative links in their semantic memory network and can activate associative relations faster than less creative individuals (Rossman & Fink, 2010). These hypotheses have been confirmed also by a recent study performed by Kenett and colleagues in 2018 in which they have demonstrated that high creative ability is related to a flexible structure of semantic memory.

It is also worth noting that these concepts are linked to the concept of “associative processes”. Associative way of thinking is an automatic and uncontrolled process that has been described as the process by which a given thought automatically activates another thought that is associated with the first one in the semantic memory store (Zabelina, 2018). Mednick’s theory (1962) has been the most influential in highlighting the role of associative abilities in creative thinking. According to this theory, creative individuals would have a more flexible organization between words or concepts in their semantic memory which allows them to activate remote ideas and built new ideas by combining very different ideas. Recent evidence seemed to confirm this hypothesis: highly creative subjects seemed to give lower estimates of the remoteness of unrelated word pairs (Rossmann & Fink, 2010), they are faster both in judging the relatedness of concepts (Vartanian et al., 2009) and to accept word associations and susceptibility to priming (Gruszka & Neçka; 2002). Another evidence involves associational fluency tasks that require the participants to make free continuous associations with a cue word, listing synonyms and generating lists of unrelated words. For example, Beaty and Silvia (2014) showed that associational fluency predicts the creative quality (rather than quantity) of DT responses in an AUT task, and Benedek and Neubauer (2013) found that higher DT abilities were associated with greater associative uncommonness. These findings indicate that associative abilities explored by associative fluency tasks explain a large portion of the variance of DT abilities. Summing up, all these evidence highlights that remote element of knowledge may be highly interconnected in highly creative individuals.

In conclusion, creative cognition is believed to be built on both episodic and semantic memory processes but goes beyond them; some authors have already proposed the idea of a goal-directed memory retrieval as a fundamental top-down process involved in creative cognition. These ability is described as “*the ability to strategically search episodic and semantic memory for task-relevant information*” (Beaty et al., 2019, pp. 22) highlighting that memory processes has to interact with other functions such as attention and different types of cognitive control functions to produce novel and creative ideas.

1.1.2. Attention: leaky, focused or flexible attention processes?

It has been recognized for many years now that attention's main function is usually to select information that is useful for the context or for the current tasks (Posner, 1988) and that this cognitive skill could vary by type (e.g., selective, divided, diffused, focused, etc.), by degree, and by individual characteristics (Zabelina, 2018). A large body of literature has addressed the role of attention during DT tasks and therefore in creative cognition with different results (Zabelina, 2018).

Many researchers have already tried to understand what type of attention is the most involved in creative cognition. Some studies have evidenced that creative people seemed to show diffused or "leaky" attention; hence, creative people usually show the tendency to notice information and to use them even if these may not be particularly relevant to the task that they are carrying out (Carson et al., 2003; Mendelsohn & Griswold, 1964). For example, creative people seem to be more prone to errors on typical attention tasks, experiencing more intrusions (Rawlings, 1985); this result has been interpreted as the propensity to introduce unusual pieces of information into cognition and that this, in turn, might lead to creative responses (Zabelina, 2018). On the contrary, some other studies have suggested that creative people are more likely to pay attention to details, and thus have a more focused attention (Nusbaum & Silvia, 2011). It has already been suggested that in order to create novel and original responses people have to focus and persist, even at a long-term (Zabelina, 2017). Finally, it is interesting how other evidence exists suggesting that more creative people can switch more easily between various attention modalities (i.e. focused or broad) and therefore seemed to show a "*flexible attention*" (Vartanian et al., 2007; Zabelina & Robinson, 2010) or even a flexible strategy application in relation to the task demand (Zabelina, 2017). Summing up, it seemed that recent convergent evidence suggests that different aspects or measures of creativity are associated with different types of attention. What appears to be quite shared by different authors is that DT tasks, with their focus on idea generation within a limited amount of time, make people rely more on selective attention and good cognitive control (Zabelina, 2018) and therefore on the ability to focus and switch attentional resources instead of having a leaky attention (Benedek & Fink, 2019). Interestingly, several recent articles have consequently suggested that DT tasks seemed to involve a *top-down* type of control of attention and cognition (Beaty et al., 2019). The role of cognitive control and different executive processes would be addressed in the next paragraph.

Finally, it is worth considering that neurosciences' evidence has also pointed to the relevance of what they called "*internally directed attention*". High creative performances have been indeed consistently associated with increased EEG alpha activity (Fink & Benedek, 2014; Kounios & Beeman, 2014). This result seems to highlight that creative cognition is often not much concerned with sensory perception, but rather relies more on imagination and thus requires to direct attention to self-generated thought processes (Benedek, 2018), this also in line with neuroimaging studies on the role of the Default Mode Network (see paragraph 1.2).

1.1.3. Cognitive control and executive functions

Behavioral, neuroimaging and lesional data agree on the role of brain areas and cognitive processes related to cognitive control and suggest that performance in DT tasks involves a top-down control of attention and cognition (Zabelina, 2018), thus with the intervention of executive functions (EF). Several research has also been focused on the role of specific executive processes during DT task (see Palmiero et al., 2022 for a review). Within a general cognitive control framework, EF could be considered as an "umbrella term" that refers to a set of different control processes that regulate human cognition and goal-oriented behavior (Gazzaniga et al., 2015). More specifically, they include several distinct processes where updating, shifting and inhibition functions (Miyake & Friedman, 2012; Miyake et al., 2000) are the most studied as key cognitive processes during DT tasks. *Updating* refers to the constant monitoring and rapid addition/deletion of material in the working memory (WM) system; *shifting* allows to switch flexibly between tasks or mental sets and *inhibition* allows the voluntary overriding of dominant or prepotent responses (Zabelina et al., 2019).

Accordingly, as concern studies which employed DT tasks, different latent factor analyses have proved a relationship between DT and different executive processes: updating (Benedek et al., 2014c; Lee & Therriault, 2013), switch between categories (Nusbaum & Silvia, 2011) and inhibition processes (Nusbaum & Silvia, 2011; Benedek et al., 2012; Benedek et al., 2014c). Consequently, several studies have suggested that high cognitive control supports the selection and implementation of effective task strategies (Gilhooly et al., 2007), facilitating the suppression of interference from inappropriate stimuli or responses (Edl et al., 2014) and by inhibiting prepotent responses (see Benedek & Fink, 2019 for a review). Thus, inhibition is particularly involved in order to suppress obvious responses and common mental sets that prevent the production of original responses (Volle, 2018). Moreover, also flexible regulation supported by cognitive control mechanisms seemed to be critical for DT performances (Zabelina, 2018).

However, results demonstrate that different EFs predict divergent thinking performances depending on their operational definition (Zabelina et al., 2019) and on the different DT index considered. For example, other studies have found also increased DT performances with decrease inhibition; this seemed to be true only for the fluency index (Radel et al., 2015) and some other authors have proved that fluency (but not originality) of DT was uniquely predicted by working memory (WM - Zabelina et al., 2019). Finally, how it was already mentioned in previous paragraphs, a *goal-directed retrieval* seemed to be needed to build ideas that could be considered novel, original but also appropriate to the request of the task (Beaty et al., 2019). A recent review on the role of the core EFs (working memory, inhibition and flexibility) in DT have highlighted how the literature is profoundly fragmented (Palmiero et al., 2022). However, the Authors proposed interesting hypotheses which seek to account for the mixed and controversial results. They advanced the idea that low inhibition would allow to broad the focus of attention and collect close and distant information at the beginning of the divergent process, while, by contrast, high inhibition might be necessary to broad the focus of attention to filter irrelevant information and construct semantic associations (plausibly remotely) between concepts at a consequent stage. In addition, they argue that low working memory capacity would be associated with defocused attention and scarce semantic associative processes, facilitating mind wandering in the initial phases of DT, whereas high working memory capacity would be associated with focused attention and semantic association processes, after the mind wandering (dissociative) phases of DT. Finally, according to them, low cognitive flexibility would contribute to narrow the focus of attention and the semantic space wherein to find associations, facilitating persistence, whereas high cognitive flexibility would support DT when attention is shifted across different categories and more distant semantic associations are formed, facilitating higher originality, regardless of the specific phase of DT.

Lastly, the importance of executive function processes and cognitive control is also sustained by neuroimaging studies that have demonstrated the critical role of brain regions that support these cognitive functions while subjects performed DT tasks; however, this topic will be addressed in the next paragraph (see paragraph 1.2.).

1.1.4. The neurocognitive framework and beyond

All this evidence has been summarized and integrated into the neurocognitive framework of creative cognition proposed by Benedek and Fink in 2019. In this model, the authors highlighted how the amount of cognitive and neuroimaging evidence has produced valuable insights on the mechanisms underlying creative cognition, evidencing how creative cognition is supported by three highly intertwined process: goal-directed and constructive memory processes and internally directed attention. However, it could be argued that other cognitive functions have been correlated with DT productions, such as abstraction (Welling, 2007), mental imagery (Palmiero et al., 2016b) and so on. Moreover, the dominant hypothesis recently strengthened by neuroimaging findings is that creativity involves both controlled and associative processes (Beaty et al., 2016; Beaty et al., 2018; Volle, 2018). It might be suggested that controlled processes are more related with DT indexes regarding the quantity of the productions (fluency) or the switching between categories (flexibility), while associative processes are more involved in the quality of idea generations (i.e., originality, elaboration - Volle, 2018). Several studies have indeed demonstrated a strong link between two cortical networks underling exactly automatic (i.e., Default Mode Network) and controlled processes (i.e., Executive Network); this topic will be addressed in the next paragraph.

Noteworthy, this is only part of the explanation of this complex cognitive ability. Going beyond the neurocognitive framework, representing the background of this dissertation, several papers and models have already highlighted that other variables come into play when trying to explain creative cognition and especially real-life creative behavior. Personality characteristics (i.e. openness to experience, extroversion) and intelligence (Jauk et al., 2014) constitute the core variables relevant to real-life creativity across domains. Furthermore, for example, a more comprehensive model proposed by Jauk (2019) have proposed that interindividual differences in these variables seemed to arise from variation in the dopaminergic system apart from the default mode and the executive control network (i.e., bio-psycho-behavioral model). But these variables, along with the impact of environment and social context and the role of motivation (Amabile, 1983), are beyond the scope of this discussion.

1.2. The neural correlates of divergent thinking and creative cognition

The last paragraph has highlighted how creative cognition and therefore DT is a complex mental ability, which can be counted among those that are called “higher cognitive ability”. Consequently, it is not a surprise that divergent thought, as a multi-componential process requires, in turn, many parts of our brain to collaborate in supporting it (Goldberg, 2018). Different brain areas have been surely linked to DT abilities, such as the hippocampus or the prefrontal cortex (PFC). Neuroimaging and metanalysis studies proved the activation of hippocampus and medial temporal lobe during DT tasks (Gonen-Yaacovi et al., 2013; Madore et al., 2019; Wu et al., 2015). This is not strange if the literature about hippocampus' functions is taken into consideration. This brain area, indeed, has been described as the central structure in the brain that works to create, update, and juxtapose mental representations (Cohen & Eichenbaum, 1993; Eichenbaum & Cohen, 2001) and that has the ability to bind together distinct aspects of experience and to interact with neocortical cortex to support the integration and flexible use of representations (see Duff et al., 2013); all these functions are fundamental for DT performances. Moreover, previous studies have also demonstrated that hippocampus supports at least three dissociable processes during episodic simulation, which are also involved during DT performances: retrieval of episodic details, recombination of those details, and the encoding of recombined information (see Addis & Schacter, 2012 and Schacter et al., 2017 for a review). Accordingly, lesion studies such as the one performed by Duff and colleagues in 2013 have demonstrated that DT perfomance can be disrupted in amnesic patients who have a specific hippocampal lesion.

Beyond that, many of the cognitive processes that have already been addressed as involved during DT performances, such as goal-directed attention, different executive functions (i.e., inhibition, updating, switching, etc.) rely on the integrity of the prefrontal cortex which plays a critical role in all the above-mentioned functions (Dietrich, 2004). Several experimental functional Magnetic Resonance Imaging[1] (fMRI) studies have already showed the large involvement of the PFC during DT tasks (Bechtereva et al., 2004; Carlsson et al., 2000; Fink et al., 2009; Howard-Jones et al., 2005; Kowatari et al., 2009; Seger et al., 2000). In particular, several research has highlighted the role of the inferior PFC (Abraham et al., 2012; Benedek et al., 2014a; Chrysikou & Thompson-Schill, 2011; Kleibeuker et al., 2013; Vartanian et al., 2013), a region associated with controlled memory retrieval (Badre & Wagner, 2007) and central executive processes (Aron, 2007). Accordingly, lesion data about patients affected by the frontal variant of fronto-temporal dementia (fvFTD) have demonstrated

[1] Functional Magnetic Resonance Imaging (fMRI) measures brain activity by the detection of changes associated with blood flow. This technique relies on the fact that cerebral blood flow and neuronal activation are coupled: when a brain area is in use, blood flow to that region increases providing an indirect measure of brain activity. More specifically, fMRI signal intensity is due to the difference of blood oxygenation between a "resting state" and an "activity state" (i.e., when the subject is performing a task). The difference in blood oxygenation is internally generated and represent an endogenous contrast: the BOLD (blood oxygenation level dependent) effect (Sacco, 2012).

a deficit in all the dimensions of DT performances (de Souza et al., 2010; Ruggiero et al., 2019). Also data from different metanalyses have confirmed the role of these two brain regions (Gonen-Yaacovi et al., 2013; X. Wu et al., 2015). Interestingly, the metanalysis performed by Boccia and colleagues in 2015 have highlighted how different brain areas seemed to be activated depending on the type of DT task that is performed (i.e., verbal versus figural): the authors suggested that creative cognition might rely on multi-componential neural networks and that different creative domains depend on the activation of different brain regions.

According to this latest evidence, focusing on single brain areas would certainly underestimate the complexity of the processes that come into play during DT thought: recent research has been consequently focused on the study of large-scale networks. These works have evidenced the interplay between three pivotal networks: the executive network (EN), the default mode network (DMN) and the Salience Network (SN).

1.2.1 The functional coupling between the Default and the Executive networks and the role of the Salience Network

Two brain networks have been extensively studied in DT literature: the executive network (EN) and the Default Mode Network (DMN). EN is a complex constellation of brain hubs in the dorsolateral prefrontal cortex (DLPFC) and in the posterior parietal cortex (PPC) which are usually activated when people are challenged with a cognitive task (i.e., "task-positive" network). Thus, it is believed to be involved when information about the outside world must be processed and to be critical for the human ability to coordinate behavior in a rapid, accurate, and flexible goal-driven way (Marek & Dosenbach, 2018). It is sometimes also called "control network" or Frontoparietal Network (FPN). On the contrary, DMN is divided into three major subdivisions: the ventral medial prefrontal cortex (vmPFC); the dorsal medial prefrontal cortex (dmPFC) and the posterior cingulate cortex (PCC) with the adjacent precuneus and the lateral parietal cortex (approximately Brodmann area 39). Another area that has been associated with the DMN is the entorhinal cortex (Raichle, 2015).

DMN is believed to be activated when no externally imposed task drives persons' cognitive processes: it is therefore engaged in internally directed thought, internally generated inputs (Raichle, 2015) and spontaneous cognition (Andrews-Hanna, 2012); sometimes, literature refers to that as a "task-negative" network. The interesting thing about these two networks is that usually they are "anticorrelated": when one is active, the other one is inactive (Goldberg, 2018): there is a causal neural mechanism by which the EN negatively regulate the DMN (Chen et al., 2013). However, intriguingly, they seemed to cooperate during DT tasks (Beaty et al., 2014, 2015, 2016).

Thus, which is their role during DT thought? During the last decades, thanks to the great improvement in neuroimaging techniques and data analyses, many articles have improved the understanding about networks dynamics during this type of tasks. First evidence from Functional Connectivity (FC) studies have highlighted higher connectivity among default mode network regions (Takeuchi et al., 2012; Wei et al., 2014) in highly creative individuals. Subsequent studies have underlined a more complex interplay between different networks. For example, Beaty and colleagues in 2014 have evidenced how high divergent thinkers showed increased FC between seed regions in inferior prefrontal cortex (bilateral IFG) in the DMN, with a cluster of voxels in the EN, the left dorsolateral prefrontal cortex (DLPFC) a region that is associated with controlled attention and working memory capacity (Curtis & D'Esposito, 2003; MacDonald et al., 2000). The authors suggested that the ability to come up with creative ideas, involves a cooperation between brain regions associated with controlled (i.e., EN) and spontaneous cognitive processes (i.e., DMN). These results have been extended in another study performed by Beaty and colleagues in 2015. In this experimental research the authors evidenced again, through a seed-based analysis, an increased connectivity between the EN and DMN (i.e., between DLPFC, PCC, and precuneus) but new information was also added. On one hand, they proved an increased connectivity between default regions (PCC and precuneus) and regions that are part of the Salience Network (SN). The SN is a network that includes the anterior insula and the anterior cingulate cortex (ACC) and it is believed to be involved in the reallocation of attentional resources to salient environmental events (Bressler & Menon, 2010) and to play a central role when the switching between networks is required, especially between the DMN and the EN (Andrews-Hanna et al., 2014; Bressler & Menon, 2010; Goldberg, 2018). On the other side, a dynamic coupling between these regions at different stages of the DT task was evidenced by a temporal analysis: PCC was more strongly connected to SN regions (i.e., bilateral insula) at the beginning of the task, followed by stronger connections with EN regions (i.e., right DLPFC). Early coupling of the PCC with the SN suggests that creative thinking may require focused internal attention at a first stage and then SN might provide a mechanism that facilitates the switching and the later coupling with the EN and thus, the focus on external environment. Indeed, the DLPFC only showed connectivity with default regions during the second half of the task, pointing to a potential role of executive processes at a later stage of DT tasks. It was hypothesized that the executive control, at this stage, might be useful to suppress salient conceptual knowledge (i.e., typical responses), facilitating flexible switching between semantic categories during memory retrieval (Nusbaum & Silvia, 2011) or by attenuating sensory input and focusing attention to internally-directed cognitive processes (Benedek et al., 2016).

These results are supported also by different recent evidence. A first study, through task and resting-state fMRI paradigms, revealed that the strength of the connectivity between the posterior DMN and the right FPN was significantly greater in the creative condition (i.e., alternative uses task) than in the control condition. Moreover, the anterior DMN and left FPN connectivity strength during the resting-state was positively correlated with the originality score derived from the DT task (Shi et al., 2018). This is also confirmed by another study, that highlighted a whole-brain network associated with high-creative ability that includes cortical hubs within the three previous mentioned networks, suggesting that highly creative people seemed to be characterized by the ability to simultaneously engage these large-scale brain networks (Beaty et al., 2018). Interestingly, to conclude and also taking up the results of the previous sections, the study performed by Chen and colleagues (2018) found that slower decrease in gray matter density within the left FPN and the right frontotemporal clusters predict enhanced creative ability. The authors conclude that goal-directed planning and accumulated knowledge are implemented in the right DLPFC (that is part of the FPN) and temporal areas, respectively, which in turn support longitudinal gains in creative performances (Chen et al., 2018). Finally, further data that support the involvement of these networks, come from a recent study of patients affected by focal frontal lesions that have suggested that damage to specific nodes within the DMN and FPN led to critical loss of different verbal creative abilities. In particular, a lesion to the right medial PFC (which damages the DMN) alters the ability to generate remote ideas, whereas a lesion to the left rostro-lateral PFC (part of the FPN) would alter the ability to appropriately combine remote ideas (Bendetowicz et al., 2018).

To conclude, however, it is worth noting that a recent study (Takeuchi & Kawashima, 2019) has also evidenced some implications of the use of large-sample neuroimaging studies of creative cognition measured by DT tasks. It has been proposed that the effect sizes of all observed correlations were weak, and that significant and robust interactions between sex and DT were observed, in particular for structural and functional connectivity analyses. According to these results, the authors suggested that increased sample sizes or robust statistics and meta-analytic approaches will be important to reveal a comprehensive picture of the neural bases of individual differences during DT tasks.

Chapter 2. Divergent thinking and the aging brain

Aging has been defined as the accumulation of morphological and functional changes in cellular and extracellular components, in regulatory systems and in homeostatic mechanisms, that can be attributed to the interaction between genetic features, environment and different social factors (Baltes, 1987; Li & Baltes, 2006). Thus, aging is a process that is genetically determined but environmentally modulated and that, consequently, may manifest with several different outcomes (Berlingeri, 2009). However, in general, it is usually characterized by a steady decline in various physiological functions that result in both physical and cognitive impairments (Deary et al., 2009).

In the next paragraphs, the studies related to the structural and functional changes that have been observed during the aging processes and the main theoretical models and hypotheses that have been formulated concerning cognitive aging, will be analyzed. At the end of the chapter, the implications for divergent thinking skills will be drawn and new evidence of its relationship with the cognitive reserve construct will be highlighted.

2.1. Structural, metabolic and neurochemical changes

During the aging process, many biological changes (i.e., structural, metabolic and neurochemical) can occur even in healthy subjects' brain. During the last century, the advent of neuroimaging techniques like CT[2] scan and functional Magnetic Resonance Imaging (fMRI, see footnote 1 for an explanation) have provided the opportunity to observe, in vivo and in a spatially detailed way, brain differences related to age progression. Thanks to these techniques, several studies have proved that global changes in gray matter, white matter and ventricular volumes are all hallmarks of normal brain aging. Moreover, the human brain seems to decrease both in size and weight (De Beni & Borella, 2015; Hof & Morrison, 2004). This decline is due to both neuron atrophy and to the decrease in synaptic branching and length of dendritic spines (De Beni & Borella, 2015; Harada et al., 2013; Sydney & Adlard, 2019). However, it is believed that the loss of weight is predominantly due to the loss of white matter rather than of the neurons (Harada et al., 2013; Pakkenberg et al., 2003) and to

[2] The CT scan is an X-ray technique that produces images using a form of tomography which acquires data from body sections or volumes. The acquired data matrix, through specific algorithms, reconstructs two-dimensional images on different planes, representative of a body layer and allows its three-dimensional representation (Sacco, 2012).

the reduction of axon myelination (Fjell & Walhovd, 2010) that therefore impedes axonal signal transduction and reduces its connection speed.

The studies have also shown that during normal aging various neuroanatomical regions are affected, but that these structural changes are not identical in all brain regions (Sydney & Adlard, 2019). Volumetric studies seemed to agree on the fact that the effect of aging on grey matter is localized more in the dorsolateral prefrontal cortex (DLPFC; Raz et al., 2005), in the orbitofrontal cortex (OFC), the precentral and inferior frontal cortex, the superior lobe of the parietal cortex (Raz et al., 1997) and, at a lesser extent, in the mesial temporal regions (Resnick et al., 2013) and in the hippocampus (Harada et al. 2013). The largest volumetric white matter changes recorded by a study performed by Fjell and Walhovd (2010) were in the putamen, nucleus accumbens, thalamus and frontal and temporal cortices; Rogalski et al. (2012) demonstrated reductions also in parahippocampal regions. Moreover, some DTI[3] (Diffusion Tensor Imaging) studies have observed that the major alterations in white matter were in the prefrontal cortex and anterior corpus callosum (Head et al., 2004). Conversely, however, some other studies have found that white matter changes were more widespread (Resnick et al., 2013). Summarizing, deterioration seems to be predominant in the anterior regions, including the PFC and its connections, and in the parietal lobe (Resnick et al., 2013) while the sensory and primary areas seem to be less sensitive to aging (De Beni & Borella, 2015). During the aging process, also metabolic (i.e. a decrease metabolic flow and oxygen consumption) and neurochemical alterations (e.g., a decrease presence of glutamate and alteration of fronto-striatal dopaminergic pathways) also occur (De Beni & Borella, 2015), but this goes beyond the focus of this discussion. Clearly, depending on where all these structural alterations arise, they will have different functional consequences.

As already mentioned, considering that DT is linked to both the anterior cortex and hippocampal activity (see section 1.2.), some authors have hypothesized a decrease in this capacity in older subjects (Heilman & Fleischer, 2018). However, as will be highlighted in the following paragraphs, the picture of changes in divergent thought during adulthood and late age seems to be more complex.

---

[3] Diffusion tensor imaging (DTI) is used to estimates, in vivo and non-invasively, the properties of the white matter and to investigate anatomical connectivity by characterizing the magnitude, the degree of anisotropy, and the orientation of directional diffusion of molecules (i.e. water; Alexander et al., 2007; Sacco, 2012).

2.2. Patterns of change: the relationship between brain activity, brain connectivity and cognition

Cognitive aging is often described in the context of loss or decline, however, emerging research suggested that the picture is more complex than this, with older adults showing both losses and gains in cognitive ability (Spreng & Turner, 2019).

Authors who have dealt with the study of the aging process and its consequences on cognition have traditionally divided cognitive abilities (De Beni & Borella, 2015) in the light of Cattel's bifactorial model (1963). This theory foresees a division into two separate factors: (i) basic mechanisms or "*fluid intelligence*" (Gf), that is biologically determined and allow people to adapt to new situations, to solve problems and is based on reasoning ability; on the contrary, (ii) "*crystallized intelligence*" (Gc), would be culturally determined and refers to the knowledge and skills acquired through experience, therefore being closely related to culture. The separation of these two factors has been demonstrated by several studies which have highlighted that these abilities would follow completely different trajectories during subjects' lifespan: Gc, typically measured by vocabulary tests, tends to remain stable throughout life (or even increase during late adulthood), while Gf tends to decrease linearly (e.g., Grégoire & Van der Linden, 1997). However, several authors have criticized the oversimplification of this subdivision to capture the real cognitive architecture linked to the aging processes. Consequently, different studies have tried to assess different cognitive functions during the lifespan through cross-sectional or longitudinal studies. For example, Reuter-Lorenz and Park (2009) have evidenced a differential impact of aging on different cognitive abilities (i.e., speed of processing, WM, long-term memory and world knowledge) though different indexes. This study, even if it was focused on more than two factors, has substantially confirmed the previously cited work by evidencing a near-linear decline in the speed of processing, WM, long-term memory (i.e., fluid intelligence), except for the world knowledge ability (i.e., crystallized intelligence), which might even show some improvements. Hence, semantic knowledge seemed to be continuously accumulated and to be preserved well into later life (Park et al., 2001; Verhaeghen, 2003). This has led some authors to refer to this phenomenon as the "semanticization of cognition" in older adulthood (Spreng & Turner, 2019).

Moreover, a relatively recent literature review performed by Hedden and Gabrieli (2004) has tried to summarize evidenced by different longitudinal studies concerning the trajectories of the different cognitive functions throughout the lifespan. In this article, the authors identified three different types of age-related behavioral patterns supporting the idea that aging process would affect different cognitive functions in diverse ways. The main patterns highlighted by this study were:

1. *life-long declines*: basic mechanisms of cognitive architecture, such as processing speed, working memory and encoding of information in episodic memory, tend to decay linearly along the life span. Following the results of the Seattle Longitudinal Study (Shaie, 1996), spatial abilities and reasoning have also been added to this category;
2. *late-life declines*: tasks that involve knowledge or have been performed many times during the subject's life show little or no decline, at least until the last decade of life. Short-term memory is one of these abilities. Measures of vocabulary and semantic knowledge are also stable until late in life, in both cross-sectional and longitudinal studies (Park et al., 2002; Shaie, 1996). It worth also noting that, according to the semanticization of cognition, it has already been proposed the hypothesis that older adults might use preserved knowledge and experience to form more effective cognitive strategies when performing tasks in which younger, on the contrary, rely on processing ability (Dixon et al., 2001; Hedden et al., 2015);
3. *life-long stability*: not all abilities decline with advancing age. Autobiographical memory, emotional processing, "theory of mind" and automatic memory processes such as implicit memory, would remain stable according to some studies evidence.

Several works have also proved that functional neural networks and their interactions change during the aging process (Damoiseaux, 2017). The most common evidence from cross-sectional studies is that older adults showed reduced functional connectivity (FC), especially within the DMN (Andrews-Hanna et al., 2007; Dennis & Thompson, 2014; Sala-Llonch et al., 2015) and the EN (Damoiseaux, 2017). Particularly, changes in the DMN seem to involve reduced suppression, as well as decreased within-network connectivity. On the contrary, increased between-networks connectivity was observed (e.g., Damoiseaux, 2017; Rieck et al., 2017; Spreng & Schacter, 2012).

Many previously cited studies have revealed how these two networks seemed to be highly involved during DT tasks (see paragraph 1.2.1.). However, far fewer studies have been conducted to investigate the neural basis of creative cognition in aging. Before going into depth of this last statement, the main theoretical models proposed by the cognitive neuroscience of aging that have tried to summarize the structural and functional changes evidenced during the aging processes will be addressed.

2.3. Theoretical models of cognitive neuroscience of aging

Studies on cognitive neurosciences of aging have highlighted various aspects related to the changes that occur during brain aging. Different theoretical models were then proposed to explain the different activation patterns that have been highlighted by the diverse experimental studies. The most important cognitive models in the field of aging research will be further investigated.

2.3.1. The HAROLD model

The HAROLD model (from *Hemispheric Asymmetry Reduction in Older Adults*), proposed by Cabeza in 2002, reports behavioral and neuroimaging evidence about a reduction of hemispheric asymmetry. This, especially in the prefrontal cortex (PFC) and during the performance of different tasks such as episodic memory recall, working memory (WM), perception, control and inhibition. In order to explain the above-mentioned decrease in the lateralization of brain activity, this model has proposed two different hypotheses:

1. *Compensation hypothesis*: neurocognitive deficits would be addressed at the cerebral level through a compensatory process involving the activation of bilateral rather than lateralized areas as occurs during earlier ages. The hypothesis would be supported, according to the author, by the positive correlation of this type of brain activity and cognitive performance: greater brain activity in older subjects would be correlated to a better performance;
2. *Dedifferentiation hypothesis*: the changes found at the neural level could represent a process of dedifferentiation, i.e., a process that implies a return to the use of general networks instead of specialized networks (a process contrary to the differentiation that occurs during adolescence and that leads to the specialization of neural networks).

It is worth noting that a more recent study performed by Berlingeri and collaborators in 2012, empirically reassessed the predictions of the HAROLD model. They employed a quantitative statistical lateralization analysis, the "*Statistical Lateralization Map*" (SLM)[3], based on a voxel-wise approach, a quantitative approach that was absent in the original studies on which the HAROLD

[3] The *Statistical Lateralization Map* is a method that makes a direct statistical comparison between the activation levels of each voxel in one hemisphere and its counterparts in the other hemisphere; this technique has the advantage of being free from the use of a priori regions and allows to estimate the magnitude of the lateralization effects.

model was based. The results of the study seemed to show that the HAROLD model, in its first version, fails to grasp the complexity of the changes that occur with aging for many reasons:

1. the HAROLD effect also occurred outside of PFC;
2. the number of clusters that showed the HAROLD effect increased proportionally as the task demand increased;
3. some of the HAROLD effects did not survive a quantitative evaluation of the BOLD response (i.e., some effects could be explained by a lack of side-independent activation);
4. the elders continued to maintain extensive hemispheric lateralization in the brain activation that sometimes also involved PFC.

As a result of this evidence, the authors hypothesized that the HAROLD model could represent a specific compensatory manifestation among the many that can be expressed during brain aging.

2.3.2. The PASA pattern

The PASA (*Posterior-Anterior Shift in Aging*) model, proposed by Davis and collaborators in 2008, highlights a clear reduction in the activity in occipital areas coupled with an increase in the activity of frontal areas (not due to task difficulty or task confidence effects) in elderly subjects. This result underlines that:

(1) the pattern might be attributed to a compensatory effect: it was found that the increase in the activity of the frontal areas is positively correlated with the performance and negatively with the activity of the occipital areas. This suggests that a higher-level cognitive process intervenes "online" in response to the deficits of the occipital areas contributing to the possible success of the performance of older subjects;

(2) positive correlations were found between PFC activations and parietal areas, a result that highlights the strong relationship between these two areas. This might indicate a compensatory activity that transfers brain activity from post-processing to processing in dorsal parietal areas associated with top-down, attention-driven control processes.

The PASA pattern of activations would be therefore useful for the elderly because they would be able to maintain high performances by exploiting more anterior activations in order to cope with some functional deficits.

2.3.3. The STAC-R model

The STAC (from *Scaffolding Theory of Aging and Cognition*) model was first proposed by Park and Reuter-Lorenz in 2009 and try to explain the maintenance of high levels of cognitive performance in older individuals despite the great changes and consequent deficits that occur at the neural and functional level. The model suggests that the pervasive increase in frontal activations (Davis et al., 2008) and the recruitment of bilateral areas (Cabeza, 2002) are important markers of brain adaptation, which would appear to use a "*compensatory scaffolding*". The latter would be understood in terms of the recruitment of additive, complementary or alternative systems in response to the difficulties encountered due to the natural neural decline mentioned in the previous paragraphs.

In 2014, Reuter-Lorenz and Park published a revised version of the model (STAC-revised, STAC-r) based on new longitudinal neuroimaging data on brain aging. Therefore, the STAC-r incorporated several factors that can occur during the entire lifespan and that underlie the growth or decrease of neural resources and therefore affect brain structure and functioning (see **Figure 3** for an overview).

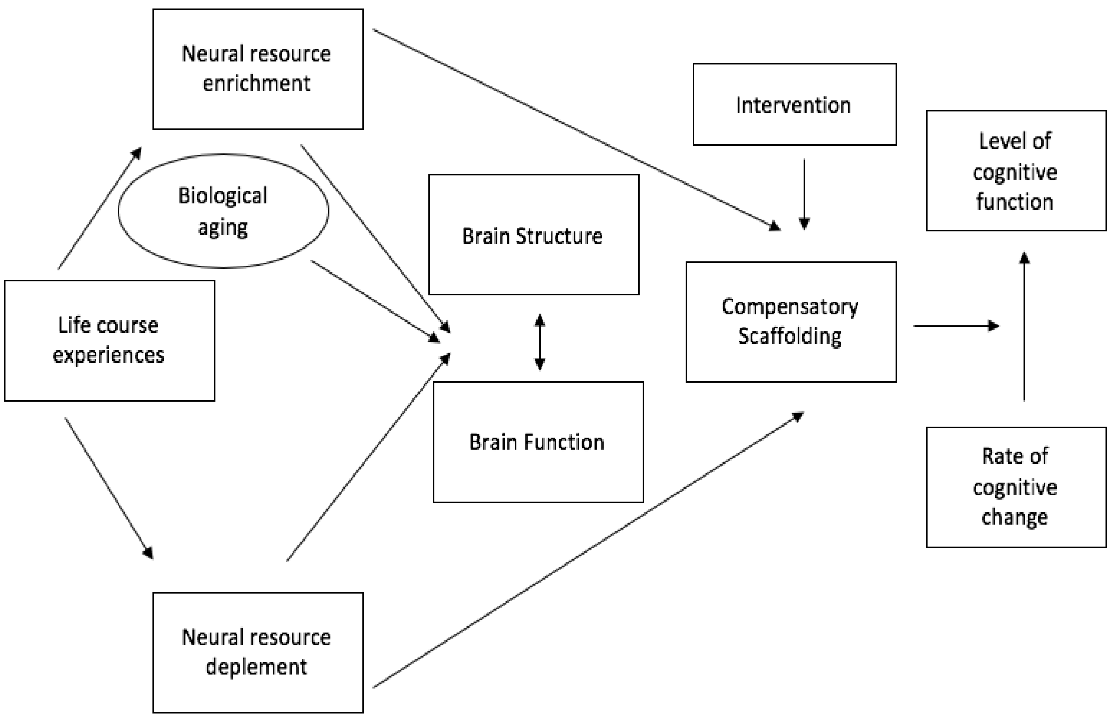

Figure 3: STAC-r model modified (and simplified) by Reuter-Lorenz & Park (2014).

Many changes have been brought into the new model:

1. in addition to the level of cognitive functions the authors added the "*Rate of Cognitive Change*", which indicates the speed of cognitive decline;

2. they introduced two new concepts, the "*neural resources of enrichment*" (i.e., actively participate in cognitive and social activities, physical activity, and so on) and the "*neural resources of depletion*" (i.e., the role of different factors such as APOE, stress, vascular disease, depression and so on). These two "factors" would allow to account for the way in which life course influences can contribute to health or neural dysfunctionality, but above all to account for the joint contribution of factors such as life experiences, genetic endowments and environmental influences. According to the authors, there are two ways in which these protective and beneficial effects can operate: a first pathway could account for a direct effect of neural enrichment in promoting efficient connectivity, increased synaptic density and other brain health indicators; a second pathway could be explained by the fact that the same factors mentioned above would increase compensatory capacity in terms of building scaffolding that would provide additional protection against cognitive decline;

3. with the division between the terms of "*Brain Structure*" and "*Brain Functions*" the STAC-r, from a life-course perspective, highlights the possibility of bidirectional changes reflecting both positive and negative effects of plasticity, development and influence of life-course factors. The maintenance of brain structure and function would, therefore, be possible depending on the age of the subject and the balance between influences of enrichment and depletion.

It is worth noting that both the old and new model include the potential benefits of formal and structured interventions (such as cognitive stimulation) on the construction and use of compensatory scaffolding and thus on brain structure and cognitive functioning.

2.3.4. The CRUNCH hypothesis

A further compensatory hypothesis is the one adopted by Reuter-Lorenz and Cappell in 2008, that is the "*Compensation-Related Utilization of Neural Circuits Hypothesis*" (CRUNCH). Neuroimaging evidence have repeatedly emphasized how elderly people often show more extensive activations than young people during tasks of a similar level of difficulty (Cabeza, 2002). According to the authors, one of the possible interpretations of this fact is that older people need the involvement of more neural resources even during tasks at a lower level of difficulty. This, in turn, did not allow elderly people to save resources for tasks that require higher cognitive loads, with the consequence that their performance in these latter tasks would worsen significantly. The CRUNCH hypothesis leads to predict that the differences in the activations between young and old, should disappear when the difficulty of the task is made subjectively comparable. The results of studies carried out in this field, and more specifically those of the study by Schneider-Garces and colleagues (2010), which tried to quantitatively confirm CRUNCH predictions through a WM task, suggest that the differences found in age-related activations (especially of the occipital cortex, PFC and dorsal-lateral parietal cortex) may be attributable to the fact that older subjects would reach a plateau in terms of behavioral performance and neural activity at a lower level of cognitive processing demand (and this would be due to differences occurring mainly in terms of memory span). These results would be in line with the authors' proposal, which suggested that the use of different task-specific neural circuits by young and old could be associated with differences in task difficulty and behavioral outcome. All this, again, supports the compensatory hypothesis that the brain of older subjects would recruit additional areas (i.e., early over-recruitment) even during the execution of low difficulty tasks in order to maintain the same levels of performance of younger participants. In the next chapter, it can be observed that some evidence on DT skills in the older population seems to confirm the CRUNCH predictions (see section 3.1.).

2.3.5. The DECHA hypothesis

Neurocognitive aging has also been explored by the observation of large-scale functional brain networks (Damoiseaux, 2017). In 2015, Turner and Spreng observed that in the elderly subjects, a greater engagement of lateral prefrontal brain regions implicated in cognitive control and a reduced default network suppression, implicated in memory and semantic processing, are functionally coupled. This evidence has led the authors to propose the *Default-Executive Coupling Hypothesis of Aging (DECHA).* They also highlight how the shift in cognitive architecture parallels changes in the functional network architecture of the brain (Spreng & Turner, 2019). It has already been highlighted in the previous paragraph that fluid abilities seemed to decline as opposed to an increase in semantic knowledge. Thus, the DECHA hypothesis predicts that, as goal-directed cognition becomes less dependent on declining control resources it would be increasingly influenced by prior knowledge (i.e., the semanticization of cognition). Thus, the default network is engaged and becomes increasingly and inflexibly coupled with lateral prefrontal brain regions.

It is worth noting that DECHA differs from the earlier compensatory accounts by stressing the role of cognitive context in determining whether these brain changes are functionally adaptive or maladaptive. For example, during DT tasks, where the access to semantic knowledge is relevant, a greater default-executive coupling should be adaptive (Adnan et al., 2019a). On the contrary, if prior knowledge is irrelevant, this pattern should lead to poorer performance (see Spreng & Turner, 2019 for a review).

2.3.6. The cognitive reserve theory

Differing from the theoretical models and frameworks described so far, the cognitive reserve hypothesis is associated with a more general cognitive and neuropsychological focus (Berlingeri, 2009). The cognitive reserve theory indeed stems from the observation of a non-linear relationship between the degree of brain pathology and its clinical and behavioral manifestations (Stern, 2002). These observations have been derived by early study that have highlighted how some individual maintained a high cognitive status despite showing classic lesions linked to AD such as abundant neurofibrillary tangles and amyloid plaques (see for example Snowdon, 1997). To explain these observations, authors have classically proposed two different models describing the concept of reserve:

1. *passive model*: according to this model (Satz, 1993), the *brain reserve* (BR) capacity would depend on a critical threshold determined by brain size and synapses count, that are considered as protective factors. In this perspective, the presence of a greater number of synapses would make possible to a subject to sustain a greater loss or damage before cognitive decline becomes apparent;

2. *active model*: in this perspective, *cognitive reserve* (CR) has been defined not as something predetermined, whereas refers to the accumulation of brain resources during the entire lifespan (Cabeza et al., 2018). According to different authors, reserve denotes a cumulative improvement in neural resources due to the interaction of genetic and environmental factors and this, in turn, might mitigate the effects of neural decline caused by physiological aging or age-related diseases (Cabeza et al., 2018; Scarmeas & Stern, 2003). This happens because CR could allow subjects to optimize their performance through more adaptable functional brain processes (Stern et al., 2018), that means differential recruitment of brain networks (both in terms of brain areas and interconnections) or alternative cognitive strategies (Stern, 2002,

2011, 2014). Thus, a subject with a higher CR would be able to use a wider range of alternative brain circuits than those with lower CR. Evidence supporting cognitive reserve includes epidemiologic data regarding lifestyle and clinical outcomes and neuroimaging studies. As concern epidemiologic data, several proxy factors that would influence CR levels throughout the lifespan have been found. Among these, there are: longer education (Kukull et al., 2002; Roe et al., 2011; Stern et al., 1994), work complexity (Andel et al., 2005, Karp et al., 2009; Kröger et al., 2008; Qiu et al., 2003), greater physical activity (Prakash et al., 2015), reading and literacy (Brewster et al., 2014; Manly et al., 2005), socioeconomics factors (Koster et al., 2005; Ouvrard et al., 2016; Rusmaully et al., 2017), social interaction and participation in demanding leisure activities (Fancourt et al., 2018; Fabrigoule et al., 1994; Scarmeas et al., 2001; Scarmeas & Stern, 2003). High levels of these factors would be associated with a higher probability of successful aging and a lower risk of incidence of age-related neurodegenerative diseases (Cabeza et al., 2018; Stern, 2002, 2009, 2014). According to these observations, it could be supposed that the cognitive skills and abilities that are acquired before the onset of neural deterioration serve as a hedge against or even to actively mitigated, loss of function due to the progressive brain failure (Stern et al., 2019).

On the other hand, neuroimaging techniques offer a methodological facility to investigate the neural implementation of these variables that are assumed to reflect reserve. Different experiments using both functional (i.e. PET, fMRI) and structural (mainly MRI) imaging is available in the aging literature. These studies generally address how CR or BR proxies relate to parameters such as brain atrophy and to cerebral blood flow or glucose metabolism patterns as well as brain network utilization during cognitive tasks (see Bartres-Faz & Arenaza-Urquijo, 2011, for a review). Evidence from these studies have confirmed that subjects engaging in more leisure activities can clinically tolerate more brain pathology (Scarmeas & Stern, 2003) leading to the possibility to conceptualize reserve as a reflecting indexes of brain plasticity (Bartrés-Faz & Arenaza-Urquijo, 2011). It is also important consider that many researchers agree on the fact that CR is not a fixed factor (Cabeza et al., 2018) and therefore can continuously be modified by life experiences (i.e., consequently also by cognitive stimulation or rehabilitation trainings), even when the brain is already affected by neuropathology (Liberati et al., 2012).

More recently, researchers have highlighted how the two models (i.e., passive and active), would not be mutually exclusive but should be considered as complementary explanations of different forms of functional plasticity (Stern, 2002). Structural features and dynamic network capacity both play a role in how the brain works in face of age-related brain changes and pathology (Stern, 2019). Even, recent contributions consider the distinction between brain and cognitive reserve as somewhat artificial, i.e., because cognition depends on the brain structures and prefer to use only the term “reserve” (Cabeza et al., 2018).

Furthermore, recent studies have highlighted the difference between three different concepts related to the concept of reserve: Reserve (i.e., BR and CR, concepts that have already been dealt with), Maintenance and Compensation. *Brain Maintenance* (BM) is defined as the reduced development over time of age-related brain changes and pathology based on genetics or lifestyle; this in contrast with BR which refers to the neurobiological capital at any point in time (Stern et al., 2018). More in detail, BM would refer to the preservation of neural resources though an ongoing repair of the brain in response to cellular and molecular damage. BM would occur throughout the lifespan and become critical in the old age (Cabeza et al., 2018) and is consequently best measured longitudinally by demonstrating relative preservation of brain morphology. On the other hand, *Compensation* can be referred to the cognition-enhancing recruitment of neural resources in response to relatively high cognitive demand. Therefore, compensation is temporally linked to variations in cognitive demands (can occur rapidly, in a matter of seconds). In light also of the previously mentioned models and studies results, three forms of compensation have been hypothesized by Cabeza and colleagues (2018): (i) compensation by upregulation, foresees that enhancement in cognitive performances is performed by boosting a neural process in response to task demands: older adults would engage this process (qualitatively equal) to a greater extent than younger subjects and at a lower task demand; (ii) compensation by selection is associated to the recruitment of different neural circuitry in the performance of a task: older adults would recruit qualitative different networks than younger adults (even if these networks are available for younger subjects). Concerning this type of compensation, the authors have also highlighted how it is important to note that this might be intimately linked with subjects CR: some older adults may have a larger range of alternative neural strategies to implement a behavior than others; (iii) compensation by reorganization may occur when older adults use a neural mechanism to respond to aging loss that is not available to younger individuals.

To conclude, all this evidence has highlighted how the relationship between brain reserve, cognitive reserve, maintenance, and compensation constructs and their contribution to the resilience to brain damage, is still much debated but of fundamental importance for the field of research concerning cognitive aging.

2.4. Neural patterns associated with divergent thinking in older adults

Some authors have hypothesized a decline of DT ability in older subjects (Heilman & Fleischer, 2018). However, as already evidenced by the different theoretical models, older people seemed to employ different cognitive and neural strategies to compensate for their structural losses. This could mean that they can use different brain areas and networks even during DT tasks, as they are getting older. However, in the literature, to date, only two studies have investigated the neural correlates of divergent thought in the elderly population. Both have been conducted following the prediction of the DECHA model.

The first study was conducted by Adnan et al. (2019a) and aimed to provide the first evidence for altered network coupling associated with creative cognition in older adults. They evidenced that the few task paradigms performed by previous works (on elderly population) have involved access to prior knowledge, where greater default-executive interactivity may be advantageous for older adults (as in DT tasks). Thus, they hypothesized, according to the DECHA model, that the functional interactions between default and executive control regions can support creative cognition in an older adult group. Thus, the study has compared, through an fMRI procedure, 30 young and 30 older subjects during an AUT task (versus a control task). Results showed no behavioral differences between the two groups; however, network interactions differed between younger and older adults. According to the authors' hypothesis, the latter group showed greater connectivity between DMN and EN (i.e., right inferior gyrus). This result has led them to suggest that this interaction might be considered as the neural marker of creative cognition in later life. They also speculated that DMN engagement may facilitate enhanced retrieval of prior knowledge representations to support DT in the context of a decline in the control abilities linked to the anterior cortex. Furthermore, they also evidenced greater connectivity between DMN and left-lateralized nodes in the middle temporal gyrus and SN areas, which are implicated in semantic control processing (Jefferies, 2013; Noonan et al., 2013). These results, together, seem to support the DECHA model, suggesting that functional interactions between default and executive control regions can support goal-directed cognitive performance when the activation of prior knowledge is congruent with task goals, also supporting the idea that creative cognition in older adults is able to benefit from the "shift" in the neural architecture to a more semanticized cognition.

The second study performed by Adnan et al., (2019b) aimed to investigate whether DT was related to connectivity among the DMN, FPN and SN and how patterns of resting-state functional connectivity (RSFC) associated with DT measures differed between young and older adults. As in the first study, the two groups did not evidence significant behavioral differences in the DT task (i.e., AUT); however unique intrinsic FC profiles were associated with their performances. Older adults showed greater FC between default and the broader executive control, specifically both with frontoparietal network (FPN) and SN, and this was associated with higher DT ability. Again, the observed results suggested that default to executive coupling seemed to be an important neural marker of creative thought in older adults. According to the DECHA model, this greater coupling observed in typical aging may support cooperation between activated prior knowledge representations mediated by DMN, and executive control processes necessary to work on these representations to build novel associations. Moreover, this study added another interesting finding. The authors also proved a pivotal role of the ventromedial PFC (vmPFC), which is a DMN hub. Indeed, they observed that greater intrinsic bilateral coupling of vmPFC, as well as a stronger within network connection with the middle temporal gyrus and stronger between-network connectivity to EN nodes, specifically within the SN, were associated with divergent thinking greater ability. Interestingly, the authors evidenced how within-network connectivity of this region to medial temporal lobe subsystems as well as between-network connections with executive control regions has already been proposed to be implicated in accessing and engaging autobiographical knowledge to support goal-directed tasks (Andrews-Hanna et al., 2014) and how, consequently, the vmPFC might represent a gateway node, controlling access to semanticized autobiographical memory (Bonnici & Maguire, 2018). In addition to what has been evidenced in the first study, the author suggested that the access to stored crystalized experiential knowledge reflected by the higher intrinsic connectivity patterns of the vmPFC, might be another important mechanism associated with creative cognition in later life.

2.5. Divergent thinking and the relationship with cognitive reserve

Finally, it is worth noting that while the study of neural substrates of creative cognition in older adults is a relatively new topic in this field of research, the behavioral study of the impact of the aging process on DT's abilities has a relatively long tradition. However, as it will be observed in the next chapter, the results of this exploration are often inconsistent and controversial due to several methodological and theoretical issues.

Nevertheless, recent evidences have proved a significant and positive relationship between DT and the construct of CR (Colombo et al., 2018; Meléndez et al., 2016; Palmiero et al., 2016a), highlighting how the study of DT in this population could be highly beneficial for this population.

More specifically, the first to examine this relationship through an experimental study were Palmiero and colleagues in 2016a. In this study, they highlighted how verbal (but not figural) DT can predict CR measures. The authors have indeed subministered to a group of 40 elderly people (age range: 50–81 years) a well-known DT test, the Torrance Test of Creative Thinking (TTCT; Italian version from Sprini & Tomasello, 1989) which evaluates both verbal and figural DT and an inventory for the measurements of CR, that is the Cognitive Reserve Index questionnaire (CRIq; Nucci et al., 2012). This last instrument collects demographic data and information that are considered proxies of CR (see the previous paragraph for further details), and consists in three sections: education (i.e. years of education and training courses; CRI-Education), working activity (i.e. five different groups based on intellectual involvement; CR-Work), and leisure activities (e.g. frequeny in performing hobbies, reading, travels, and so on; CRI-Leisure time). There is a specific sub-score associated with each section, as well as a general score that expresses the CR index. The study results have evidenced that, fluency and originality indexes specifically seemed to be positively correlated (i.e. moderately to largely, from .56 to .69) with CRI-Education, CRI-Leisure time, and CRI general scores (but not with CR-work). Furthermore, verbal (but not figural) DT predicted CR (R^2 Adjusted= .29) over and above intelligence. The authors have consequently speculated that among the complex mental activities that are already proved to be involved in CR, DT could be also considered as part of this construct and that, consequently, could be considered as a pivotal protective factor against cognitive decline.

On the contrary, the study performed by Melendez et al. (2016) aimed to demonstrate that CR and personality variables, such as openness to experience, could predict DT (i.e., verbal and graphic). The authors have proved, through a structural equation model, that: (i) CR and openness to experience can well predict DT (measured by PIC-A, the Test of Creative Imagination for Adults; Artola et al., 2010, inspired by the TTCT); (ii) CR has a greater predictive power than openness to experience in predicting DT; (iii) both constructs predict verbal DT to a greater degree than figural ones. The authors concluded that DT might increases the possibilities of efficaciously solve the many challenges associated with aging. Consequently, they have put forward the idea that preventive intervention program might be focused on strengthening the CR components and to promote openness to experience in older adults.

Finally, Colombo et al., (2018) seemed to connect the two previous results. The authors indeed highlighted how most of the proxies used to assess CR share the same characteristics (i.e. to be able to keep an open mind, to establish new and unusual relationships and to change their perspective) that allow people to use alternative strategies of thought, which are the same operations that have been used to define the creative process (see for example Antonietti et al., 2011). Consequently, they have hypothesized a positive bidirectional relationship between CR and DT. Accordingly, results have shown both an effect of CR on DT (measured through one AUT and one acronyms tasks) and of DT on CR. As concerns the former relationship, results have highlighted that CR proxies influenced the performance in the DT tasks but in different ways. More specifically, higher scores in the Vocabulary subtest (i.e., task that assess crystallized intelligence by evaluating verbal and semantic abilities) from the WAIS-IV (Wechsler, 2008) led participants to be more original in verbal DT tasks, partially confirming the results of Palmiero et al. (2016a), who found that only verbal creativity predicts CR. Moreover, they have found that the frequency of leisure activities was the proxy most closely linked to all the performance indexes (i.e., fluidity and originality) of both DT tasks. Instead, as concerns the latter relationship, the authors have evidenced that, for example, the type of job (creative vs. non-creative) influenced almost all the proxies of CR. Moreover, a more refined analysis was performed and suggested that job complexity can influence CR (Stern et al., 1994; Richards & Sacker, 2003; Staff et al., 2004) and that, interestingly, the creative component of the job, more than the complexity per se, affects CR indexes.

In conclusion, recent studies have evidenced that the relationship between DT and CR appears to be bi-directional and that verbal DT is the most connected with the construct of CR. Therefore, although further experimental studies are necessary to confirm these results, a few deductions can be made which will be proposed and explored in more detail in the following paragraphs.

SECTION 2. NORMAL AGING

Chapter 3. Divergent thinking abilities in healthy aging

3.1. Study 1. The controversial role of age on divergent thinking: a systematic review

3.1.1. Introduction

The positive correlation highlighted between DT and CR (Colombo et al., 2018; Palmiero et al., 2016a; see paragraph 2.5) and the deduction according to which stimulating divergent thinking could increase cognitive reserve, has renewed the interest of researchers to study this skill during both healthy and pathological aging. Despite this, while the literature provides many insights into divergent thinking skills and related factors in younger adult's populations, fewer studies have been focused on the study of DT in the elderly population, with results being often inconsistent. One first explanation for this controversy may lie in the fact that the study of creativity and DT has a long tradition, but only recently they have been recognized as two separate concepts. Consequently, the fact that different literature reviews (Abraham, 2013; Dietrich, 2019a; Dietrich & Kanso, 2010; Sawyer, 2011; Yoruk & Runco, 2014) have evidenced that the research field has been heavily fragmented and theoretically incoherent, is not surprising. For example, during the last century, creative output has been sometimes confused with creative ability (Romaniuk & Romaniuk, 1981). Early studies, indeed, have been focused on the creative output considering only the production of eminent individuals in the fields of science, art, music, and drama by analyzing histography and histometric data. The first attempt to experimentally confirm these results among the general population has been carried out by Dennis and Bromley only in 1956 administering a test of creative output, the "Shaw Test", which consists of four blocks that can be arranged into different series (see the original article for further details). In the same direction, after the '70s, several authors moved their interests from the product to the processes underlying the creative output.

In this regard, the construct of Divergent Thinking (DT) has become pivotal because, as anticipated in Chapter 1, it is believed to elicit the cognitive processes leading to creative responses (Barbot et al., 2019) and because it can be easily measured by psychometric tools.

However, studies results concerning DT abilities in the elderly population have been often inconsistent and controversial, leading to different and apparently opposite hypotheses. On one hand, some researchers proposed the peak-decline-hypothesis (Lindauer, 1998), assuming that the best DT performance is reached before the '40s and then start to decline. On the other hand, the no-decline-hypothesis (Sasser-Coen, 1993) assumes that DT changes during the life-span might be a result of the changes that occur in the underlying cognitive processes (e.g. fluid intelligence, speed of elaboration, and so on). According to this model, older participants might think as divergently as younger subjects if specific intervening variables are considered (see also Palmiero et al., 2017).

A possible explanation for these controversies could be related to the way DT has been studied: sometimes it has been used as a synonym of (Piffer, 2012), or used as a proxy for the generic construct of creativity, instead of being considered a measure of domain-specific components (Barbot, 2018). Another widely debated aspect concerns DT assessment. Different measures involving open-ended problems and DT processes exist and the most commonly used instruments include tasks in which people have to produce multiple ideas in response to verbal or figural prompts (Kim, 2006). However, early studies, for example, tend to consider a composite score of DT, without considering the differential impact of the type of employed material (i.e. verbal or visuo-spatial) and of the different cognitive processes underlying verbal (VDT) versus figural (FDT) DT. Finally, another open debate concerns the scoring methods, their validity and comparability. Torrance scores of fluency, flexibility, and originality (Torrance, 1998) are widely used, as well as Wallach and Kogan's uniqueness scoring (1965), Amabile's Consensual Assessment Technique-CAT (1982) and Silvia and colleagues' subjective scoring method (2008). These approaches have been operationalized in different ways leading to potential confounding results (Barbot et al., 2019).

In our opinion, it is very important to consider all the aforementioned aspects related to DT construct in a life-span perspective to elucidate whether and how DT skills are influenced by age, what specific DT ability declines, and which are the potential underlying cognitive processes responsible for this decline. However, no systematic search on this topic has been performed yet: thus, this systematic review aims to summarize the main empirical findings and to highlights their practical implications.

3.1.2. Method

This systematic review was conducted following the Preferred Reporting Items for Systematic reviews and Meta-Analyses guidelines (PRISMA; Liberati et al., 2009).

Search strategy

The online search strategy was designed and executed independently by three of the authors (GF, SL, MC). The systematic literature search was performed through three different electronic databases (Pubmed, Psychinfo and Scoupus) and ended on March 06, 2019. The search was conducted with the following keywords: “creativity AND older”, “creativity AND aging”, “creativity AND ageing”, “creativity AND aging process”, “creativity AND age changes”, “divergent thinking AND older”, “divergent thinking AND aging”, “divergent thinking AND ageing”, “divergent thinking AND aging process” and “divergent thinking AND age changes”. To identify possible additional relevant articles, cross-references of the selected studies were also considered.

Inclusion and exclusion criteria

We selected only full-text journals article published in English. The following years range has been inserted in the database: 1970-2018. 1970 was set as cut-off because, as stated in the 3.1.2. Introduction section, it has been the first time that empirical studies on creativity began to be conducted on the general population instead of elitists (Ruth & Birren, 1985) and to be focalized on the creative process instead of products. Additionally, it is worth noting that in Scopus database we selected the following subject areas: “*Medicine, Health Professions, Arts and Humanities, Psychology, Neuroscience, Social Sciences*” and “*Undefined or Multidisciplinary*” when present, while in Psychinfo we selected the next major headings: “*creativity*”, “*age differences*”, “*aging*” and “*divergent thinking*”.

We considered only articles concerning our target population, that is healthy older adults (i.e., > 50 years old) and that have employed a specific DT psychometric task through a behavioral procedure. Accordingly, articles on clinical populations or on young adults, as well as reviews or commentaries, were excluded by the scanning of titles and abstracts. We excluded from this exploration also articles with a focus on neuroimaging or on protocol to enhance DT abilities (i.e., training and/or experimental procedures) and those with a more general focus on artistic creativity such as arts, literature, poetry, and so on. In particular, this review was focused on papers that have assessed DT abilities in older adults by comparing different age groups.

Study selection and data collection

The three authors independently screened the titles and abstracts of the database outputs to initially identify which studies were suitable for the research. Thus, they screened the full-texts of the selected articles in order to check for inclusion criteria. The 16 articles selected for the present review were found and agreed by all the three authors; any concern about studies inclusion has been discussed between them. Therefore, data collections included: evidence about the sample such as size, demographic data (age, gender and educational level) and information about the subdivisions of the sample (how many groups were considered) and if the authors followed explicit references for the age levels subdivision. Subsequently, two other tables were built by dividing the articles that considered VDT from the ones that assessed FDT (see next sections for more details). In these tables, the following information were included: authors (year), DT tasks employed and their features such as time constraints, scoring methods and number of raters involved; finally, statistical analysis and main findings have been reported for each of the selected articles.

3.1.3. Results

Number of selected studies

The search has identified a total of 3,726 (sum of the results returned by all databases) potentially relevant articles. After titles and abstracts (N= 3,699) and full-texts (N= 11) screening, a total of 16 studies were included in this review. Specifically, the screening of titles and abstracts concerned the removal of results that are not matched with inclusion criteria (see inclusion/exclusion criteria section). The selection process flow is presented in the original version of the paper (Fusi et al., 2020b).

Study design and sample characteristics

Some of the main characteristics of the selected studies are presented in **Table 1** Almost all the studies employed a cross-sectional study design. Only one article (McCrae et al., 1987) presented results from a cross-sectional, a cross-sequential and a longitudinal design. Sample sizes varied from 36 to 825 subjects. The authors of three studies have decided to analyze only adults or late adulthood (Parisi et al., 2009; Ripple & Jaquish, 1981; Sharma & Babu, 2017); six studies chose to compare one young group to an older one (Addis et al., 2014; Alpaugh et al., 1982; Foos & Boone, 2008; Leon et al., 2014; Palmiero et al., 2014; Roskos-Ewoldsen et al., 2008) and, in the last six studies, authors divided their sample into three or more age groups (Alpaugh & Birren, 1977; Jaquish & Ripple, 1981; McCrae et al., 1987; Palmiero, 2015; Palmiero et al., 2017; Reese et al. , 2001; Ruth & Birren, 1985). It is worth noting that some studies reported insufficiently or did not report essential information about socio-demographics data such as gender (Jaquish & Ripple, 1981; Leon et al., 2014) or educational level (Foos & Boone, 2008; Jaquish & Ripple, 1981; McCrae et al., 1987; Roskos-Ewoldsen et al., 2008; Ruth & Birren, 1985). Some of them were focused on a specific group such as men (McCrae et al., 1987), women (Alpaugh et al., 1982) or had disproportionate samples (Roskos-Ewoldsen et al., 2008; Parisi et al., 2009). Some works were focused only on sample with high educational score level (Parisi et al., 2009; Leon et al., 2014) and, finally, one study was focused on a specific population of teachers (Alpaugh & Birren, 1977).

Study ID	Authors, Year	Research Design	Sample size	Gender	Level of education	N of Groups
1	Alpaugh & Birren, 1977	Cross-sectional	N= 111. 20-29 (N=16); 30-39 (N=18); 40-49 (N=19); 50-59 (N=20); 60-69 (N=16); 70-83 (N=22).	42 Me 69 W	At least 4 years of college	6
2	Jaquish & Ripple, 1981	Cross-sectional	N= 218. 18-25(N=70): young adults; 26-39 (N=58): adults; 40-60(N=51): middle-age; 61-84 (N=39): older adults.	No gender information.	Not clearly specified (e.g. some years of college)	4
3	Ripple & Jaquish, 1981	Cross-sectional	N= 39; 61-84 (M = 71).	14 Me 25 W	Primarily college educated	1
4	Alpaugh et al., 1982	Cross-sectional	N=61. 20-38 (M= 28.87, SD=6.39; N=30): younger group; 60-83 (M=67.58, SD= 5.37; N=31): older group.	W	Younger group: 15.7 (2.48); Older group: 16.03 (2.75)	2
5	Ruth & Birren, 1985	Cross-sectional	N= 150. 25-35 (N=46): young; 45-55 (N=54): middle-aged; 65-75 (N=50): old.	86 Me 64 W	Not specified	3
6	McCrae et al., 1987	Cross-sectional, sequential, Longitudinal	N= 825 (17-101); Longitudinal: 33-38 (N=33); 39-44 (N=38); 45-50 (N=57); 51-56 (N=51); 57-62 (N=38); 63-68 (N=20); 69-74 (N=26).	Me	Most have at least a college degree	7
7	Reese et al., 2001	Cross-sectional	N=400.17-22 (M= 20.2; N=100): young (Y); 40-50 (M= 44.4; N=92): middle-aged (MA); 60-70 (M= 66; N=113): young-old (YO); >75 (M= 80.5; N=95): old-old (OO).	Y:50%W; MA:53.3%W; YO:55.8%W; OO: 52.6% W.	Coded in years: high school diploma; undergraduate degree; postgrad. education	4
8	Foos & Boone, 2008	Cross-sectional	N=120: 60 (M=20.53, SD=2.51): young; 60 (M=72.10, SD=7.71): old.	Young: 20 Me, 40 W; Old: 25 Me, 35 W	Not specified	2
9	Roskos-Ewoldsen et al., 2008	Cross-sectional	N=82: 18-22 (M=19,37; N=41): younger adults; 61-86 (M=73.05; N=41): older adults.	Younger: 49W; Older: 73% W	Not specified	2

Study ID	Authors, Year	Research Design	Sample size	Gender	Level of education	N of Groups
10	Parisi et al., 2009	Cross-sectional	N=189 (Age range: 55-93; M=72.9 years, SD=8.2 years).	34% Me 66% W	12-20 (M=16.1, SD=2.7)	1
11	Palmiero et al., 2014	Cross-sectional	N=70; 19-25 (M= 22; SD=2,17; N=35): younger; 57-82 (M= 65; SD=7,62; N=35): older.	Younger: 14 Me, 21 W; Older: 15 Me, 20 W	At least 5 years	2
12	Leon et al., 2014	Cross-sectional	N=60: 18-30 (M=20.21; N=30); Young Adults (YAs). 65-80 (M= 72.93; N=30); Older Adults (OAs).	Not specified	YAs: M= 14.27 OAs: M= 17.23	2
13	Addis et al., 2014	Cross-sectional	N= 36: 18 Young (M= 21.89, SD=3.61); 18 Older (M= 74.89, SD= 5.56)	Young:9Me, 9 W; Old: 7 Me, 11 W	M=14.56, SD= 2.09; M=16.39, SD=2.62	2
14	Palmiero, 2015	Cross-sectional	20-29 (M=23, SD= 5.02): young; 30-39 (M=36, SD= 2.83): adult; 40-49 (M=47, SD= 2.9;): middle-aged; 50-59 (M=53, SD= 2.18): adult-old; 60-69 (M=64, SD= 3.02): old; 70-80 (M=75, SD= 3.7): old-old. (25 each group)	14Me/11W 8Me/17W 8Me/17W 12Me/13W 8Me/17W 11Me/14W	At least 5 years	6
15	Palmiero et al., 2017	Cross-sectional	N=159; 20-35 (M=26.7, SD=3.7; N=37) young adult; 36-55 (M=48.3, SD=4.9; N=30) middle-aged adult; 56-74 (M=65.4, SD=5; N=38) young old group; 75-85 (M=80, SD=3.66; N=29) old group; 86-99 (M=89.46, SD=3.35; N=25); oldest-old.	83 Me 76 W	M= 8.79±4.13	5
16	Sharma & Babu, 2017	Cross-sectional	N=58: 50-54 (M=52.05; N=20); 55-59 (M=57.21; N=19); 60-64 (M=62.05; N=19)	43,1% Me 56,9% W	Graduate: 48, 27%; Postgraduate: 51,72%	3

Table 1: Empirical studies on the effect of aging on DT abilities: summary of study design, sample size, groups subdivisions, gender and educational level information. N= number of participants; W= woman; Me=men. M= Mean; SD= Standard Deviation (Fusi et al., 2020b).

Instruments and scoring methods

All the studies were selected for their focus on DT, but authors have employed different instruments to evaluate it. Eleven of them have evaluated VDT and three assessed figural FDT. The first ones are summarized in **Table 2** and the latter in **Table 3**; however, some other studies have evaluated both. Where possible, results have been reported in the corresponding tables, however when mixed results (e.g., only a general score) were reported they have been included in a distinct table (see **Table 4**).

As concern VDT, two studies (Jaquish & Ripple, 1981; Ripple & Jaquish, 1981) employed the "Sounds and Images" task (Cunnington & Torrance, 1965) in which subjects responded in writing to the presentation of four groups of auditory stimuli (i.e., abstract or familiar) and their productions were evaluated using the classic DT indexes (i.e., fluency, flexibility and originality). Two other studies (McCrae et al., 1987; Foos & Boone, 2008) employed the same battery composed by six DT tasks, that are: Associational Fluency, which asks for synonyms; Expressional Fluency, which asks subjects to write sentences with words beginning with specific letters; Ideational Fluency, which asks to the subject to name objects in specific classes; Word Fluency, which asks subjects to write words containing a designated letter, and Consequences, which asks subjects to imagine the possible consequences of unusual situations. However, noteworthy, they employed different conditions (i.e., with time-constraint or comparing the time-constraint and no time-constraint conditions). Other two studies (Palmiero et al., 2014; Palmiero et al., 2017) employed the Torrance Test for Creative Thinking, TTCT-Form A (Italian version, Sprini & Tomasello, 1989), that assesses both VDT and FDT. The verbal part is composed by seven subtasks that provide opportunities to ask unusual questions, to improve a product, to guess causes and consequences, to find different uses of common objects and to think about consequences of a "just suppose" problem. However, Palmiero et al. (2017) decided to extract and administer only one verbal task from the whole verbal battery. Other studies employed another well-known verbal test called the "Alternate Uses Task" (AUT; Guilford, 1967; Guilford et al., 1978) which requires to describe as many different uses of common objects as possible, in a given time: participants were stressed to come up with new, unusual and original ideas. This task was employed alone (Addis et al., 2014; Palmiero, 2015) or supplemented by other tests such as Word Association Test, in which participants see and/or listen a series of word and for each of them they were asked to anwer with the first word that comes to their mind (Reese et al., 2001), Associational Fluency (see above for a description, Leon et al., 2014) or Consequences and Plot Titles (Alpaugh et al., 1982; see Guilford, 1967 for a detailed description). It should be noticed that some studies used tasks with a time-constraint (Jaquish & Ripple, 1981; Reese et al., 2001; Ripple & Jaquish, 1981; Palmiero et al., 2014; Addis et al., 2014; Palmiero, 2015) but some others did not

(Alpaugh et al., 1982; Leon et al., 2014). Finally, almost all the articles reported a multi-rater scorer approach, except for Foos and Boone (2008), Palmiero (2015) and Palmiero et al., (2014) studies, which did not specify if more raters were involved in the scoring procedure.

Authors, Year	DT Tasks	Time	SM: Indexes	SM: Raters	Analysis	Findings
Jaquish & Ripple, 1981	Sounds and Images	TC	Fluency Flexibility Originality	2 raters (reported inter-rater and test-retest reliability)	-Multiple t-test pairwise comparison between age groups in the different indexes (Tukey Critical Range correction). -3 stepwise multiple regression with fluency, flexibility and originality as VD and age, self-esteem as VI. No covariates included.	- The first three groups were more fluent than older group. - Young and middle-age adults have higher score in flexibility than elderly group (no with adults). - Only middle adults were significantly more original than the elderly. - Middle-aged adults seemed to perform better on all measure of DT. DT seemed to not follow a linear age-decrement model (more pronounced in quantity).
Ripple & Jaquish, 1981	Sounds and Images	TC	Fluency Flexibility Originality	2 raters (reported inter-rater and test-retest reliability)	-Pearson Correlation computed among personal characteristics, DT indexes and self-esteem. -Multiple regressions with DT indexes as VD and self-esteem, age and level of education as VI.	- Level of education as the best predictor of all indexes of DT. - Age differentiated the ability to be fluent, and flexible but did not affect originality. - In the multiple regression with self-esteem, age and level of education as VI only educational level account for variance.
Alpaugh et al., 1982	Use of Objects (UO); Consequence (C); Plot titles (PT).	NTC	PT: Originality Ideational Fluency (according to Manual); C & UO: Originality Fluency Flexibility	2 raters (DT tasks);	- T-test between young and adult group. - Stepwise multiple regression analysis: intelligence entered first, followed by age group as VI and DT indexes as VD.	- Younger performs better than older group (heterogeneity of scores within groups); qualitative differences were also found in creative process: older adults may rely more on crystallized intelligence, whereas younger people draw more on DT abilities. - Age differences emerged for all component abilities measured by creativity tests (in favor of the younger group, even if there was great variability), intelligence residualized.
McCrae et al, 1987	Associational Fluency (AF); Expressional Fluency (EF); Ideational Fluency	TC	All DT test were originally scored by contract A Total score was	6 raters (inter-rater reliability reported).	- Cross-sectional: simple correlations between age and DT scores and partial correlations (intelligence); curvilinear correlations: to identify specific	- DT tasks were negatively related to age (especially when controlling for intelligence); - There were curvilinear trends, with a peak at age 24 for WF, and between 34 and 40 for AF, EF, IF and C; age accounted only for 10% of the variance in DT

Authors, Year	DT Tasks	Time	SM: Indexes	SM: Raters	Analysis	Findings
	(IF); Word Fluency (WF); Consequences (C), Form A.		built by summing standardized scores on the different tasks.		trends in DT; - Partial correlations of DT tests with age and WAIS vocabulary analysis: word fluency and WAIS Vocabulary as covariates to analyze the effect of speed of production.	scores. - Subjects in the youngest age groups showed increases, whereas those in the oldest groups declined over the interval. The only exception was IF, which significantly increased in the older adult group. - When WF was partialized from the correlations between DT tests and age, a marked decrease in the magnitude of the associations was seen, although significant negative correlations remained for IF and for C. When both WF and WAIS Vocabulary were partialized out, however, all the correlations were significant. There is a general decline in DT in later adulthood, which can't be attributed entirely to speed of production.
Reese et al., 2001	Word Association Test (WAT); AUT (coat hanger and brick, reference not provided).	TC	WAT: Associational fluency (AF, or verbal productive thinking). Score=the mean N of associations x item/ 12 item. AUT: production fluency, flexibility originality.	Independent scorers (N= not specified) with reported inter-scorer reliability.	- Hierarchical multiple regression analysis to verify the relation between DT indexes (AF,production fluency, flexibility, originality) and different intellectual variables (linear, quadratic and cubic components of each independent variable were entered in that sequence); - Univariate analysis of variance to test the main effect of age and gender on DT and Multivariate analysis of variance to test the joint effect of age and gender.	- The strongest relations of DT variables were with vocabulary, level of education, inductive reasoning and memory span. - Marked age group differences in DT as reflected by production fluency and flexibility. Production fluency, flexibility and originality were curvilinearly related to age: there would be a peak in the middle-age and then a marked decline in the later portion of old age; associational fluency was linearly related to age (decreases with age). - No relations between DT and gender.

Authors, Year	DT Tasks	Time	SM: Indexes	SM: Raters	Analysis	Findings
Foos & Boone, 2008	Associational Fluency (AF) Expressional Fluency (EF) Ideational Fluency (IF) Word Fluency (WF); Consequence (C).	TC vs NTC	Not specified	A subset of answer sheets were randomly selected and given to a second scorer to assess the reliability.	- MANOVA was conducted with age (young/old) and timing condition (TC/NTC) as between subject VI and scores on the five tests of DT as VD. - Five univariate ANOVAs to examine the effects of age and timing condition on each of the DT tasks.	Significant effects of age and timing and the interaction between age and timing conditions was significant. Overall performance was higher for young than for old adults and in not timed than in timed conditions: old adults would per- form as well as young adults when time limits were removed.
Leon et al., 2014	AUT (brick, pencil, paperclip, toothpick, and a sheet of paper); Associative Fluency (AF).	NTC	AUT: Fluency Originality AF: Total number of responses and Uniqueness	4 raters (inter-rater reliability not reported)	- MANOVA with age group as between subject VI and total fluency and mean uniqueness as VD; - MANCOVA: age group and total fluency and mean uniqueness as VI with lexical semantic tests as covariates to compare performance (controlling verbal skills, assuming they are related to educational level). - Correlations: with Young and Older group examined together or individually.	-Older participants produced a greater number of unique responses in both AU and AF tasks in NTC conditions, even when adjusting for lexical-semantic abilities on DT. - The OAs showed significant correlations between AF and AU total fluency and WAIS-R vocabulary performance, and AF total fluency and WM and for uniqueness scores on both the AF and AU tasks with the WM measure, suggesting that older adults relied more heavily on WM and lexical access to produce responses in DT tasks.
Palmiero et al., 2014	TTCT - Form A	TC	Fluency Flexibility Originality	Not specified	MANOVA: with flexibility, fluency and originality scores as VD and age group as between factor VI.	No difference between younger and older participants in terms of VDT (supporting the no-decline hypothesis).

Authors, Year	DT Tasks	Time	SM: Indexes	SM: Raters	Analysis	Findings
Addis et al., 2014	AUT (eyeglasses, shoes, keys, button, wooden pencil & tire).	TC	Fluency, Flex,Appropriateness, Elaboration Originality	3 raters	Independent samples t-test	The analysis revealed that age did not affect performance on any of the 5 measures.
Palmiero, 2015	AUT (brick and newspaper).	TC	Fluency Flexibility Originality Elaboration.	Not specified	MANCOVA: AUT fluency, flexibility, originality, and elaboration were treated as VD, "age group" as the between factor VI. Gender and educational level as covariates.	Significant effect of age on all DT indexes. In addition, the covariate of education was also significant. The analysis revealed that the peak of DT is reached before 40 years rather than during middle age and declines thereafter. No difference was found in any component of DT after the age of 40 and seemed to decline after 70. Older people hold the potential to think divergently, at least in verbal domain.
Palmiero et al., 2017	Only one verbal task from TTCT-A	TC	Fluency Flexibility Originality (From Technical Manual)	2 raters (inter-rater reliability not reported)	MANCOVA with fluency, flexibility and originality as VD; age as between factor VI; educational level as covariate.	No differences between young adults and middle-aged adults and between the young old, the old and oldest-old group in any component of VDT; the young adult group scored better than the young old, the old and the oldest-old group in all VDT; the middle-aged adult group scored better than the young old, the old and the oldest-old group in verbal fluency; better than the old and the oldest-old group in verbal flexibility.

Table 2: Empirical studies that have employed Verbal DT (VDT) tasks: summary of study characteristic, types of DT tasks and scoring methods (SM) employed, data analysis and findings. TC= time constraint conditions, NTC= no time constraint conditions. VD= dependent variable; VI= independent variable. TTCT= Torrance Test of Creative Thinking; AUT= Alternative Uses Task (Fusi et al., 2020b).

On the other hand, four studies evaluated the influence of the aging processes on FDT abilities (see **Table 3**.). These studies employed all (Roskos-Ewoldsen et al., 2008; Palmiero et al., 2014; Sharma & Babu, 2017) or only one specific (Palmiero et al., 2017) task from the TTCT- Figural Form (Torrance, 1987; Torrance, 1998). The figural part of the TTCT consists of three different tasks which consist in the construction of one or more drawings beginning with different given stimuli. All these research used the technical manual in order to evaluate DT indices but, in spite of that, they reported different indicators (sometimes according to the different test versions; see Table 3 for more details). Two studies employed multiple (i.e., two) raters (Roskos-Ewoldsen et al., 2008; Palmiero et al., 2017) but only one of them reported inter-rater reliability (Roskos-Ewoldsen et al., 2008). It is worth noting that all the TTCT tasks were under a time-constraint condition.

Authors (Year)	DT Tasks	Time	Indexes	Raters	Analysis	Findings
Roskos-Ewoldsen et al., 2008	TTCT (Form B), CIT (Creative Invention Task)	TC	Fluency, Flexibility, Originality, Elaboration, abstractness of titles, Bonus and a composite score.	2 raters, Inter-rater reliability reported.	- Correlations among visual WM, TTCT, and all CIT measures. - Multivariate ANOVA of the 5 TTCT indices with age as between VI. Bonus and composite index were analysed separately using a single factor (age) between subject's analysis of variance. - Same analysis with visual WM test performance as a covariate.	Small to moderate correlations appears between visual WM task and some measure of TTCT (abstractness of title and bonus). Difference related to age groups appears only after considering visual WM abilities. After adjustment, older adults showed higher abstractness of titles scores than younger adults (may due to their advantages in vocabulary).
Palmiero et al., 2014	TTCT (Form A)	TC	Flexibility; Fluency; Originality; Elaboration.	Not specified	MANOVA: Flexibility, Fluency, Originality, Elaboration sub-scores were treated as VD, whereas age group was treated as the between factor VI. Univariates ANOVA.	Younger participants (19-25) showed higher visual fluency scores than older participants (57-82) in the visual form of the TTCT.
Palmiero et al., 2017	Only one visual task from TTCT-A.	TC	Fluency; Flexibility; Originality (From Technical Manual)	2 raters (inter-rater reliability not reported)	MANCOVA with fluency, flexibility and originality from figural task as VD; age as between factor VI. Educational level as covariate.	No differences were found between the young adults and the middle-aged adults neither between the young old, the old and the oldest-old group in any component of FDT. The young adult group scored better than the old and oldest-old group in terms of visual fluency, flexibility and originality. The middle-aged adult group scored better than the young old, the old and the oldest-old group in terms of visual flexibility and better than the oldest-old group in visual originality.
Sharma & Babu, 2017	TTCT (Form not specified)	TC	Fluency, Orig., Title Abstractness, Elab., Resistance	Not specified	Kruskal-Wallis H	- No differences between age groups in FDT. - There was a significant difference in speed of processing.

Table 3: Empirical studies that have employed Figural DT tasks (FDT): summary of study characteristic, types of DT tasks and scoring methods (SM) employed, data analysis and findings. TC= time constraint conditions, NTC= no time constraint conditions. VD= dependent variable; VI= independent variable. TTCT= Torrance Test of Creative Thinking; AUT= Alternative Uses Task (Fusi et al., 2020b).

Finally, **Table 4** reports the articles that have not considered a differential role of aging on verbal and figural DT. Indeed, three studies (Alpaugh & Birren, 1977; Parisi et al., 2009; Ruth & Birren, 1985) employed a battery made up of several DT tests, but a composite score of these tasks was used for the analyses. Furthermore, all the three articles shared the fact that DT tasks were not under a time-controlled condition and authors did not specify whether they used more than one rater to make the scoring of subject's performances. Moreover, one of the studies (Parisi et al., 2009) did not report any elucidation of the scoring methods which were employed. Alpaugh and Birren (1977) seemed to focus their scoring approach only on ideational fluency and originality, while Ruth and Birren (1985) also considered flexibility.

Authors (Year)	DT Tasks	Time	Indexes	Raters	Analysis	Findings
Alpaugh &Birren, 1977	New Uses (NU); Useful Changes (UC); Match problems (MP5); Match problems III (MP3); Plot titles (PT); Symbol production (SP). Barron-Welsh Art Scale (BWAS): preference for complexity.	NTC	Plot Titles scored for: Ideational fluency Originality	Not specified	- A composite creativity index of Guilford's tests (COMP) was computed (not specified how) and used for the analyses; - Stepwise Multiple regression: COMP as VD and age was entered in the model as VI, after the variance due to intellectual variable was removed; -Correlations (between COMP and BWAS) and Partial correlation (age held constant); - Analysis of the same data separately for women and men.	- The composite index and most of individual tests showed age differences, which favored the younger groups (only in UC there were no differences). - DT abilities showing age differences were originality and fluency. -There was a lower ideational fluency in the sixth and seventh decades, as compared to all other groups. - There were no age differences in WAIS subtests. - Older performed worse than younger groups in BWAS: age differences in specific creative abilities and preference for complexity could be salient variables in explaining the decline in highly creative contributions in old age.
Ruth & Birren, 1985	Uses of objects; Just suppose; Patterns; Inkblots.	NTC	Fluency, Flexibility, Originality.	Not specified	ANOVAs and correlations (intelligence scores used as co-variates in ANOVA); the composite score of creativity was entered as VD; age, sex and setting used as VI. A composite creativity score was created (not specified how).	There are age differences in creativity, especially between the young and middle-aged groups (visible in all indexes). The differences between the middle-aged and old-aged groups were rather small. There are also sex differences. The men showed higher test scores for the Uses of Objects and for Pattern tests and it seemed to rely on their ability to draw on their technical and practical knowledge (may be tied to the choice of tests).
Parisi et al., 2009	Substitute Uses, Ornamentation, and Opposites Test; Alternate Uses and Word Association.	NTC	Not specified	Not specified	-Pearsons correlations; -Regression analysis (no covariates) with DT as VD and age as VI; - Regression analysis (with no covariates) with DT as VD and age, predisposition and activity engagement as VI.	- Low negative correlations (-.21) between age and DT abilities. - Age significantly predict DT but its influence was reduced (R^2=.04) when controlled for predispositional engagement (R^2=.02).

Table 4: Empirical studies which have considered mixed results of VDT and FDT: summary of study characteristic, types of DT tasks and scoring methods (SM) employed, data analysis and findings. VD= dependent variable; VI= independent variable. TC= time constraint conditions, NTC= no time constraint conditions

3.1.3.4. Analyses and findings

Regarding the analyses of VDT (see **Table 2**) only some of the studies have considered important socio-demographic variables as covariates: gender was considered by Reese et al. (2001), educational level was considered by Ripple and Jaquish (1981), Alpaugh et al. (1982), Palmiero et al. (2017); both variables were considered only by Palmiero (2015). Interestingly, many articles considered different covariates, such as intelligence (Alpaugh et al., 1982; McCrae et al., 1987), verbal skills (Leon et al., 2014), speed of processing (McCrae et al., 1987) working memory (WM) abilities (Leon et al., 2014) or predisposition and activity engagement (Parisi et al., 2009). All the studies except for Palmiero et al. (2014) and Addis et al. (2014), who did not find any change in VDT between a younger and an older group, observed differences in the performances considering the different age brackets: most of the studies showed a decline in all or only just some DT abilities. Moreover, different article explained the differences between the performance of young and old groups because of the decline in specific cognitive functions or abilities such as crystallized intelligence (McCrae et al., 1987), speed of elaboration (Foos & Boone, 2008) or WM abilities (Roskow-Ewoldsen et al., 2008; Leon et al., 2014). The only longitudinal study selected in this review (McCrae et al., 1987), gave strong evidence of a decline in DT abilities in later adulthood: the youngest groups showed general increases (between the two testing times), while the oldest groups' performances showed a decline in all DT indexes over the interval, except for "Ideational Fluency" which seemed to increase at least until the age of 68 and then decline in the 69-74 age group.

Similarly, for the analysis of FDT (see **Table 3**), only some of the studies considered important socio-demographic variables as covariates: Palmiero (2015) considered gender and educational level while Palmiero et al. (2017) only the last one. Two of the four studies found different performances between young and old participants: in Palmiero et al. (2014) younger participants (19-25) showed higher visual fluency scores than older ones (57-82). However, Palmiero et al. (2017) found a substantial difference among the younger and the older groups but a relative stabilization from the young-old group (56-74) to the oldest-old group (86-99). Sharma and Babu (2017) did not report any change in DT abilities in the considered three age brackets. On the other hand, Roskos-Ewoldsen et al. (2008) found higher abstractness of title score in the older group performing the figural part of TTCT-B when visual WM memory abilities were considered in the analyses.

Finally, in the articles that considered mixed DT indexes (see **Table 4**), only gender was contemplated in the analysis (Alpaugh & Birren, 1977; Ruth & Birren, 1985). Moreover, only two studies (Alpaugh & Birren, 1977; Ruth & Birren, 1985) considered intellectual abilities as a covariate.

All the four articles found small to moderate differences in the performances of the young compared to the old participants, with younger participants performing better in almost all the considered DT indexes even if different explanations were provided.

3.1.4. Discussion

We selected 16 peer-reviewed scientific articles from 1970 to 2018 with the aim to evaluate the role of the aging process on DT abilities. However, even if the focus has been directed specifically on DT skills, the selected studies have drawn again a complex picture, with the findings being sometimes fragmented and often inconsistent. According to the previously mentioned *peak-decline-hypothesis* (Lindauer, 1998), some studies have found a curvilinear relationship between age and DT abilities highlighting a peak in middle-age (Jaquish & Ripple, 1981; Reese et al., 2001), but no differences between young (17-22 years) versus older old subjects (75+ years; Reese et al., 2001) or peaks at different ages depending on the task (see ì McCrae et al., 1987 original article for more details). On the contrary, according to the *no-decline hypothesis* (Sasser-Coen, 1993), other studies did not find any difference (Addis et al., 2014; Sharma & Babu, 2017), or none at all if specific moderator/mediator factors such as time constraint and speed of processing (Foos & Boone, 2008), WM (Leon et al., 2014) or lexical access (Leon et al., 2014) were considered. Even, Roskos-Ewoldsen et al. (2008) found higher "abstractness of title" score in the older group when visual WM memory ability was considered. Interestingly, other authors have found a peak in the middle-aged adults or before '40s and then a stabilization (Ruth & Birren, 1985; Palmiero, 2017): this could be domain-specific (Palmiero et al., 2015) or due to a differential impact of aging on VDT than on FDT (Palmiero, 2014), with the former being unimpaired.

Findings appear quite complex also considering the specific indexes (i.e. fluency, flexibility and originality). One study evidenced a negative correlation between age and all the indexes (Alpaugh et al., 1982), whereas others found no differences in any of them (Roskos-Ewoldsen et al., 2008; Addis et al., 2014). Instead, some others have found a different impact of age on the different indexes. As concerns the *fluency* index, some studies highlighted a moderate negative correlation with age (Ripple & Jaquish, 1981), a decline in the elderly group (Jaquish & Ripple, 1981), or a selective decline in the figural tasks (Palmiero et al., 2014). However, it seems that recent research highlights a non-linear relationship between these variables. Reese and colleagues in 2001 have proved a correlation between fluency and a quadratic (i.e., non-linear) age component and, similarly, Palmiero (2015) has found a non-linear decline in verbal fluency. Moreover, Palmiero et al., 2017, interestingly, found a peak in young and middle-aged group but a stabilization of this ability during adulthood and later age (from 56 to 99). The picture seems quite identical for the *flexibility* index, whereas for the *originality* index, the situation appears slightly different, often highlighting contradictory results. Ripple and Jaquish (1981) did not find a negative correlation between originality and age and, according to this result, Reese et al. (2001) evidenced a slightly less marked decline for originality than for fluency and flexibility. On the contrary, other authors evidenced a decline (Jaquish & Ripple, 1981; Leon et al., 2014), even if it could be non-linear (Palmiero, 2015; Palmiero et al., 2017).

Taken together, these findings suggest that a complex and multidimensional, rather than a simple linear relationship seems to exist between the aging processes and DT performances, in particular if the different indexes of VDT and FDT are considered separately. However, the results of more recent studies appear to be encouraging for older people. It seems that a sparing of verbal DT (Palmiero et al., 2015) or at least a partial maintenance of all the indexes of DT (Palmiero et al., 2017) could be observed during the last decades of life. Certainly, elderly people performed worse than middle-aged adults (almost in all indexes), but later their performances seemed to stabilize, highlighting the potentiality to think as divergently as adults, or even as younger subjects, especially if they have enough time to perform the task (Foos & Bone, 2008) and if the required workload is not too high (Leon et al., 2014). Indeed, it can be observed that the relationship between age and DT different abilities could be influenced by a set of different variables such as educational level, intelligence, WM abilities, speed of processing and other cognitive abilities that play a significant role during DT tasks. Particularly, it seems that the discrepancies between young and older adults decrease if WM abilities or speed of processing are considered in the analyses (Foos & Boone, 2008; Leon et al., 2014). Although this evidence needs to be further investigated by other experimental studies, it could be hypothesized that this might occur according to the prediction of the CRUNCH model proposed by Reuter-Lorenz and Cappell in 2008 (see paragraph 2.3.4). This neurocognitive aging model predicts overactivations in the elderly subjects at a lower level of task difficulty that allows them to compensate and maintain performance at an equivalent, or slightly lower, level respect to the younger. However, when the task demand increases, i.e., giving them time constraints or a heavy WM load in the case of DT tasks, they can no longer compensate the aging gap and their performance drops. This could have important implications for future studies which can try to reduce the workload and remove time constraints to reach older adult’s best performances.

However, what we argue in this review is that the comparison between studies published so far is sometimes difficult according to the great difference that characterized them. Before going into depth, a general theoretical discussion needs to be tackled. Most of the studies have addressed the complex relationship between aging and DT abilities using Guilford's studies as a working framework. However, some others have claimed to generalize the results obtained by DT measures to general creativity (Alpaugh et al., 1982; Ruth & Birren, 1985; Sharma & Babu, 2017), while some articles have considered DT as a general cognitive ability (Jaquish & Ripple, 1981; Ripple & Jaquish, 1981; Parisi et al., 2009) and one article (Roskos-Ewoldsen et al., 2008) has even addressed the same topic considering it from a completely different theoretical basis, that is the "*Geneplore model*" (Finke et al., 1992). This lack of a coherent theoretical framework could have contributed to the confounding results so far reached.

In addition, the discrepancies of the findings could be due also due to the three classes of differences (according to the Results section) that seemed to occur between the selected studies.

The first concerns the *research design and the sample characteristics*. In some studies, only an adult or late adulthood group has been considered, in some others one young group was compared to an older one and again, in some others the sample has been divided into three or more age groups. It is worth noting that only one article (Palmiero et al., 2017) relies on a theoretical basis for the subdivision of the sample and that some authors have already proposed the idea that differences would be evidenced only if more than two groups were considered for the analyses (Palmiero et al., 2017). This could have had a great impact on the results: for example, it could be argued that Sharma and Babu (2017) didn't find any differences between their groups because they considered only a narrow age range (50-64 years) without considering the last life decades. Moreover, the significant differences in the recruited samples might represent a great limitation for the generalization of the findings (i.e., focusing only on specific groups like men, women, high level-educational, or population of teachers).

The second relates to the employed *instruments and scoring methods*. Firstly, some studies have improperly considered DT as a "single-domain" factor, thus by computing a composite score (Alpaugh & Birren, 1977; Ruth & Birren, 1985; Parisi et al., 2009). This could be considered as a huge weakness given that verbal and figural DT have been proved to rely on different cognitive abilities (verbal vs visuo-spatial) and on diverse brain activations patterns (Boccia et al., 2015; Chen et al., 2019; Gonen-Yaacovi et al., 2013), which are differently affected during the aging process (Hedden & Gabrieli, 2004; Salthouse, 2010). Secondly, significant and potentially confounding variations have occurred in the administration of the same instrument (e.g., different time restrictions, the selection of different items or subtasks, and so on) or in the applied scoring method (e.g. lacking descriptions). Selecting only one stimulus from a whole battery or choosing different items between studies could be a great deal for the comparison between these studies because of the well-known poor alternate-form reliability of DT tasks and the impact of different variables such as prior experience with the selected stimuli (Barbot, 2019; Forthmann et al., 2016; Reiter-Palmon et al., 2019). Moreover, it was already also proved that the selected scoring method (Reiter-Palmon et al., 2019; Vartanian et al., 2018a) and time restrictions (Leon et al., 2014) could affect and influence study results and, consequently, prejudice the comparability of these studies.

The last class of differences concerns how *data analyses* was carried out. Some of the selected studies, as highlighted before, measured DT abilities as a unique entity, using a composite score made up of different tasks (Alpaugh & Birren, 1977; Ruth & Birren, 1985; Parisi et al., 2009; Sharma & Babu, 2017). On the contrary, all the other selected studies considered the different DT indexes as different dependent variables in order to distinguish the possible differential effect of the aging process on these different indicators. Besides this important aspect, many authors have considered for their analyses different covariates or independent variables which surely have had an impact on the results and need to be considered in case of studies comparison.

Finally, it is worth to highlight how new and more accurate information about which of the DT abilities might be preserved or impaired in the elderly population could have significant practical implications. Indeed, it has already been proved that DT abilities can be considered proxies of CR (Colombo et al., 2018; Palmiero et al., 2016a). Spared DT abilities, especially verbal DT (Palmiero et al., 2015), might consequently be considered as a target for cognitive enhancement programs designed to support active aging and to reduce the risk of dementia (Cera et al., 2018). The ability to think in a divergent and flexible way could, in fact, be considered as a pivotal life-skill which can potentially help older people to better cope with the real-life challenges imposed by the normal aging process and could also have an important role for their general wellbeing (Cera et al., 2018).

3.1.5. Current limitations and future research direction

It is worth noting that this review could have some limitations due to the collection and selection processes. Even if a systematic search and review process following PRISMA rules were performed, relevant studies could be missed due to different authors' choice: 1) no attempts to access unpublished results were performed; 2) only articles written in English were considered; 3) only studies which have employed specific DT measures were selected, not considering a possible range of experimental tasks which could be also useful for the topic (see inclusion and exclusion criteria section). Moreover, a limitation of the selected literature is the monopoly of cross-sectional research design. Thus, the findings discussed until now could be biased by cohort effects and might overestimate age-related differences (Hedden & Gabrieli, 2004).

In line with both our observations and with the most recent literature, future research must address some methodological issues before the construction and implementation of empirical studies (Barbot et al. 2019) to reach more accurate and comparable findings. We acknowledge the importance of more clear and specific study designs: first, by explicitly employing a theoretical framework and then by choosing appropriate instruments and discussing the results based on that setting. For example, the results obtained with DT measures cannot be generalized to creativity in general (Snyder et al., 2019). It is also possible to suggest a comparison between different age groups (i.e., more than two) and to follow a theoretical criterion for the subdivision; this could help researcher to detect with greater accuracy the complex trajectory of DT abilities during adulthood and older age. Furthermore, researchers could be more reliable if the different facets of DT (i.e., verbal vs figural) were addressed by measuring different indexes (i.e., fluency, flexibility, originality) instead of a general and less significant DT general score. Afterwards, a comprehensive description about task instructions, conditions (such as the use of time constraints) and scoring methods has to be made (see Barbot et al., 2019). Indeed, it has already been evidenced that instructions could have an impact on the cognitive strategies employed for the resolution of DT tasks (Nusbaum et al., 2014; Rosen et al., 2017; Kaya & Acar, 2019). Moreover, according to the evidence that also scoring methods have an impact on experimental findings (Reiter-Palmon et al., 2019) and even on brain activations (Vartanian et al., 2018a), an informed choice about scoring method (i.e. suitable for the research aim and for the chosen instrument) has to be performed. Additionally, being aware of the limitations of some of the most used DT tasks, such as interdependence with convergent thinking (Cortes et al., 2019) and poor alternate-form reliability (Reiter-Palmon et al., 2019) have raised the need for the reliance on a range of DT tasks, rather than on a single measurement, to achieve improved validity and reliability.

3.1.6. Conclusions

In conclusion, it could be argued that a complex and multidimensional, rather than a simple linear relationship, seems to exist between the aging processes and the different DT indices, especially if verbal and figural DT are considered separately. Recent research, however, has highlighted how elderly people might think as divergently as younger people, especially in the verbal domain, and if no time constraints are imposed or the workload is not too high. These results could have significant practical implications: verbal DT might be considered as a potential target of cognitive enhancement programs to promote active aging. Nevertheless, giving that the reported findings are difficult to compare, the need for further and more accurate explorations to reach consistent results about the role of the aging processes on the DT indices was argued.

3.2. Study 2. The effect of psychological symptoms on divergent thinking in healthy older adults

3.2.1. Introduction

As highlighted in the previous paragraphs, many authors have tried to study DT abilities in the healthy elderly population, however the results have been often inconsistent (Fusi et al., 2020b). In addition to the various theoretical and methodological issues highlighted in the systematic literature review described above (paragraph 3.1.), another possible explanation of this inconsistency could be that most of the studies that have evaluated DT abilities in this population did not consider the effect of possible intervening variables such as psychological ones (i.e., the presence of depression, anxiety or apathy symptoms). More specifically, even if some studies controlled for the presence of psychological pathological condition such as depression (i.e., excluding from their studies subjects over or under a specific cut-off), they did not consider a wide range of psychological symptoms (e.g., avoiding for example the presence of anxiety or apathy) and the possible negative effect of the variance of these psychological variables on creative performance. Indeed, it has already been proven both that these psychological symptoms are frequent in the aging population, and that usually have negative effects on cognition (Baune et al., 2007; Beaudreau & O'Hara, 2009; Biringer et al., 2005; Darke, 1988). A literature review, for example, has highlighted how the prevalence of major depression range from 0.9% to 42% in the elderly (Djernes, 2006), conceivably around 17% according to a meta-analysis (Luppa et al., 2012; see Van der Linde et al., 2012 for a review) and other authors have evidenced how depression could be linked to anxiety (Lenze et al., 2000; Schoevers et al., 2005) or apathetic symptomatology (Yuen et al., 2015). Anxiety disorders result also to be common in later life: the overall prevalence was estimated at 10.2%, with generalized anxiety disorder as the most common disorder (7.3%) (Beekman et al., 1998) and is the most commonly found in comorbidity with other psychiatric disease (Flint, 2005; Lenze et al., 2000; Parmelee et al., 1993; Schoevers et al., 2005). Moreover, apathy has been recognized as frequent during late adulthood (Brodaty et al., 2010; Esposito et al., 2014) and negatively related to CR: higher level of apathetic symptoms seem to predict lower level of CR (Altieri et al., 2019). Specifically, Marin and colleagues (1991) defined apathy as a syndrome that involve a lack of motivation evidenced by diminished goal-directed behavior (i.e., lack of effort and initiative), diminished goal-directed cognition (i.e., lack of interest and concern about one's personal, health, or financial problems) and diminished emotional effort (i.e., lack of emotional responsivity to positive or negative events, absence of excitement). In addition to being quite common, all these symptoms seem also to have a direct negative effect on cognition: for example, a negative association between depression and cognitive functions was proved not only in severely ill patients, but also in the healthy aging population (Baune et al., 2007; Biringer et al., 2005; Dotson et al., 2020; Hudon et al., 2020). Moreover, a negative relationship has been found between anxiety and specific cognitive functions: subjects with higher score of anxiety showed poorer processing speed and lower ability in shifting, inhibition (Beaudreau & O'Hara, 2009) and in WM task (Darke, 1988). Finally, it is worth noting how these psychological symptoms are believed to be significant risk factors for the development of subsequent cognitive decline and decreased daily functioning (Clarke et al., 2010; Comijs et al., 2003; Ishii et al., 2019; Paterniti et al., 2002; Potvin et al., 2011).

Interestingly, even if few studies concerning the relationship between psychological symptoms and creativity have been published, one study has proved that the level of depressive symptoms has a moderating effect on the relationship of creativity and successful aging (Flood, 2006). On the other hand, when examining the relationship between anxiety and creativity, results are less clear: for example, a metanalysis highlighted how these findings seemed to be inconsistent showing that anxiety has been found to be negatively, positively, or not significantly related to performance on creative tasks (Byron & Khazanchi, 2011). Even considering these studies as first steps, not many research projects have addressed this topic specifically considering the effect on DT abilities, and none of them have considered apathetic symptomatology that, as discussed above, seems to have an interesting relationship with variables linked to CR.

Therefore, the aims of our study are to explore the impact of the variance in psychological symptoms (i.e., depression, anxiety and apathy) on DT abilities, and to investigate the possible moderating effect of educational level (i.e., a proxy of CR) on these relationships. Based on the evidence reported and discussed, even if scarce, we hypothesized that the variability of psychological symptoms could have negative effects on DT performances of healthy elderly subjects.

3.2.2. Materials and methods

Participants

The study involved a total of 50 healthy elderly subjects. However, after checking for normality and removing the outliers, the final sample considered for the analyses was composed by 45 participants

(Mean age: 74.2 ± 5.71; age range 65-85; educational level, mean= 6.51 ± 2.58, range: 5-13; 33 participants were women). These subjects are also part of a more inclusive study performed to compare DT abilities between healthy elderly subjects and patients affected by Mild Cognitive Impairment (Fusi et al., 2020a). The healthy elderly subjects were enrolled from a pool of community-dwelling volunteers. All participants underwent an assessment in order to be screened for the inclusion criteria which include: age ≥ 65-years-old, Mini Mental State Examination ≥ 24 (MMSE; Folstein & Folstein, 1975; Measso et al, 1993) and no history of vascular, neurological or psychiatric disease. All tests were administered individually and in a single session which lasted approximately one hour. The evaluation was performed in a quiet setting, without disturbing elements. An informed consent was signed by all the participants. The research protocol and procedure were approved by the institution (i.e. the hospital that begun the original research) ethical committee (see Fusi et al., 2020a) and was conducted following the Declaration of Helsinki.

Materials

Psychological measures

1. Apathy Evaluation Scale (AES; Marin et al., 1991). AES is a questionnaire designed to measure apathy, i.e. the level of participation and motivation to interact with the environment. It consists of 18 questions on a scale of 1 to 4 (1= a lot; 2= somewhat; 3= slightly; 4= not at all). The total score can be divided into 4 subscales that correspond to 4 dimensions of apathetic syndrome: cognitive, behavioral, emotional plus an “other” category. The overall score is between 18 and 72: higher score indicates higher apathy levels; the cut-off score for the presence of apathy is 39.

1. State-Trait Anxiety Inventory (STAI; Spielberg et al., 1983; Pedrabissi & Santinello, 1989) is a questionnaire that assesses state anxiety. This scale is composed of 20 items corresponding to different sensations (i.e. somatic, emotional, behavioral) related to possible variations in the levels of anxiety (e.g. feeling upset, shaken, and so on); for each item subjects provide an answer regarding how they feel when they are filling out the questionnaire on a scale from 1 to 4 (1= a lot; 2= somewhat; 3= slightly; 4= not at all). Score range is 20-80: higher score indicates higher levels of state anxiety.

2. Beck Depression Inventory (BDI; Beck, 1961) is a questionnaire designed for the evaluation of depressive symptoms. It consists of 21 multiple-choice items: participants are asked to

mark the statement that best corresponds to their current state of mind. The total score ranges from 0 to 63; higher score indicate higher depression symptoms levels; the cut-off score for the presence of depression is 16.

Divergent thinking measure

1. Abbreviated Torrance Test for Adults (ATTA; Goff, 2002) is designed to evaluate DT abilities and therefore subjects' creative potential. This test, an abbreviated form of the widely used Torrance Test of Creative Thinking (TTCT; Torrance, 1998), was initially selected because of the restrictions of clinical practice, as it is fast and easy to administer, and already used in the Italian clinical context (Canesi et al., 2012; 2016; Colautti et al., 2018). The instruction "be creative" is given before the starting of each administration. This test consists of three different tasks: one verbal and two figural. The first verbal task requires the participants to list all the problems that could happen following an implausible situation assumed to be true. The second and third tasks evaluate figural DT abilities by asking to the participants to make a drawing starting from different incomplete figures or from nine equal stimuli and to give a title to their productions. Three minutes are given to perform each task. The fluency, flexibility, originality, elaboration indexes and the creative indicators were calculated according to the scoring manual. More specifically, fluency is considered as a simple count of pertinent responses, flexibility as the different ways to consider the same stimulus, originality as the ability to produce idea that generally are not produced or ideas that are totally new or unique (i.e. subjects responses are compared with usual responses proposed by the manual) and elaboration is described as the ability to embellish ideas with details. The manual proposed by Goff (2002) provides examples for the scoring of all the above-mentioned indexes. The sum of creative indexes and indicators composes the total score: DTTS (Divergent Thinking Total Score).

3.2.2. Results

Descriptive statistics regarding general cognition (MMSE), psychological measures (i.e., BDI, STAI and AES) and the ATTA test (i.e. total score and all the subscales) are reported in **Table 5.**

	MMSE	BDI	STAI	AES	ATTA Fluency	ATTA Originality	ATTA Flexibility	ATTA Elaboration	DTTS
M	27.56	8.89	38.33	31.62	8.27	3.42	1.89	1.27	54.09
SD	1.73	5.23	10.24	5.22	2.90	1.59	1.58	1.92	5.49

Table 5: Descriptive statistics (M= mean; SD= standard deviation) of cognitive, psychological and DT measures.

According to our hypothesis, we first performed a series of one-tailed negative correlations among the ATTA scores and the psychological measures. The r values and significance levels are reported in **Table 6.**

		STAI	BDI		AES	
DTTS	r	0.053	-0.103		**-0.377**	**
	p-value	0.636	0.249		**0.005**	
ATTA_fluency	r	0.127	-0.040		**-0.366**	**
	p-value	0.798	0.397		**0.007**	
ATTA_originality	r	-0.175	**-0.260**	*	-0.123	
	p-value	0.125	**0.042**		0.210	
ATTA_elaboration+	r	-0.190	0.025		-0.180	
	p-value	0.106	0.564		0.119	
ATTA_flexibility	r	0.246	-0.207		**-0.322**	*
	p-value	0.948	0.086		**0.016**	

Table 6: One-tailed correlations between DT subscales and psychological measures. + a square root transformation was performed to reach normality strict criterion; *<0.05; **<0.01.

Interestingly, negative correlations could be observed between apathetic symptoms and DT total score and, particularly, with the fluency and flexibility indexes. On the contrary, depressive symptoms are negatively correlated with the originality index. No other significant correlation emerged.

Then, we run a linear hierarchical regression with DTTS as dependent variable. In the first step, age and educational level were added to control their effect. Then, in the second step AES total score was entered as single predictor. The analysis revealed that the first model was statistically significant (F (2,42) = 5.832, $p < .005$), and explained 18% of variance ($R^2 = .217$; R^2 Adjusted = .180). At stage two, the total variance explained was 26.6% (F (3,41) = 6.321, $p < .001$- $R^2 = .316$; R^2 Adjusted = .266). The introduction of the AES total score explained additional 8.6% variance (R^2 change = .099; F(1,41) = 5.931, $p < .05$). In the general model, age (B = -.340, $p <.05$) and AES (B = -.334, $p <.05$) were both significant.

Finally, we run a moderation analysis with bootstrapping to verify the possible moderating effect of CR proxy (i.e., educational level) on the relationship between apathy and divergent thinking. As it was evidenced in the previous analysis a direct negative effect of apathy on DTTS can be observed, while no complete moderation effect was highlighted (see **Table 7a**). However, it is worth noting that specific effects can be observed if the different educational level is considered (see **Table 7b**).

	Estimate	SE	95% Confidence Interval Lower	Upper	Z	p
Moderation Estimates (a)						
AES	-0.378	0.135	-0.642	-0.125	-2.806	0.005*
Educational Level +	2.927	1.626	-0.449	5.909	1.801	0.072
AES ✻ Educational level +	0.140	0.312	-0.497	0.708	0.449	0.654
Simple Slope Estimates (b)						
Average	-0.378	0.132	-0.624	-0.105	-2.856	0.004*
Low (-1SD)	-0.442	0.195	-0.824	-0.077	-2.262	0.024*
High (+1SD)	-0.315	0.181	-0.659	0.052	-1.737	0.082

Table 7: Moderation analysis with bootstrapping: a) shows the general moderation estimates; b) shows the simple slope estimates. + a square root transformation was performed to reach normality strict criterion; *<0.05.

A partial moderation of educational level on the relationship between apathy and divergent thinking can be indeed observe in the average and lower scores (-1 standard deviation, SD) of the educational level variable (see figure in the online paper version, Fusi et al., 2021a).

3.2.3. Discussion

The main purpose of this study was to assess the possible negative impact of the variance of psychological symptoms on DT performances in a group of healthy elderly participants. As cited before, previous works have already proven how some psychological symptoms such as depression, anxiety and apathy are frequent in the elderly population (see Van der Linde et al., 2012 for a review) and how these symptoms can have negative effects on cognitive performance (see Baune et al., 2007; Beaudreau & O'Hara, 2009; Biringer et al., 2005; Darke, 1988), including creative skills (Byron & Khazanchi, 2011; Flood, 2006). However, this last evidence is still scarce and the relationship between psychological measures and DT skills has yet to be expanded. This gap can also be observed in the literature concerning the study of DT abilities in the elderly population that have often reported inconsistent results (see Fusi et al., 2020a for a review); it is reasonable to hypothesize that this inconsistency could also be due to the fact that almost all these studies have neglected the evaluation of psychological measures that could have a negative impact on the different DT indexes.

Our data support the hypothesis that psychological symptoms could negatively affect DT performance. The correlational analyses have highlighted negative correlations between apathy and different DT subscores. More specifically, it seemed that higher apathetic symptomatology that includes less finalized behaviour, decreased interests and reduction in emotional responses measured through a self-report questionnaire (i.e., AES) seemed to have a negative impact on the total score in the DT task and on the subjects' ability to be fluent and flexible in their responses. Moreover, AES score negatively predicts DT general performance, even when age and educational level were controlled for in the analysis. This result is not surprising given the fact that apathy has already been linked to an executive deterioration (Kawagoe et al., 2017). It has also already been suggested that apathy and executive functions may share some biological mechanisms both in the healthy aging population (Kawagoe et al., 2017) and in individuals affected by different neurological disease (Ducharme et al., 2018; Esposito et al., 2010; Lohner et al., 2017; Raimo et al., 2016). This, together with the fact that fluency and flexibility indexes seem to be the most related to the executive functioning and that, in general, performances in DT tasks have been linked to different executive skills such as WM skills, inhibition and shifting ability (Benedek et al., 2012; Benedek et al., 2014c; Gilhooly et al., 2007; Lee & Therriault, 2013; Zabelina et al., 2019), seems to support the correlations found in our analyses. Future studies might explore and deepen the relationship between apathy, different executive functions (e.g., WM, shifting, inhibition, and so on) and DT performances in the elderly population.

Moreover, an interesting negative correlation was also found between depression and the originality subscore. Subjects with higher self-reported depressive symptoms, showed lower level of originality in their responses to DT tasks stimuli. Even if some studies have reported an interesting link between depression and general "creativity" (see e.g., Akinola & Mendes, 2008 and Holm-Hadulla & Hofman, 2010), this usually relates to artistic creativity. In contrast, recent studies have confirmed the negative relationship between depression and originality index, which seemed to be more related to the quality of idea generation involved in DT-like tasks rather than the production of some product with artistic values (Forgeard et al., 2020). According to these authors it is therefore possible that depressive symptoms may interfere with the ability to generate unique and unusual ideas; however, the underlying mechanisms and the findings themselves need further investigation and to be confirmed in the healthy elderly population.

No other correlations were found. By the way, it is worth noting that these first results suggest that different psychological symptoms (apathy vs depression) might have negative effects on different DT indexes, maybe reflecting different alterations at both a behavioral and neural level, that have yet to be explored.

Finally, a partial moderating effect of educational level, which can be considered a CR proxy, on the relationship between apathy symptoms and DT performances has been evidenced. More specifically, it seems that subjects with average CR or lower CR scores (-1SD) suffer more from the impact of apathetic symptomatology, making the DT scores to decline more on the divergent thinking task, while subjects with higher CR seem to be better protected from the effects of psychological symptoms. This result is interesting for two reasons: the first is that even the relationship between psychological symptomatology and DT skills can be influenced by other intervening variables and the second is certainly the significant moderating effect of the level of education that, being a CR proxy, leads to hypothesize a moderating effect of CR on this relationship. Seniors with higher education, and thus hypothetically higher CR, might be more protected from the negative effects of psychological symptomatology on cognitive functions and therefore also on DT abilities. Future studies may further investigate this interaction.

The limitations of the present study concern the small sample size and the fact that the sample has been considered only as a whole group of elderly individuals without performing a subdivision into different age groups. However, even if more experimental studies are needed to confirm our results, this exploration highlights how different psychological symptoms such as apathy and depression might be negatively correlated to different DT indexes in older subjects and, in particular for the relationship between apathy and DT, how educational level might have a moderating effect. Future studies aiming at measuring DT's abilities in both healthy and pathological elderly subjects, will have to consider on one hand the possible presence and impact of psychological symptoms on DT performances, where apathy seems to play a pivotal role and on the other hand the possible moderating role of CR measured by specific scale, not only with educational level. Moreover, considering the relationship found between DT and CR (Colombo et al., 2018; Mendes et al., 2020; Palmiero et al., 2016), it could be hypothesized that, decreased DT abilities might, in turn, lead to lower level of CR. Noteworthy, a negative relationship between apathy and CR has already been proved (Altieri et al., 2019). This consideration might have some practical implications: the relationship between apathy, DT and CR could indeed be fundamental for the design of prevention and stimulation programs, which might focus on lowering apathy and enhancing DT skills, which seem to be spared both in healthy elderly subjects (Fusi et al., 2020a) and in the early stages of pathological states (especially verbal ability - Fusi et al., 2020b).

3.2.4. Conclusions

This study highlights how different psychological symptoms can be correlated to a decline on several DT indexes in a group of healthy elderly Italians. Specifically, apathetic symptoms seem to be negatively correlated to the ability to be fluent and flexible in a DT task, while scores of depressive symptoms negatively correlate to the capability to produce original ideas. Moreover, a possible specific moderation effect of the educational level, and therefore hypothetically of CR, has been discussed. Consequently, future studies aiming at assessing DT abilities both in healthy and pathological elderly samples should consider the presence of psychological symptoms, their possible negative effects on different DT indexes and the possible moderating effect of CR. Finally, intervention programs should consider focusing also on apathetic symptomatology to increase DT abilities and, consequently CR.

SECTION 3 - PATHOLOGICAL AGING

Chapter 4. Divergent thinking in pathological aging

4.1. A literature overview

As stated in the previous chapters, during the last decades researchers' attention has been attracted by the study of creativity and DT abilities also in patients affected by different neurological diseases, especially by dementia, for their potential role in early diagnosis and rehabilitation programs (see Palmiero et al., 2012 for a review). Early studies of patients' creative abilities were mainly focused on the qualitative examination of artistic productions or on the evaluation of the changes in the artistic style of artists who suffered from these diseases (Abraham, 2019). However, with the improvements in the behavioral assessment methods (i.e. quantitative methods) and in the neuroimaging techniques, the study of specific creative abilities such as DT has known a great development also in these patients. In the following paragraphs, studies that have specifically analyzed DT skills in patients suffering from neurodegenerative diseases, and specifically from different types of dementia, will be explored as they represent the theoretical basis from which we started for the design of the third experimental study described in paragraph 4.2.

4.1.1. Neurodegenerative diseases and divergent thinking abilities: what do we know so far?

Several articles and literature reviews (de Souza et al., 2014; Palmiero et al., 2012) have highlighted how artistic creativity (i.e. arts productions) can be expressed in some exceptional cases of patients affected, for example, by specific forms of frontotemporal dementia (FTD) such as FTD temporal variant (see Miller & Miller, 2013 for a summary) or primary progressive aphasia (PPA, Mell et al., 2003; Seeley et al., 2008; Wu et al., 2015). This phenomenon was sometimes interpreted through the concept of "*Paradoxical Functional Facilitation*" (PFF), firstly proposed by Kapur in 1996. PFF was hypothesized to explain the observation of "superior" performances manifested by patients with some brain damage. As concern creative productions, some authors (see Acosta, 2014 for a review) proposed the idea that a lesion to the left, dominant hemisphere, which was designed for the human ability to perceive the world through pattern recognition mechanisms (Snyder, 2009; see also paragraph 1.1.), and which forces us to perceive the world in some fixed and predictable ways (Goldberg, 2018), could lead to the relapses of the inhibition of the left, over the right hemisphere, allowing patients to consider new ways to see things and their associations. On the contrary, it has been evidenced that creative and divergent thinking abilities tend to decrease in patients affected by different types of dementia such as FTD (Fusi et al., 2021b), Alzheimer disease (AD; Cummings & Zarit, 1987; Crutch et al., 2001; Maurer & Prvulovic, 2004; Serrano et al., 2005; Van Buren et al.,

2013) and Lewy's body dementia (Drago et al., 2006; Sahlas, 2003) or, in some rare cases to be, at best, preserved (Fornazzari, 2005).

However, going beyond an initial impetus to find a sort of a "silver lining" in dementias (Goldberg, 2018), it was recently observed that the "de novo" productions in this type of patients are surely rare and almost none of these productions could be considered prodigious (Abraham, 2019). Consequently, researchers have begun to consider the artistic expression exhibited by these patients, such as the necessity of some form of communication, (Zaidel, 2014), as a general "drive" to produce (Canesi et al., 2012), or as a "pseudo-creative production" triggered by cognitive or behavioral characteristics like perseveration or disinhibition specifically related to the disease (de Souza et al., 2014; de Souza et al., 2010). These suggestions have been supported by the few studies that have specifically measured DT abilities through standardized tests in patients affected by different types of dementia (see **Table 8** for the main characteristics of the selected studies).

Authors, Year	Type of Dementia	Participants	DT Measures	DT Material	DT indexes and scoring procedure	Results
Bigler et al., 1988	DAT	15 DAT (9 women; 6 men; Mean age = 77.42); 10 HC (Mean age=75.9)	Design Fluency (DF) test	Figural	Number of novel design and number of perseverative errors were counted.	DF is impaired in DAT patients. The greatest deficits were associate with right frontal lesions. Some perseverative errors were observed.
Bigler, 1995	DAT (vs MID, DAA)	17 DAT (12 women; 5 men; Mean age = 71.06 ± 9,.2); 15 MID (9 women; 6 men; Mean age = 71.33 ± 6.03); 6 DAA (not of interest for this dissertation); 16 MC (12 women; 4 men; Mean age = 70.44 ± 7.64).	Design Fluency test	Figural	The total design fluency score was determined as the total number of drawings minus perseverative errors and non-novel design.	The three dementia groups displayed significant deficits in the ability to generate novel designs. The DAT group had greater difficulty and tend to perseverate. Dementia, regardless of its origin, appears to reduce the individual's ability to generate novel designs.
Hart & Wade, 2006	Early AD FTD	19 early AD; 4 FTD; AD and FTD treated as a unique "dementia group" (Mean age = 70.5 ± 8.4); HC (12, Mean age = 70.4, ± 5.9).	Two fluency tasks: adapted AUT and Possible Jobs (see the original article for more details).	Verbal	Not specified. Only a total score of the two tasks were provided.	Dementia patients were impaired in all fluency tasks but complex fluency tasks such as DT tasks (AUT and Possible Jobs) were more sensitive to early cognitive decline. The analyses were also run without FTD patients and the results were the same.
Rankin et al., 2007	AD, FTD, SD	16 AD (Mean age = 71.00, ± 11.24); 18 FTLD (9 FTD, Mean age = 57.00, ± 5.96; 9 SD Mean age = 63.67, ± 6.87); HC (Mean age= 66.73, ± 9.37).	TTCT (picture completion task only)	Figural	Fluency; Originality; Elaboration; Resistance to premature closure. (+ checklist of creative strengths).	SD patients performed very poorly on standardized testing of non-verbal DT task. FTD failed to resist to premature closure, instead AD performance is not distinguishable from HC.
de Souza et al., 2010	fvFTD	17 fvFTLD (Mean age = 71.1, ± 9.13), 17 HC (Mean age = 67.6, ± 6.71) and 12 non-demented PD.	TTCT	Verbal and Figural	Total scores (and three sub-scores) for verbal vs figural DT.	The fvFTLD performed worse in all the DT tasks with respect to HC. Some perseverative errors and some responses characterized by disinhibition were observed.

Ruggiero et al., 2019	FTD (fvFTD, SD)	11 FTD (Mean age = 70, ± 4.83; 8fvFTD, 3SD) 15 HC (Mean age = 61.87, ± 8.55); 17 PD.	DTT (Ruggiero et al., 2018; Williams, 1994).	Verbal + Figural	Fluidity, flexibility, originality, processing. For the verbal task also "allocation of title" was considered.	The FTD patients showed worst performances in all DT subscores (except for the processing subscore).

Table 8: Description of the articles that have measured DT abilities in patients affected by different types of dementia using standardized tests. DAT= Dementia of Alzheimer Type; MID=multi-infarct dementia; DAA=dementia associate with alcoholism; MC=medical control; PD= Parkinson Disease; HC= Healthy controls; AD= Alzheimer Disease; FTD= fronto-temporal dementia; fvFTD= frontal variant of fronto-temporal dementia, SD= semantic dementia. DTT= Divergent Thinking Test; AUT= Alternative Uses Tasks; TTCT: Torrance Test of Creative Thinking.

Almost all of the studies highlighted a decline in DT abilities. The first two studies performed by Bigler and colleagues (Bigler, 1995; Bigler et al., 1988), considered only figural DT ability by means of a test called “design fluency” with the aim to find a non-verbal analog to word fluency test for patients’ early evaluation. They administered the design fluency task to patients affected by different types of dementia (Dementia of Alzheimer Type, DAT; multi-infarct dementia, MID; Dementia associated with Alcoholism, DAA) comparing their performances with an MC group (Medical Control, see the original article for further details): the authors found an impaired performance in this task for all types of dementia patients, also highlighting some perseverative errors. However, it is worth noting that they considered only a total score that represents the ability only to generate multiple designs (i.e., fluency) without considering the different characteristics believed to be fundamental for DT performances such as flexibility, originality or the elaboration of responses. Oddly, the study performed by Rankin et al., (2007) is the only one that did not find any difference between AD patients and healthy controls in a standardized figural DT task such as the Picture Completion from TTCT (Torrance, 1998). Nevertheless, this study highlighted poorer performances in all DT indexes (i.e., fluency, originality, elaboration and resistance to premature closure) in patients affected by Semantic Dementia (SD) and only in the resistance to premature closure index in FTD patients. On the other hand, Hart and Wade (2006) conducted a study that evaluated verbal DT in patients affected by early AD and FTD considering them as a unique “dementia group”. They found poor performances in the two complex verbal fluency tasks in dementia patients, suggesting that these tests could be more sensitive than the usual neuropsychological tests used for early diagnosis because they required a series of intact cognitive abilities (i.e., semantic memory store, speed of elaboration, conceptual flexibility, association, inhibition and set-shifting abilities). Finally, the last two studies (De Souza et al., 2010; Ruggiero et al., 2019) evaluated both verbal and figural DT and seem to agree on the fact that patients affected by the frontal variant of FTD are impaired in almost all DT abilities: not only with both materials (verbal and figural) but also in all the classic DT indexes (i.e., fluency, flexibility, originality).

However, it is worth noting that, even if it was recognized how DT abilities tend to decline early during these neurodegenerative diseases, none of these studies have investigated them in prodromal phases such as Mild Cognitive Impairment (MCI). This will be the subject of the next experimental study (Study 3) which will be presented in the next section (paragraph 4.2.) however, before that, the evolution of the concept of MCI, incidence data, conversion rates and its clinical features need be examined in the following paragraphs.

4.1.2. Neurodegenerative diseases: a focus on Mild Cognitive Impairment

4.1.2.1. Classification and evolution of nomological terminology

The rise of the average age and the spread of neurodegenerative diseases, particularly of dementia, has led researchers to a careful study of these conditions. Over time, the interest has shifted from knowing the mechanisms of the diseases to the study of its progression and developmental trajectories. Several studies have shown that signs of these diseases begin to appear many years before the evidence due to the clinically detectable cognitive decay (Jack et al., 2018; Sperling et al., 2011). Therefore, researchers have focused on the study of early or prodromal phases trying to identify early biological signs, their clinical features and to understand their evolutions. Over the years several terms have been used to describe this transitional period (see Anderson, 2019 for a review) between normal and pathological aging (i.e. a clear state of dementia, see **Table 9** for a summary).

Terminology	Authors	Description and/or Criteria
Benign senescence forgetfulness	Kral (1962)	Memory complaints
Age-associated memory impairment	Crook et al., (1986)	Memory impairment defined by a decrement on formal cognitive test.
Ageing-related cognitive decline	DSM IV (APA, 1980)	Objective decline in cognitive functioning.
Mild cognitive decline	IDC-10 (WHO, 1993)	Disorder of memory learning and concentration corroborated by cognitive tests.
Mild Cognitive Impairment (MCI)	Mayo Clinic, Petersen et al., (1999)	(1) Memory complaint preferably corroborated by an informant; (2) objective memory impairment for age and education; (3) largely normal general cognitive functioning; (4) essentially normal activities of daily living; and (5) not demented.
Mild Cognitive Impairment 2.0	Mayo Clinic, Petersen (2004)	Existence of different types of MCI (aMCI, na-MCI, md-MCI) due to different aetiologies.
Mild cognitive impairment due to AD	NIA-AA (Albert et al., 2013)	(1) concern regarding a change in cognition, from the patient, an informant, or a skilled clinician; (2) impairment in one or more cognitive domain relative to a person's age and educational attainment; (3) independence in functional abilities (although they make take more time or be performed less efficiently); and, (4) not demented.
Mild neurocognitive disorder (mild NCD)	DSM-V (APA, 2013)	(1) Evidence of cognitive decline in one or more cognitive domains, obtained from reports from the client, an informant, or a clinician, or from objective testing; (2) preserved functional independence; (3) the cognitive impairments do not occur exclusively during episodes of delirium; (4) the cognitive deficits cannot be better explained by another condition (e.g. depression); and (5) no dementia.

Table 9: Description of the terms' evolution concerning the transitional stage from normal aging to dementia (modified by Ritchie & Touchon, 2000).

One of the most influential authors in this field is surely R.C. Petersen (1999, 2004, 2016; Petersen et al., 2007) who, with his group at the Mayo Clinic, has originally proposed the concept of "*Mild Cognitive Impairment*" (MCI; Petersen, 1999). The criteria for the diagnosis of MCI proposed by the group can be seen in Figure 4. This dissertation will focus on summarizing the main concepts derived from Petersen's classifications, as the experimental study in the next paragraph (Study 3) will refer to this conceptualization. Indeed, also the concept of MCI itself has evolved over time: as research on MCI has advanced, it has become apparent that several clinical subtypes of MCI exist. As a result, the Mayo group suggested a new classification of different MCI subtypes (Petersen, 2004) representing the factorial crossing of single-domain/multiple-domain and amnestic/non-amnestic (Anderson, 2019). More specifically, with the observation of the serious limitations in the consideration of only a specific memory impairment (amnestic-MCI, a-MCI) dictated by the first proposed criteria, they observed a second type of MCI called multidomain MCI (md-MCI) which involves various degrees of impairment in different cognitive domains such as language, executive function and visuospatial skills that can coexist (amnestic MCI multiple domains) or not (non-amnestic multiple domains) with memory impairments (see Petersen, 2004 for a figural representation).Moreover, it is worth noting that, in addition to the clinical subtypes described above, there can also be multiple etiologies or causes (i.e., degenerative, vascular or psychiatric) for each MCI subtype, as can be seen in **Figure 4**.

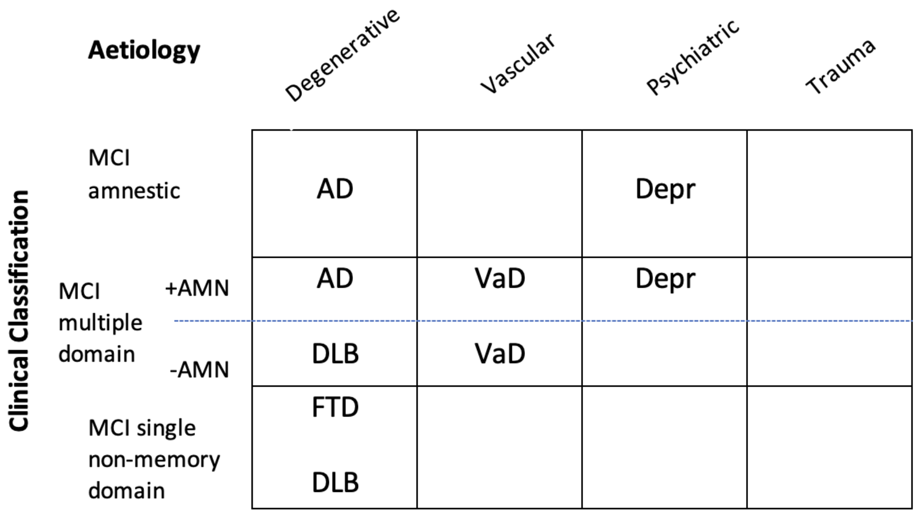

Figure 4: Classification of the diverse presumed etiology of the different clinical MCI subtypes (modified by Petersen et al., 2001). AMN= amnesitic deficit; AD= Alzheimer Disease; DLB= Lewy Body Disease; FTD= Fronto-temporal dementia; VaD= Vascular Disease; Depr= Depression.

Finally, it is important to note that greater attention has recently been paid to a biological definition of the disease, therefore on biomarkers that can be detected early and in vivo (Jack et al., 2018). The following paragraphs will be dedicated to summarizing the neuropathological changes (i.e., detected in vivo by biomarkers) specifically related to the prodromal stages of Alzheimer's disease (AD) and the possible clinical developmental trajectories.

4.1.2.2. Biological markers

There are different types of neuropathological processes that can be found in prodromal phases of AD. These, accordingly to recent reviews (Anderson, 2019; Mattsson et al., 2009) include atrophy of medial temporal lobe regions (particularly hippocampus and entorhinal regions) and posterior cingulate cortex (Fennema-Notestine et al., 2009), hypometabolism in temporoparietal and posterior cingulate cortex as assessed by FDG- PET[4] (Kim et al., 2010) and hypoperfusion of parietal cortices and hippocampus measured by SPECT[5] (see Anderson, 2019 for a review).

Other biomarkers include the accumulation of the protein fragment AD-amyloid (i.e., beta-amyloid plaques; Ab42) outside of the neurons and the accumulation of protein tau, also called neurofibrillary tangles, inside neurons. Researchers have hypothesized that beta-amyloid plaques may contribute to cell death by interfering with neuron-to-neuron communication at synapses, while tau tangles block the transport of nutrients and other essential molecules inside neurons (Alzheimer Association, 2019). Amyloid beta concentration can be detected in the cerebrospinal fluid (CSF): notably, lower level of CSF Ab42 indicates higher level of brain Ab42, whereas elevated CSF concentrations of total tau and phosphorylated tau indicate neuronal injury and predict progression from MCI to AD related dementia (Jack et al., 2018). Finally, also the APOE-e4 (i.e., the epsilon allele of the apolipoprotein gene), confers risk both for MCI and AD (Qian et al., 2017).

Moreover, according to the most recent criteria proposed by the NIA-AA Research Framework (Jack et al., 2018), which have claimed for a biological definition of Alzheimer Disease, there are three categories of biomarkers (i.e., A, T, N), based on the nature of the pathologic process, which have to be considered for the diagnosis of AD.

More specifically:

1. [A]: biomarkers of Ab plaques or associated pathologic state; substantially it refers to cortical amyloid PET ligand binding (amyloid PET) or low CSF Ab42;
2. [T]: biomarkers of aggregated fibrillar tau (neurofibrillary tangle) or associated pathologic state given by higher CSF phosphorylated tau (P-tau) and cortical tau PET ligand binding (tau PET);

[4] FDG-PET or fluorodeoxyglucose positron emission tomography, is a nuclear medicine technique based on the measurement of positron emission from radio-labelled tracer molecules. These radiotracers allow biologic processes to be measured and brain images to be obtained which demonstrates sites of radiotracer accumulation. The most common radiotracer in use today is the 18Ffluorodeoxyglucose (18F-FDG). This is the only technique that allow to evidence ipo/iper metabolism areas and to study neurotransmitter systems. (Sacco, 2013).

5 SPECT or single photon emission computed tomography is another nuclear medicine tomographic imaging technique that use gamma rays and different types of radiotracers (e.g., Technetium, or hexamethyl propylene amine oxime HMPAO). This technique is characterized by a lower spatial resolution but lower costs than PET technique (Sacco, 2013).

3. [N]: Biomarkers of neurodegeneration or neuronal injury are CSF total tau, FDG-PET hypometabolism, and atrophy on MRI.

According to these guidelines, the term “Alzheimer’s disease” would be applied only if biomarker evidence of both Ab and pathologic tau are present (see **Table 10**). In this way, Alzheimer’s pathological changes revealed by biomarkers and AD are not regarded as separate entities but as earlier and later phases of the “Alzheimer’s continuum” (an umbrella term that includes both); the authors have also suggested that these definitions could be applied independently from the clinical symptoms.

AT(N) profiles	Biomarker category	
1. T- (N)-	Normal AD biomarkers	
A+ T- (N)-	Alzheimer's pathologic change	Alzheimer Continuum
A+ T+ (N)-	Alzheimer's disease	
A+ T+ (N)+	Alzheimer's disease	
A+ T- (N)+	Alzheimer's and concomitant suspected non-Alzheimer's pathologic change	
A- T+ (N)-	Non-AD pathologic change	
1. T- (N)+	Non-AD pathologic change	
A- T+ (N)+	Non-AD pathologic change	

Table 10: Biomarker profiles and categories representation according to the NIA-AA Research Framework (modified by Jack et al., 2018). Every patient can be placed into one of these general biomarker categories based on biomarker profiles: those with normal AD biomarkers (no color), those with non-AD pathologic change (dark grey), and those who are in the Alzheimer's continuum (light grey).

Finally, it is worth noting that recent studies have highlighted how different types of MCI also appear to have different degrees of biomarker presence. More specifically, according to Eliassen and colleagues in 2017, for example, subjects suffering from a-MCI would show the highest burden both for levels of CSF tau and thinner entorhinal cortex; these, also in line with the clinical data that will be highlighted in the next paragraph.

4.1.2.3. Prevalence, clinical characteristics, evolution and conversion rates

Empirical evidence concerning the prevalence and conversion rates to dementia varies greatly according to the different definitional applied criteria (Tuokko & Hultsch, 2020). The epidemiological studies have indeed estimated that the prevalence of MCI in the elderly population ranges from 3% to 19% (Bischkopf et al., 2002; Busse et al., 2003a; Gauthier et al., 2006; Carretti et al., 2013); other estimates however raised up to 30% (Busse et al., 2003a, 2003b). More specifically, following Petersen's criteria, a study conducted by the Mayo Clinic Study of Aging, found the overall prevalence of MCI to be 16% in residents aged 70 years and older. However, not only does the MCI condition appear to have a high prevalence, but it also implies an increased risk of developing dementia. According to the great variation in the epidemiologic evidence, studies have estimated that the 11% to 49% of the subjects with MCI progressed to dementia (mainly AD) within two years (Gauthier et al., 2006; Bondi et al., 2014), while other authors have evidenced that annual conversion seemed to range from 1 to over 40%, varying by sample, diagnostic criteria, and severity of the impairment (see Tuokko & Hultsch, 2020).

According to the different subtypes of MCI described in the previous paragraphs, different neuropsychological deficits have been recognized in these patients (i.e. memory, executive functions, abstract thinking; for a review see Yanhong et al., 2013). Considering the significantly higher risk of MCI patients to progress to dementia, it is worth noting that cognitive assessment can also help to differentiate MCI patients that will progress to AD from those related to cognitive fluctuations due to normal aging or other non-morbid conditions. For example, a recent meta-analysis performed by Belleville and colleagues (2017) evidenced that measures of verbal memory were excellent predictors with very good (≥ 0.7) specificity and sensitivity values and also that predictive accuracy was highest when combining memory measures with a set of other cognitive domains or when relying on broad test batteries. These, accordingly also to the data from Bradfield et al. (2018) that have evidenced how memory impairment per se, impairment in multiple cognitive domains and severity of memory impairment were all associated with a greater risk of developing AD dementia.
Summing up, it seems that subjects with amnestic deficits (a-MCI) or amnestic multi-domains, and especially those with atrophy beyond the medial temporal lobe (Karas et al., 2008) are those with higher pathological burden frames and consequently are those most likely to convert to dementia (see for example Schmidtke & Hermeneit, 2008).

4.2. Study 3. A comparison of divergent thinking abilities between healthy elderly subjects and MCI patients: preliminary findings and implications

4.2.1. Introduction and aim of the study

According to the literature overview just introduced, it is clear that researchers in the last years have developed a renewed attention on DT abilities in pathological aging. This is because of its significant and positive correlation with CR (Meléndez et al., 2016; Palmiero et al., 2016; Colombo et al., 2018) and its potential both for early diagnosis (Hart & Wade, 2006) and rehabilitation programs (Palmiero et al., 2012). In particular CR, as was already evidenced in the previous paragraphs, is considered a protective factor against cognitive decline and refers to a functional benefit that seem to provide protection against the effects of brain damage or pathology. Thus, people with higher CR are believed to cope better with potential brain damage by recruiting different compensatory processes (Stern, 2002, 2009, 2014). As a result of this proven relationship, DT has been proposed as a possible target for cognitive stimulation interventions (Palmiero et al., 2012, 2019). Exercising divergent and creative thinking has thus been taken into consideration as a way to promote mental health and active aging by fostering creative cognition in daily life (Cropley, 1990), thereby reducing the risk of dementia (Palmiero et al., 2016a), and also trying to slow down cognitive decline during the course of neurodegenerative diseases (Palmiero et al., 2012; Ruggiero et al., 2019).

In spite of this significant evidence, few studies have evaluated DT abilities through standardized tests in patients affected by different types of dementia (Bigler et al., 1988; Bigler, 1995; Rankin et al., 2007; de Souza et al., 2010; Ruggiero et al., 2019). Almost all of these studies highlighted a decline in DT abilities in this type of patients, even at early stage of the disease (Hart & Wade, 2006): in light of these considerations, early assessment and intervention in patients at risk of dementia could be considered crucial. However, to our knowledge, no research has studied DT abilities in patients affected by MCI, which is generally considered to be a transitional stage between normal and pathological aging (see Petersen, 2016 for a review) or as a prodromal stage of the onset of Alzheimer's disease (AD, Petersen et al., 2001). This assessment might be particularly important when considering data on the prevalence of MCI and conversion rate to dementia; indeed, even if these data vary greatly according to the different definitional applied criteria (Bischkopf et al., 2002), epidemiological studies have estimated that the prevalence of MCI in the elderly population ranges from 3 to 19% (Gauthier et al., 2006) and that 11 to 49% of people with MCI progressed to dementia (mainly AD) within 2 years (Gauthier et al., 2006; Bondi et al., 2014). Therefore, it is considered a priority to find early cognitive markers for the diagnosis of MCI (see, for example, Arnáiz &

Almkvist, 2003) and also to develop training and cognitive stimulation programs that might help these patients to compensate for their cognitive difficulties. Cognitive stimulation training could, in fact, offer to these patients some protection against cognitive decline by stimulating pre-existing neural reserves or recruiting neural circuitry as compensatory scaffolding (Reuter-Lorenz & Park, 2014; Sherman et al., 2017), promoting brain plasticity (Li et al., 2011), and could thereby reduce the risk or delay the progression of dementia (Anderson, 2019). Consequently, the aim of this study was to examine DT abilities in a sample of patients diagnosed with MCI by comparing their performance to a healthy older adults' control group to verify whether they are spared or altered in this early pathological state.

4.2.2. Material and Methods

Participants

The study involved a total of 75 participants. 25 MCI patients (MCI) and 50 Healthy Controls subjects (HC). However, due to the lack of proportion of the two sample, a random selection of 25 subjects from the HC groups was performed. Socio-demographical data are summarized in **Table 11**. No differences between groups emerged both for demographic data (i.e. age, sex and educational level) and psychological (control) variables such as apathy, anxiety or depression respectively measured by the Apathy Evaluation Scale (AES, Marin et al., 1991), the State-Trait Anxiety Inventory (STAI, Spielberger et al., 1983; Pedrabissi & Santinello, 1989) and the Beck Depression Inventory (BDI, Beck, 1961).

	MCI (N= 25)	HC (N= 25)	t (48), U	p
Age	75.32 ± 5.47	74.16 ± 5.35	-0.758	0.45
Educational level	8.40 ± 4.34	7.44 ± 4.50	-0.768	0.45
Gender	13 W	19 W	237.50	0.08
AES	34.12 ± 7.89	31.84 ± 5.84	-1.162	0.25
STAI	35.88 ± 10.23	39.16 ± 11.67	1.057	0.30
BDI	6.36 ± 6.55	9.20 ± 5.46	1.665	0.10

Table 11: Sample demographic data. W= women; STAI= State Trait Anxiety Index; AES= Apathy Evaluation Scale; BDI= Beck depression Inventory.

HC participants were enrolled from a pool of older adult volunteers while MCI patients were recruited at the Neuropsychology Service of the ASST Spedali Civili in Brescia (Italy). Patients group included subjects diagnosed as affected by Mild Cognitive Impairment according to Petersen's criteria (Petersen et al., 1999; Petersen, 2004). This means the presence of a subjective or proxy cognitive complaint; objective impairment in memory and/or at least one other cognitive domain; a relatively intact competence to perform basic and instrumental daily life activities independently autonomously. All patients underwent an extensive neuropsychological assessment in order to verify these conditions and they were screened for inclusion criteria which included: age > 50 years old, Mini Mental State Examination > 22 (MMSE; Folstein & Folstein, 1975; Measso et al, 1993) and no sign of vascular lesions, and of neurological or psychiatric diseases. All tests were administered to the whole sample individually and in a single session which lasted approximately one hour; the evaluation was performed in a quiet setting. The research protocol and procedure were approved by the Hospital ethical committee and were conducted following the Declaration of Helsinki. An informed consent was signed by all participants.

Materials

Cognitive measure

2. Montreal Cognitive Assessment (MoCA; Santangelo et al., 2015). This is a screening test which evaluate general cognition and is considered a sensitive tool for the detection of MCI (Boccardi, et al., 2020). It is composed of 12 sub-tasks that evaluate different cognitive functions such as attention, executive functions, memory, language, abstraction, calculation, orientation and visuo-constructional abilities (maximum total score is 30).

Divergent thinking measure

3. *Abbreviated Torrance Test for Adults* (ATTA; Goff, 2002). This test was selected to evaluate DT abilities and therefore subjects' creative potential. ATTA is the abbreviated form of the TTCT (Torrance, 1988). ATTA was chosen considering the clinical practice time limitation. This instrument it indeed easy and require short time to be administered and it was already used in the clinical Italian context by Canesi and colleagues (2016, 2017) and by Colautti et al. (2018). For further details about this task and its administration see paragraph 3.2.2. Note that the sum of the creative indexes and creative indicators constitute the total score: DTTS (Divergent Thinking Total Score).

4.2.3. Data analysis

Data analyses were performed using SPSS software (version 24.0.0). Normality was checked for all the variables with Shapiro-Wilk test and the observation of skewness and asymmetry indexes were performed; a check for outliers was run. Almost all the variables met the assumptions of normality; transformations (square root) were performed when necessary and parametric tests were then used for all the analyses. Two independent t-tests were performed to ensure that the two groups (HC vs MCI) did not differ in important demographic data; no significant differences were found for age and years of education. A Welch's t-test was used to compare gender which resulted as being non-significant (see **Table 13**). To assess for significant differences between the two groups in cognitive and psychological variables, different independent t-tests were performed; the homogeneity of variances assumption was checked using Levene's Test. By considering the high correlations (i.e., greater than .30) between the different DT indexes, a multivariate analysis of variance (MANOVA) was chosen to test between-groups difference in these variables. Finally, a hierarchical logistic regression was run to evidence the possible predictive role of cognitive and DT measures to discriminate between the two groups.

4.2.4. Results

As it could be predicted from previous literature, MOCA scores differed significantly, $t(48) = 3.762$, $p<.001$ between MCI patients and HC groups, with MCI patients performing worse than HC (see **Table 12**).

Measure	MCI	HC	t (76)	F	p
General Cognition					
MoCA	18.88 ± 3.54	22.12 ± 3.60	3.210		**0.01**
Divergent thinking					
ATTA_DTTS	51.52 ± 5.06	54.28 ± 7.62			
ATTA_Fluency	6.72 ± 3.01	8.80 ± 4.44		3.756	0.06
ATTA_ Flexibility	1.36 ± 1.32	2.08 ± 2.16		2.025	0.16
ATTA_Originality	3.24 ± 2.13	3.76 ± 2.47		0.636	0.43
ATTA_Elaboration	0.84 ± 1.07	1.04 ± 1.57		0.278	0.60
ATTA_Verbal_indicator	0.60 ± 0.65	0.76 ± 0.83		0.578	0.45
ATTA_Figural_indicator	1.32 ± 1.22	2.08 ± 1.04		5.655	**0.02**

Table 12: Descriptive statistics and between groups differences for general cognition and divergent thinking measures. Significant values are in bold.

A multivariate analysis of variances (MANOVA) was performed with fluency, flexibility, originality, elaboration scores and verbal and figural indicator scores of the ATTA test as dependent variables, whereas "group" was treated as the between factor variable. The analysis returned a non-significant effect of group, Wilks' Lambda= 0.830, $F(6, 43) = 1.472$, $p > .05$. The Univariate ANOVA revealed that only figural indicator was significantly affected by group, $F(1, 48) = 5.655$, $p < .05$, with MCI patients performing significantly worse (M = 1.32, SD = 1.22) than HC (M = 2.08, SD = 1.04). A comparison between drawings from one MCI patient and one matched HC subject is presented in the figure in the online paper (Fusi et al., 2020a). Fluency, $F(1, 48)=3.756$, $p>.05$, originality, $F(1, 48)=.636$, $p>.05$, elaboration, $F(1, 48) =.278$, $p>.05$, flexibility, $F(1, 48)=2.025$, $p>.05$, and verbal indicator $F(1, 48)= 0.578$, $p>.05$ were not affected by the independent variable.

Considering these exploratory results, a hierarchical logistic regression was run in order to check for the possible predictive value of Figural Indicator, over the general cognition variable (MoCA), as predictor of the group variable. The regression results are shown in **Table 13.**

Variables		95% CI for Odds Ratio			
	Lower CI	**Exp (B)**	**Upper CI**	**Wald**	**Sign.**
Model 1					**0.002**
Intercept		.988		.002	
MoCA	.183	.371	.752	7.575	**.006**
Model 2					**.001**
Intercept		3.226		3.402	.65
MoCA	.160	.344	.739	7.489	**.006**
Figural_Indicator	.273	.504	.931	4.784	**.029**

Table 13: Hierarchical Logistic Regression analysis predicting the dependent variable "group". Significant values are in bold.

Model 1 have tested the effect of MoCA as the only predictor of the dependent variable (VD) "group". The estimated coefficients for Model 1 indicate that MoCA significantly predict the VD (Wald= 7.58, $p<.05$) and accounted for 68% of correctly classified cases. Then a second block was added so that Model 2 tests the predictive effects of Figural Indicator predictor on the VD "group", over the effect of MoCA. The change in the amount of information explained by the second model is significant ($\chi 2(1) =15.06$, $p<.001$). The significance values of the Wald statistics of the two predictors indicate that both MoCA (Wald= 7.49, $p<.05$) and Figural Indicators (Wald= 4.78, $p<.05$) significantly predict the dependent variable; furthermore the odds ratios of MoCA, (Exp(B)=0.34, CI0.95=[0.16,0.74]) and Figural Indicator (Exp(B)= 0.50, CI0.95=[0.27,0.93]) indicate that if the values of MoCA or Indicators Figural goes up by 1 point, the odds of being part of group of HC increase. Together, the predictors accounted for 76 % of correctly classified cases.

4.2.5. Discussion

The present study aimed to preliminarily explore the possibility that DT skills, considering all the indices and indicators (i.e., fluency, flexibility, originality, elaboration; verbal versus figural indicators), are affected in MCI patients. The between-groups comparison has highlighted that MCI patients performed worse only in the figural indicator score. This result is partially in line with previous literature which has already proved the impairment of visual/figural DT in dementia of Alzheimer type (Bigler et al., 1988; Bigler, 1995) and has hence suggested the possibility to use design fluency test as a sensitive measure of performance deficit in these types of patients. Similarly, Hart and Wade in 2006 have assessed verbal DT abilities in early AD and FTD patients. However, no one has evaluated DT in prodromal phases like MCI until now. The fact that the figural indicator is already impaired in these patients might represent another evidence for the possible good value of complex figural DT tasks as an early sign (even earlier than verbal ones) of cognitive impairment. Indeed, our analysis showed that the predictive value of the figural indicator score added an 8% accuracy in the detection of MCI patients, and this is significant over the prediction of the MoCA test, that is considered one of the most sensitive tools for the detection of slight cognitive impairment (Boccardi et al., 2020). This is particularly relevant for the field because the discovery of the long preclinical phase of AD and the other types of dementias, has led to an enhanced interest to establish early diagnostic indices of dementia (Bischkopf et al., 2002). Thus, figural DT abilities might be considered by future research as an early cognitive marker; nevertheless, more experimental studies are needed in order to confirm this result and to confirm the predictive value of visual DT abilities.

Nonetheless, interestingly, all the other indexes (i.e., fluency, originality, flexibility and elaboration) and the verbal indicator score seemed to be unaffected. These results are partially in line with the complex and sometimes inconsistent literature that have evaluated the impact of the aging processes on DT abilities (Fusi et al., 2020b). Indeed, some authors have already highlighted a major impact of normal aging on visual DT abilities compared to verbal ones (Palmiero et al., 2014), or at least an almost linear decline in visual abilities (Palmiero et al., 2017). These results also agrees with previous studies concerning the aging brain which have highlighted how verbal abilities could remain intact across the lifespan (Kemper & Kemtes, 1999; Park et al., 2002, see also paragraph 2.2.), or at least do not encounter a decline until late-in-life (Hedden & Gabrieli, 2004). Moreover, elderly people seemed to perform significantly better than younger subjects in verbal tasks, whereas they performed worse in visual tasks (Passafiume et al., 2010); as a result, it seemed that figural DT is then more affected even in MCI patients. Additionally, this result also seems in line with the existing literature about the relationship between DT and CR which have evidenced that verbal (Colombo et al., 2018; Palmiero et al., 2016a), but not visual (Palmiero et al., 2016a) DT predict CR. Thus, the idea that CR can be generally related to verbal ability it has been already advanced (Palmiero et al., 2016a). It is consequently possible to hypothesize that CR might have a protective role on verbal (but not figural) DT abilities during early and prodromal stages of the disease that allow patients to perform in a way comparable to control subjects. This also means that among complex mental activities that are certainly involved in CR, activities that involved a divergent way of thinking and the generation of creative ideas could be a pivotal protective factor against the cognitive decline.

Moreover, the fact that this type of patients could perform like healthy elderly subjects in all the other DT indexes that are considered fundamental for the ability to produce divergent and creative responses, is certainly a significant result and might have important practical implications, always considering its relationship with CR. The sparing of verbal DT might be considered as a target by future research that try to design cognitive training and stimulation programs. The potential beneficial effect of cognitive training to enhance cognitive and functional abilities for these types of patients has already been highlighted by several review and meta-analyses (see for example Jean et al., 2010; Li et al., 2011; Sherman et al., 2017). Thus, the stimulation of verbal DT abilities (and consequently of CR) or, more specifically, the enhancement of verbal proficiency and verbal abilities to think of different and creative, original solutions might also help MCI patients to develop new, useful and flexible cognitive strategies (Palmiero et al., 2016a) as well as to cope with their daily life problems.

In conclusion, our preliminary results highlight a slight impairment in DT abilities in patients affected by MCI, but only in the figural indicator score. Thus, figural abilities seemed to be affected earlier than verbal ones in mild pathological aging. This result has two significant practical implications: first, figural DT might be considered for early diagnosis of MCI patients and secondly, the sparing of all the other DT abilities (i.e., verbal DT abilities, fluency, flexibility, originality and elaboration) may suggest that, considering its relationship with CR, verbal DT could be considered as a possible and meaningful target for prevention or early cognitive stimulation programs.

4.2.6. Limitations and future research directions

Some limitations must be reported. First, the sample size for each group was relatively small and could not be fully representative of the population. Secondly, a mixed MCI group was considered. Further analysis considering the different MCI subtypes (amnestic vs non-amnestic, single domain vs multiple domains; see Petersen, 2016 for a review) might be important to clarify if the reported results can be generalized to all types of MCI patients, or if the different subtypes are linked to diverse impairment in DT abilities. Consequently, future research might consider also the idea to assess the main cognitive functions that are believed to be involved during DT tasks (i.e., attention, memory, executive functions, etc.) to determine the relationship between specific cognitive functions and DT abilities in the different subtypes of MCI patients. Finally, although our results showed that figural indicator is impaired in MCI patients more experimental studies are needed to confirm this result, especially by using different measures that address DT figural abilities (following criteria proposed by Barbot et al., 2019).

Conclusions

The overall aim of the present dissertation was to explore the effect of healthy and pathological aging processes on DT abilities. Notwithstanding the controversies that have been discussed in the previous chapters and the theoretical and methodological problems encountered, the general conclusion is that especially verbal DT, which is linked to CR, can be spared in healthy older people and individuals diagnosed with prodromal phases of neurodegenerative disease such as MCI. On the contrary, figural DT seemed to decline in these early phases, so much that it might be considered as an early marker of disease. Moreover, to draw a coherent picture of DT skills in this population, our results support the idea that some psychological symptoms such as apathy and depression, that are frequent in the elderly populations, need to be considered as an intervening variable because of their negative effects on cognition and on DT performances.

These results have some important practical implications for researchers and clinicians. The sparing of verbal DT skills might in fact be considered a possible target for prevention or early cognitive stimulation interventions to improve elderly CR and consequently their resilience to any brain damage by helping them to use novel strategies and to exploit compensatory processes. This could be considered a significant result considering the huge economic burden related to the 40–50 million people currently living with dementia and the associated managing costs amounting to billions of dollars per year (e.g., according to the World Health Organization the total global societal cost of dementia was estimated to be US$ 818 billion in 2015). Moreover, data that are more than doubled from 1990 to 2016 (Nichols et al., 2019) and projections say the number of people with dementia will continue to rise. The construction and implementation of training of cognitive enhancement or cognitive stimulation in clinical practice (i.e., non-pharmacological treatments) are therefore considered important today to prevent or at least try to slow down the course of these types of diseases. This, in turn, would have beneficial effects both at the individual and societal level.

This research project is part of a Ph.D. program focusing on “Human Capital Formation and Labour Relations” that well represents the need to keep a multidisciplinary approach when dealing with human and psychological sciences. Accordingly, these results can be considered, in applicational terms, in several areas. The development and improvement of divergent thinking and creative thinking skills can be implemented in different areas, from the health care with the above-mentioned purposes or in the work environment to maintain occupational performances and the efficiency, over a high level of wellbeing, of the elder's workers which represent today a large part of the workforce in most of the companies and represent a resource to be valued (Raffaglio, 2011).

Finally, a necessary consideration must be done in view of the time frame in which this dissertation is written. In 2020, the advent of the global Sars-Cov-2 (Covid-19) pandemic has forced all professions to rethink their practices and approaches. In particular, as concern the elderly population, which in Italy represents a large part of the population, it is worth noting that literature has evidenced how they seem to be much more at risk, than younger subjects, as for the worsening of perceived wellbeing (see for example articles about previous pandemic experiences such as severe acute respiratory syndrome, SARS, such as Lau et al., 2008) and of social isolation and loneliness (Berg-Weger & Morley, 2020) with negative consequences on physical and mental health. These, in turn, can cause an increase not only in physical diseases such as hypertension, obesity, cardiovascular disease, but also in psychological symptomatology like anxiety, depression, and a faster cognitive decline (Morrow-Howell et al., 2020). In this sense, social isolation can also have a negative effect, even if mediated by the cognitive reserve, on cognitive abilities (Evans et al., 2018). COVID-19 pandemic and the challenges that it poses have therefore led to the observation that older people and especially those with ongoing cognitive decline (e.g., with MCI or AD) can be considered among the most vulnerable populations because they had to deal with a break in their normal routines, fear of being abandoned and the consequent risk of depression (Alzheimer Europe, 2020). In particular, it has become evident the need for a new proposal of remote interventions through different forms of telemedicine, to be validated (also in terms of effectiveness). These, to provide, on the one hand, cognitive stimulation interventions that allow for greater cognitive flexibility and consequently a more functional adaptation, and on the other hand psychological and/or practical support to caregivers (De Vita et al., 2020). It is indeed worth noting that in recent years, several studies have been conducted on this topic and some literature reviews have highlighted how telemedicine interventions seem to be promising for different types of patients (Charvet et al., 2017; Cotelli et al., 2019), even if more studies are needed to prove their efficacy (see for example the Cochrane review performed by Gates et al., 2019).

To conclude, the construction and implementation of cognitive training involving verbal divergent thinking exercises, though both face-to-face and different types of telemedicine (Colombo et al., *in press*), could be considered by the clinical practice to address the new challenges of our national health system. Particularly, with respect to the demands of elderly people who have more difficulty in accessing services and patients suffering from different types of neurodegenerative diseases, who cannot, for example, participate in traditional face-to-face cognitive stimulation groups in hospitals.

APPENDICES

List of figures

List of tables

References

Abraham, A. (2013). The promises and perils of the neuroscience of creativity. *Frontiers in Human Neuroscience*, 7(June), 1–9. https://doi.org/10.3389/fnhum.2013.00246

Abraham, A. (2019). The neuropsychology of creativity. *Current Opinion in Behavioral Sciences*, 27, 71–76. https://doi.org/10.1016/j.cobeha.2018.09.011

Abraham, A., Beudt, S., Ott, D. V. M., & Yves Von Cramon, D. (2012). Creative cognition and the brain: Dissociations between frontal, parietal-temporal and basal ganglia groups. *Brain Research*, 1482, 55–70. https://doi.org/10.1016/j.brainres.2012.09.007

Abraham, A., & Bubic, A. (2015). Semantic memory as the root of imagination. *Frontiers in psychology*, 6, 325.

Acar, S., & Runco, M. A. (2014). Assessing associative distance among ideas elicited by tests of divergent thinking. *Creativity Research Journal*, 26, 229-238.

Acar, S., & Runco, M. A. (2015). Thinking in multiple directions: Hyperspace categories in divergent thinking. *Psychology of Aesthetics, Creativity, And The Arts*, 9, 41-53.

Acosta, L. M. Y. (2014). Creativity and neurological disease. *Current Neurology and Neuroscience Reports*, 14(8). https://doi.org/10.1007/s11910-014-0464-6

Addis, D. R., Pan, L., Musicaro, R., & Schacter, D. L. (2016). Divergent thinking and constructing episodic simulations. *Memory*, 24(1), 89–97. https://doi.org/10.1080/09658211.2014.985591

Addis, D. R., & Schacter, D. L. (2012). The hippocampus and imagining the future: Where do we stand? *Frontiers in Human Neuroscience*, 5(JANUARY 2012), 1–15. https://doi.org/10.3389/fnhum.2011.00173

Adnan, A., Beaty, R., Lam, J., Spreng, R. N., & Turner, G. R. (2019a). Intrinsic default—executive coupling of the creative aging brain. *Social Cognitive and Affective Neuroscience*, 14(3), 291–

303. https://doi.org/10.1093/scan/nsz013

Adnan, A., Beaty, R., Silvia, P., Spreng, R. N., & Turner, G. R. (2019b). Creative aging: functional brain networks associated with divergent thinking in older and younger adults. *Neurobiology of Aging*, 75, 150–158. https://doi.org/10.1016/j.neurobiolaging.2018.11.004.

Akinola, M., & Mendes, W. B. (2008). The dark side of creativity: Biological vulnerability and negative emotions lead to greater artistic creativity. *Personality and Social Psychology Bulletin*, 34(12), 1677-1686.

Alexander, A. L., Lee, J. E., Lazar, M., & Field, A. S. (2007). Diffusion tensor imaging of the brain. *Neurotherapeutics*, 4(3), 316-329.

Alpaugh, P.K., & Birren, J.E. (1977). Variables affecting creative contributions across the adult life span. *Journal of Human Development*, 20, 240–248.

Alpaugh, P.K., Parham, I.A., Cole, K.D., & Birren, J.E. (1982). Creativity in adulthood and old age: An exploratory study. *Educational Gerontology: An International Quarterly*, 8, 101–116.

Altieri, M., Trojano, L., Gallo, A., & Santangelo, G. (2019). The Relationships Between Cognitive Reserve and Psychological Symptoms: A Cross-Sectional Study in Healthy Individuals. *American Journal of Geriatric Psychiatry*, (August). https://doi.org/10.1016/j.jagp.2019.07.017

Alzheimer's Association. (2019). 2019 Alzheimer's disease facts and figures. *Alzheimer's & Dementia*, 15(3), 321-387.

Amabile, T. M. (1982). Social psychology of creativity: A consensual assessment technique. *Journal of Personality and Social Psychology*, 43(5), 997–1013. https://doi.org/10.1037//0022-3514.43.5.997.

Amabile, T. M. (1983). Social psychology of creativity: A componential conceptualization. *Journal of Personality and Social Psychology*, 45, 997-1013.

Anderson, N. D. (2019). State of the science on mild cognitive impairment (MCI). *CNS Spectrums*, 24(1), 78–87. https://doi.org/10.1017/S1092852918001347.

Albert, M. S., DeKosky, S. T., Dickson, D., Dubois, B., Feldman, H. H., Fox, N. C., Gamst, A., Holtzman, D.M., Jagust, W.J., Petersen, Snyder, P. J., Carrillo, M.C., Thies, B., & Phelps C.H. (2013). The diagnosis of mild cognitive impairment due to Alzheimer’s disease: recommendations from the National Institute on Aging-Alzheimer’s Association workgroups on diagnostic guidelines for Alzheimer’s disease. *Focus*, 11(1), 96-106.

Andel, R., Crowe, M., Pedersen, N. L., Mortimer, J., Crimmins, E., Johansson, B., & Gatz, M. (2005). Complexity of work and risk of Alzheimer's disease: a population-based study of Swedish twins. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, 60(5), P251-P258.

Andrews-Hanna, J.R., 2012. The brain's default network and its adaptive role in internal mentation. *The Neuroscientist*, 18, 251–270.

Andrews-Hanna, J.R., Smallwood, J., Spreng, R.N. (2014). The default network and self-generated thought: component pro- cesses, dynamic control, and clinical relevance. *Annals of the New York Academy of Sciences*, 1316(1), 29–52.

Andrews-Hanna, J. R., Snyder, A. Z., Vincent, J. L., Lustig, C., Head, D., Raichle, M. E., & Buckner, R. L. (2007). Disruption of large-scale brain systems in advanced aging. *Neuron*, 56(5), 924-935.

Antonietti, A., Colombo, B., & Pizzingrilli, P. (2011). The WCR model of creativity. From concept to application. *The Open Education Journal*, 4(1).

APA, American Psychiatric Association. (1980). *American Psychiatric Association diagnostic and statistical manual.* American Psychiatric Association.

APA, American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders (DSM-5®).* American Psychiatric Pub.

Arnáiz, E., & Almkvist, O. (2003). Neuropsychological features of mild cognitive impairment and preclinical Alzheimer's disease. *Acta Neurologica Scandinavia*. 107, 34–41. doi: 10.1034/j.1600-0404.107.s179.7.x

Aron, A.R. (2007). The neural basis of inhibition in cognitive control. *The Neuroscientist*, 13, 214–228.

Artola, T., Ancillo, I., Barraca, J., Mosteiro, P., Poveda, B., & Sánchez, N. (2010). *PIC-A: Prueba de Imaginación Creativa para Adultos [Test of Creative Imagination for Adults]*. TEA Ediciones.

Badre, D., & Wagner, A.D. (2007). Left ventrolateral prefrontal cortex and the cognitive control of memory. *Neuropsychologia*, 45, 2883–2901.

Baltes, P. B. (1987). Theoretical propositions of life-span developmental psychology: On the dynamics between growth and decline. *Developmental psychology*, 23(5), 611.

Barbot, B. (2018). The dynamics of creative ideation: Introducing a new assessment paradigm. *Frontiers in Psychology*, 9(DEC), 1–8. https://doi.org/10.3389/fpsyg.2018.02529.

Barbot, B. (2019). Measuring creativity change and development. *Psychology of Aesthetics, Creativity, and the Arts*, 13(2), 203–210. https://doi.org/10.1037/aca0000232.

Barbot, B., Hass, R. W., & Reiter-Palmon, R. (2019). Creativity assessment in psychological research: (Re)setting the standards. *Psychology of Aesthetics, Creativity, and the Arts*, 13(2), 233–240. https://doi.org/10.1037/aca0000233.

Bartrés-Faz, D., & Arenaza-Urquijo, E. M. (2011). Structural and functional imaging correlates of cognitive and brain reserve hypotheses in healthy and pathological aging. *Brain topography*, 24(3-4), 340.

Batey, M., Chamorro-Premuzic, T., & Furnham, A. (2009). Intelligence and personality as predictors of divergent thinking: The role of general, fluid and crystallised intelligence. *Thinking Skills and Creativity*, 4(1), 60–69. https://doi.org/10.1016/j.tsc.2009.01.002.

Baune, B. T., Suslow, T., Arolt, V., & Berger, K. (2007). The relationship between psychological dimensions of depressive symptoms and cognitive functioning in the elderly - The MEMO-Study. *Journal of Psychiatric Research*, 41(3–4), 247–254. https://doi.org/10.1016/j.jpsychires.2006.06.004

Beaudreau, S. A., & O'Hara, R. (2009). The Association of Anxiety and Depressive Symptoms With Cognitive Performance in Community-Dwelling Older Adults. *Psychology and Aging*, 24(2), 507–512. https://doi.org/10.1037/a0016035

Beaty, R. E., Benedek, M., Kaufman, B.S., & Silvia, P. J. (2015). Default and Executive Network Coupling Supports Creative Idea Production. *Scientific Reports,* 5, 1–14. https://doi.org/10.1038/srep10964.

Beaty, R. E., Benedek, M., Silvia, P. J., & Schacter, D. L. (2016). Creative Cognition and Brain Network Dynamics. *Trends in Cognitive Sciences*, 20(2), 87–95. https://doi.org/10.1016/j.tics.2015.10.004.

Beaty, R. E., Benedek, M., Wilkins, R. W., Jauk, E., Fink, A., Silvia, P. J., Hodges, D.A., Koschutnig, K., & Neubauer, A. C. (2014). Creativity and the default network: A functional connectivity analysis of the creative brain at rest. *Neuropsychologia*, 64, 92–98. https://doi.org/10.1016/j.neuropsychologia.2014.09.019.

Beaty, R. E., Chen, Q., Christensen, A. P., Kenett, Y. N., Silvia, P. J., Benedek, M., & Schacter, D. L. (2020). Default network contributions to episodic and semantic processing during divergent creative thinking: A representational similarity analysis. *NeuroImage*. https://doi.org/10.1016/j.neuroimage.2019.116499.

Beaty, R. E., Kenett, Y. N., Christensen, A. P., Rosenberg, M. D., Benedek, M., Chen, Q., Fink, A., Qiu, J., Kwapil, T.R., Kane, M.J. & Silvia, P. J. (2018a). Robust prediction of individual creative ability from brain functional connectivity. *Proceedings of the National Academy of Sciences of the United States of America*, 115(5), 1087–1092. https://doi.org/10.1073/pnas.1713532115.

Beaty, R. E., Thakral, P. P., Madore, K. P., M., B., & Schacter, D. L. (2018b). Core Network Contributions to Remembering the Past, Imagining the Future, and Thinking Creatively. *Journal of Cognitive Neuroscience*, 1–13. https://doi.org/10.1162/jocn_a_01327.

Beaty, R. E., Seli, P., & Schacter, D. L. (2019). Network neuroscience of creative cognition: mapping cognitive mechanisms and individual differences in the creative brain. *Current Opinion in Behavioral Sciences,* 27, 22–30. https://doi.org/10.1016/j.cobeha.2018.08.013.

Beaty R. E., & Silvia P. J. (2012). Why do ideas get more creative across time? An executive interpretation of the serial order effect in divergent thinking tasks. *Psychology of Aesthetics, Creativity, and the Arts*, 6:309 10.1037/a0029171.

Bechtereva, N. P., Korotkov, A. D., Pakhomov, S. V., Roudas, M. S., Starchenko, M. G., & Medvedev, S. V. (2004). PET study of brain maintenance of verbal creative activity. *International Journal of Psychophysiology*, 53, 11–20.

Beck, A. T., Ward, C. H., Mendelson, M., Mock, J., & Erbaugh, J. (1961). An inventory for measuring depression. *Archives of general psychiatry,* 4, 561–571. .

Beekman, A. T. F., Bremmer, M. A., Deeg, D. J. H., Van Balkom, A. J. L. M., Smit, J. H., De Beurs, E., Van Dyck, R., & Van Tilburg, W. (1998). Anxiety disorders in later life: A report from the longitudinal aging study Amsterdam. *International Journal of Geriatric Psychiatry*, *13*(10), 717–726. https://doi.org/10.1002/(SICI)1099-1166(1998100)13:10<717::AID-

Belleville, S., Fouquet, C., Hudon, C., Zomahoun, H. T. V., & Croteau, J. (2017). Neuropsychological Measures that Predict Progression from Mild Cognitive Impairment to Alzheimer's type dementia in Older Adults: a Systematic Review and Meta-Analysis. *Neuropsychology Review*, 27(4), 328–353. https://doi.org/10.1007/s11065-017-9361-5.

Bendetowicz, D., Urbanski, M., Garcin, B., Foulon, C., Levy, R., Bréchemier, M. L., Rosso, C., Thiebaut de Schotten, M. & Volle, E. (2018). Two critical brain networks for generation and combination of remote associations. *Brain*, 141(1), 217-233.

Benedek M. (2018). Internally directed attention in creative cognition. In Jung R.E. & Vartarian O. *The Cambridge Handbook of the Neuroscience of Creativity* (pag. 588- 619). Cambridge University Press.

References

Benedek, M., Beaty, R.E., Jauk, E., Koschutnig, K., Fink, A., Silvia, P.J., & Neubauer, A.C. (2014a). Creating metaphors: the neural basis of figurative language production. *NeuroImage*, 90, 99–106.

Benedek, M., Borovnjak, B., Neubauer, A. C., & Kruse-Weber, S. (2014b). Creativity and personality in classical, jazz and folk musicians. *Personality and Individual Differences*, 63, 117–121. https://doi.org/10.1016/j.paid.2014.01.064.

Benedek, M., Christensen, A. P., Fink, A., & Beaty, R. E. (2019). Creativity assessment in neuroscience research. *Psychology of Aesthetics, Creativity, and the Arts*, 13(2), 218–226. https://doi.org/10.1037/aca0000215.

Benedek, M., & Fink, A. (2019). Toward a neurocognitive framework of creative cognition: the role of memory, attention, and cognitive control. *Current Opinion in Behavioral Sciences*, 27, 116–122. https://doi.org/10.1016/j.cobeha.2018.11.002.

Benedek, M., Franz, F., Heene, M., & Neubauer, A. C. (2012). Differential effects of cognitive inhibition and intelligence on creativity. *Personality and Individual Differences*, 53(4), 480–485. https://doi.org/10.1016/j.paid.2012.04.014.

Benedek M., Jauk E., Beaty R.E., Fink A., Koschutnig K., & Neubauer A.C. (2016). Brain mechanisms associated with internally directed attention and self-generated thought. *Science Report*, 6:22959.

Benedek, M., Jauk, E., Sommer, M., Arendasy, M., & Neubauer, A. C. (2014c). Intelligence, creativity, and cognitive control: The common and differential involvement of executive functions in intelligence and creativity. *Intelligence*, 46(1), 73–83. https://doi.org/10.1016/j.intell.2014.05.007.

Benedek, M., & Neubauer, A. C. (2013). Revisiting Mednick's model on creativity-related differences in associative hierarchies. Evidence for a common path to uncommon thought. *The Journal of Creative Behavior,* 47, 273–289. http://doi.org/10.1002/jocb.35.

Benedek, M., Schües, T., Beaty, R. E., Jauk, E., Koschutnig, K., Fink, A., & Neubauer, A. C. (2018).

To create or to recall original ideas: Brain processes associated with the imagination of novel object uses. *Cortex*, 99, 93–102. https://doi.org/10.1016/j.cortex.2017.10.024.

Berg-Weger, M., & Morley, J. E. (2020). Loneliness and social isolation in older adults during the COVID-19 pandemic: Implications for gerontological social work. *The journal of nutrition, health & aging*, 24(5), 456-458.

Berlingeri M. (2009). *Brain dynamics associated with graceful and pathological aging: new morphometric and fMRI evidence.* [Doctoral dissertation, University of Milano Bicocca]. BOA, Bicocca Open Access.

Berlingeri, M., Danelli, L., Bottini, G., Sberna, M. & Paulesu, E. (2013). Reassessing the HAROLD model: Is the hemispheric asymmetry reduction in older adults a special case of compensatory-related utilisation of neural circuits?. *Experimental Brain Research* 224, 393–410 (2013). https://doi.org/10.1007/s00221-012-3319-x

Bigler, E. D. (1995). Design Fluency in Dementia of Alzheimer’s Type, Multi-Infarct Dementia and Dementia Associated With Alcoholism. *Applied Neuropsychology*, 2(1), 7–14. https://doi.org/10.1207/s15324826an0201_2.

Bigler, Erin D., Schultz, R., Grant, M., Knight, G., Lucas, J., Roman, M., Hall, S., & Sullivan, M. (1988). Design fluency in dementia of the Alzheimer’s type: Preliminary findings. *Neuropsychology*, 2(3–4), 127–133. https://doi.org/10.1037/h0091736.

Biringer, E., Mykletun, A., Dahl, A. A., Smith, A. D., Engedal, K., Nygaard, H. A., & Lund, A. (2005). The association between depression, anxiety, and cognitive function in the elderly general population - The Hordaland health study. *International Journal of Geriatric Psychiatry*, 20(10), 989–997. https://doi.org/10.1002/gps.1390

Bischkopf, J., Busse, A., & Angermeyer, M. C. (2002). Mild cognitive impairment—A review of prevalence, incidence and outcome according to current approaches. *Acta Psychiatrica Scandinavic*a, 106, 403–414.

Boccardi, M, Nicolosi, MS, Festari, C., Bianchetti, A.et al., 2019. (2019). Italian consensus recommendations for the biomarker-based etiological diagnosis in MCI patients. *European*, 1–29. https://doi.org/doi: 10.1111/ENE.14117.

Boccia, M., Piccardi, L., Palermo, L., Nori, R., & Palmiero, M. (2015). Where do bright ideas occur in our brain? Meta-analytic evidence from neuroimaging studies of domain-specific creativity. *Frontiers in psychology*, 6, 1195.

Bonnici, H.M., Maguire, E.A. (2018). Two years later revisiting autobiographical memory representations in vmPFC and hippocampus. *Neuropsychologia*, 110, 159–69.

Bondi, M. W., Edmonds, E. C., Jak, A. J., Clark, L. R., Delano-Wood, L., McDonald, C. R., et al. (2014). Neuropsychological criteria for mild cognitive impairment improves diagnostic precision, biomarker associations, and progression rates. *Journal of Alzheimer Disease*, 42, 275–289. doi: 10.3233/jad-140276.

Bradfield, N. I., Ellis, K. A., Savage, G., Maruff, P., Burnham, S., Darby, D., Lautenschlager, N., Martins, R.N., Masters, CL., Rainey-Smith, S.R., Robertson, J., Rowe, C., Woodward, M., & Ames, D. (2018). Baseline Amnestic Severity Predicts Progression from Amnestic Mild Cognitive Impairment to Alzheimer Disease Dementia at 3 Years. *Alzheimer Disease and Associated Disorders*, 32(3), 190–196. https://doi.org/10.1097/WAD.0000000000000252.

Bressler, S. & Menon, V. (2010). Large-scale brain networks in cognition: Emerging methods and principles. *Trends in Cognitive Sciences*, 14, 277–290.

Brewster, P. W., Melrose, R. J., Marquine, M. J., Johnson, J. K., Napoles, A., MacKay-Brandt, A., Farias, S., Reed, B., & Mungas, D. (2014). Life experience and demographic influences on cognitive function in older adults. *Neuropsychology*, 28(6), 846.

Brodaty, H., Altendorf, A., Withall, A., & Sachdev, P. (2010). Do people become more apathetic as they grow older? A longitudinal study in healthy individuals. *International Psychogeriatrics*, 22(3), 426–436. https://doi.org/10.1017/S1041610209991335

Budson, A.E., & Price, B.H. (2005). Memory dysfunction. *New England Journal of Medicine*, 352, 692-699.

Busse, A., Bischkopf, J., Riedel-Heller, S. G., & Angermeyer, M. C. (2003a). Mild cognitive impairment: Prevalence and incidence according to different diagnostic cri- teria. Results of the Leipzig Longitudinal Study of the Aged (LEILA). *British Journal of Psychiatry*, 182, 449–454.

Busse, A., Bischkopf, J., Riedel-Heller, S. G., & Angermeyer, M. C. (2003b). Mild cognitive impairment: Prevalence and predictive validity according to current approaches. *Acta Neurologica Scandinavica*, 108, 71–81.

Byron, K., & Khazanchi, S. (2011). A meta-analytic investigation of the relationship of state and trait anxiety to performance on figural and verbal creative tasks. *Personality and Social Psychology Bulletin*, 37(2), 269–283. https://doi.org/10.1177/0146167210392788.

Cabeza, R. (2002). Hemispheric asymmetry reduction in older adults: the HAROLD model. *Psychology and aging*, 17(1), 85.

Cabeza, R., Albert, M., Belleville, S., Craik, F. I., Duarte, A., Grady, C. L., Lindenberger, U., Nyberg, L., Park, D.C., Reuter-Lorenz, P.A., Rugg, M. D., Steffener, J., & Rajah, M.N. (2018). Maintenance, reserve and compensation: the cognitive neuroscience of healthy ageing. *Nature Reviews Neuroscience*, 19(11), 701-710.

Canesi, M., Rusconi, M. L., Cereda, E., Ranghetti, A., Cereda, V., Moroni, F., & Pezzoli, G. (2017). Divergent Thinking in Parkinsonism: a case–control study. *Frontiers in Neurology*, 8, 534.

Canesi, M., Rusconi, M. L., Isaias, I. U., & Pezzoli, G. (2012). Artistic productivity and creative thinking in Parkinson's disease. *European Journal of Neurology*, 19(3), 468–472. https://doi.org/10.1111/j.1468-1331.2011.03546.x.

Canesi, M., Rusconi, M. L., Moroni, F., Ranghetti, A., Cereda, E., & Pezzoli, G. (2016). Creative Thinking, Professional Artists, and Parkinson's Disease. *Journal of Parkinson's Disease*, 6(1), 239–246. https://doi.org/10.3233/JPD-150681.

Carlsson, I., Wendt, P. E., & Risberg, J. (2000). On the neurobiology of creativity. Differences in frontal activity between high and low creative subjects. *Neuropsychologia*, 38, 873–885.

Carretti, B., Borella, E., Fostinelli, S., & Zavagnin, M. (2013). Benefits of training working memory in amnestic mild cognitive impairment: Specific and transfer effects. *International Psychogeriatrics*, 25(4), 617–626. https://doi.org/10.1017/S1041610212002177.

Carson, S. H., Peterson, J. B., & Higgins, D. M. (2003). Decreased latent inhibition is associated with increased creative achievement in high-functioning individuals. *Journal of Personality and Social Psychology*, 85, 499–506.

Cera, R., Cristini, C., & Antonietti, A. (2018). Conceptions of Learning, Well-being, and Creativity in Older Adults. *ECPS - Educational Cultural and Psychological Studies*, (18), 241–273. https://doi.org/10.7358/ecps-2018-018-cera.

Charvet, L. E., Yang, J., Shaw, M. T., Sherman, K., Haider, L., Xu, J., & Krupp, L. B. (2017). Cognitive function in multiple sclerosis improves with telerehabilitation: Results from a randomized controlled trial. *PloS one*, 12(5).

Chen, A. C., Oathes, D. J., Chang, C., Bradley, T., Zhou, Z. W., Williams, L. M., Glover, G.H., Deiserroth, K., & Etkin, A. (2013). Causal interactions between fronto-parietal central executive and default-mode networks in humans. *Proceedings of the National Academy of Sciences*, 110(49), 19944-19949. doi.org/10.1073/pnas.1311772110.

Chen, Q., Beaty, R. E., Wei, D., Yang, J., Sun, J., Liu, W., Yang, W., Zhang, Q., & Qiu, J. (2018). Longitudinal alterations of frontoparietal and frontotemporal networks predict future creative cognitive ability. *Cerebral Cortex*, 28(1), 103-115.

Chrysikou, E.G., & Thompson- Schill, S.L. (2011). Dissociable brain states linked to common and creative object use. *Human Brain Mapping*, 32, 665–675.

Clarke, D.E., Ko, J.Y., Lyketsos, C., Rebok, G.W., & Eaton, W. W. (2010). Apathy and cognitive and functional decline in community- dwelling older adults: Results from the Baltimore ECA longitudinal study Diana. *International Psychogeriatrics*, 22(5), 819–829. https://doi.org/10.4324/9781315609607-7

Cohen N.J., & Eichenbaum H. (1993). *Memory, amnesia and the hippocampal system*. MIT Press.

Colautti, L., Baldissini, D., Colombo, V., Mottura, S., Sacco, M., Sozzi, M., Corbo, M., Rusconi, M. L., & Antonietti, A. (2018). CREC: The role of serious games in improving flexibility in thinking in neuropsychological rehabilitation. *British Journal of Educational Technology*, 49, 717-727 (doi:10.1016/bjet.12629).

Colombo, B., Antonietti, A., & Daneau, B. (2018). The relationships between Cognitive Reserve and creativity. a study on American aging population. *Frontiers in Psychology*, 9(MAY), 1–11. https://doi.org/10.3389/fpsyg.2018.00764.

Colombo, B., Fusi, G., Pabla, S., Caravita, S.C. (2022). Challenge your brain. Blogging during the COVID lockdown as a way to enhance well-being and cognitive reserve in an older population. *Journal of Integrative Neuroscience* (*in press*).

Comijs, H. C., Beekman, A. T. F., Jonker, C., & Deeg, D. J. H. (2003). Depressive symptoms and cognitive decline in community-dwelling elderly persons. *Research and Practice in Alzheimer's Disease*, 7(April 2000), 108–112.

Cortes, R. A., Weinberger, A. B., Daker, R. J., & Adam, E. (2019). ScienceDirect Re-examining prominent measures of divergent and convergent creativity. *Cobeha*, 27, 90–93. https://doi.org/10.1016/j.cobeha.2018.09.017.

Cotelli, M., Manenti, R., Brambilla, M., Gobbi, E., Ferrari, C., Binetti, G., & Cappa, S. F. (2019). Cognitive telerehabilitation in mild cognitive impairment, Alzheimer's disease and frontotemporal dementia: a systematic review. *Journal of telemedicine and telecare*, 25(2), 67-79.

Crook, T., Bartus, R. T., Ferris, S. H., Whitehouse, P., Cohen, G. D., & Gershon, S. (1986). Age-associated memory impairment: Proposed diagnostic criteria and measures of clinical change—report of a national institute of mental health work group. *Developmental Neuropsychology*, 2: 261–76.

Cropley, A. J. (1990). Creativity and mental health in everyday life. *Creativity Research Journal*, 3, 167–178. doi: 10.1080/10400419009534351

Crutch, S. J., Isaacs, R., & Rossor, M. N. (2001). Some workmen can blame their tools: artistic change in an individual with Alzheimer's disease. *Lancet*, 357, 2129–2133. doi: 10.1016/S0140-6736(00)05187-4

Cummings, J. L., & Zarit, J. M. (1987). Probable Alzheimer's disease in an artist. *JAMA* 258, 2731–2734. doi: 10.1001/jama.1987.03400190113039.

Cunnington, B.F., & Torrance, E.P. (1965). *Sounds and images.* Ginn.

Curtis, C.E., & D'Esposito, M. (2003). Persistent activity in the prefrontal cortex during working memory. *Trends in Cognitive Science* 7, 415–423.

Damoiseaux, J. S. (2017). Effects of aging on functional and structural brain connectivity. *NeuroImage*, 160, 32–40.

Darke, S. (1988). Anxiety and working memory capacity. *Cognition and Emotion*, 2(2), 145–154. https://doi.org/10.1080/02699938808408071.

Davis, S. W., Dennis, N. A., Daselaar, S. M., Fleck, M. S., & Cabeza, R. (2008). Que PASA? The posterior–anterior shift in aging. *Cerebral cortex*, 18(5), 1201-1209.

De Beni, R., & Borella E. (2015). *Psicologia dell'invecchiamento e della longevità*. Il mulino.

de Souza, Leonardo C., Guimarães, H. C., Teixeira, A. L., Caramelli, P., Levy, R., Dubois, B., & Volle, E. (2014). Frontal lobe neurology and the creative mind. *Frontiers in Psychology*, 5(JUL), 1–21. https://doi.org/10.3389/fpsyg.2014.00761.

De Souza, Leonardo Cruz, Volle, E., Bertoux, M., Czernecki, V., Funkiewiez, A., Allali, G., Leroy, B., Sarazin, M., Habert, M., Dubois, B., Kas, A., & Levy, R. (2010). Poor creativity in frontotemporal dementia: A window into the neural bases of the creative mind. *Neuropsychologia*, 48(13), 3733–3742. https://doi.org/10.1016/j.neuropsychologia.2010.09.010.

Deary, I. J., Corley, J., Gow, A. J., Harris, S. E., Houlihan, L. M., Marioni, R. E., Penke, L., Rafnsson S.B. & Starr, J. M. (2009). Age-associated cognitive decline. *British medical bulletin*, 92(1), 135-152.

Dennis, B., & Bromley, B.A. (1956). Some experimental tests of the effect of age on creative intellectual output. *Journal of Gerontology*, 11, 74–82.

Dennis, E.L., & Thompson, P.M. (2014). Functional brain connectivity using fMRI in aging and Alzheimer's disease. *Neuropsychology Review*, 24, 49e62.

Devita, M., Bordignon, A., Sergi, G., & Coin, A. (2021). The psychological and cognitive impact of Covid-19 on individuals with neurocognitive impairments: research topics and remote intervention proposals. *Aging clinical and experimental research*, 33(3), 733-736.

Dietrich, A. (2004). The cognitive neuroscience of creativity. *Psychonomic Bulletin & Review*, 11(6), 1011–1026.

Dietrich, A. (2019a). Types of creativity. *Psychonomic Bulletin and Review*, 26(1). https://doi.org/10.3758/s13423-018-1517-7.

Dietrich, A. (2019b). Where in the brain is creativity: a brief account of a wild-goose chase. *Current Opinion in Behavioral Sciences*, 27, 36–39. https://doi.org/10.1016/j.cobeha.2018.09.001.

Dietrich, A., & Kanso, R. (2010). A review of EEG, ERP, and neuroimaging studies of creativity and insight. *Psychological Bulletin*, 136(5), 822–848. https://doi.org/10.1037/a0019749.

Dixon, R. A., de Frias, C. M., & Bäckman, L. (2001). Characteristics of self-reported memory compensation in older adults. *Journal of Clinical and Experimental Neuropsychology*, 23(5), 650-661.

Djernes, J. K. (2006). Prevalence and predictors of depression in populations of elderly: A review. *Acta Psychiatrica Scandinavica*, 113(5), 372–387. https://doi.org/10.1111/j.1600-0447.2006.00770.x

Dotson, V. M., McClintock, S. M., Verhaeghen, P., Kim, J. U., Draheim, A. A., Syzmkowicz, S. M., Gradone, A.M., Bogoian, H.R. & De Wit, L. (2020). Depression and Cognitive Control across the Lifespan: a Systematic Review and Meta-Analysis. *Neuropsychology review*.

Drago, V., Crucian, G. P., Foster, P. S., Cheong, J., Finney, G. R., Pisani, F., & Heilman, K.M. (2006). Lewy body dementia and creativity: case report. *Neuropsychologia* 44, 3011–3015. doi: 10.1016/j.neuropsychologia.2006.05.030

Ducharme, S., Price, B. H., & Dickerson, B. C. (2018). Apathy: a neurocircuitry model based on frontotemporal dementia. *Journal of Neurology, Neurosurgery & Psychiatry*, 89(4), 389-396.

Duff, M. C., Kurczek, J., Rubin, R., Cohen, N. J., & Tranel, D. (2013). Hippocampal amnesia disrupts creative thinking. *Hippocampus*, 23(12), 1143–1149. https://doi.org/10.1002/hipo.22208.

Eagleman D. & Brandt A. (2017). *The Runaway Species: How Human Creativity Remakes the World.* Catapult.

Edl, S., Benedek, M., Papousek, I., Weiss, E. M., & Fink, A. (2014). Creativity and the Stroop interference effect. *Personality and Individual Differences*, 69, 38–42. https://doi.org/10.1016/j.paid.2014.05.009.

Eichenbaum H., & Cohen N.J. (2001). *From Conditioning to Conscious Recollection: Memory Systems of the Brain*. Oxford University Press.

Eliassen, C. F., Reinvang, I., Selnes, P., Grambaite, R., Fladby, T., & Hessen, E. (2017). Biomarkers in subtypes of mild cognitive impairment and subjective cognitive decline. *Brain and Behavior*, 7(9), 3–9. https://doi.org/10.1002/brb3.776.

Esposito, F., Rochat, L., Van der Linden, A. C. J., Lekeu, F., Quittre, A., Charnallet, A., & Van der Linden, M. (2010). Apathy and executive dysfunction in Alzheimer disease. *Alzheimer Disease & Associated Disorders*, 24(2), 131-137.

Esposito, F., Rochat, L., Juillerat Van der Linden, A. C., Lekeu, F., Charnallet, A., & Van der Linden, M. (2014). Apathy in aging: Are lack of interest and lack of initiative dissociable? *Archives of*

Gerontology and Geriatrics, *58*(1), 43–50. https://doi.org/10.1016/j.archger.2013.09.002.

Evans, I. E., Llewellyn, D. J., Matthews, F. E., Woods, R. T., Brayne, C., Clare, L., & CFAS-Wales Research Team. (2018). Social isolation, cognitive reserve, and cognition in healthy older people. *PloS one*, 13(8).

Fabrigoule, C., Letenneur, L., Dartigues, J. F., Zarrouk, M., Commenges, D., & Barberger-Gateau, P. (1995). Social and leisure activities and risk of dementia: a prospective longitudinal study. *Journal of the American Geriatrics Society*, 43(5), 485-490.

Fancourt, D., Steptoe, A., & Cadar, D. (2018). Cultural engagement and cognitive reserve: museum attendance and dementia incidence over a 10-year period. *The British Journal of Psychiatry*, 213(5), 661-663.

Fennema-Notestine, C., McEvoy, L. K., Hagler Jr, D. J., Jacobson, M. W., Dale, A. M., & Alzheimer's Disease Neuroimaging Initiative. (2009). Structural neuroimaging in the detection and prognosis of pre-clinical and early AD. *Behavioural neurology*, 21(1, 2), 3-12.

Fink A., & Benedek M. (2014). EEG alpha power and creative ideation. *Neuroscience & Biobehavioral Reviews*, 44:111-123.

Fink, A., & Benedek, M. (2019). The Neuroscience of Creativity. *Neuroforum*. https://doi.org/10.1515/nf-2019-0006.

Fink, A., Grabner, R. H., Benedek, M., Reishofer, G., Hauswirth, V., Fally, M., Neuper, C., Ebner, F., & Neubauer, A.C. (2009). The creative brain: Investigation of brain activity during creative problem solving by means of EEG and FMRI. *Human Brain Mapping*, 30, 734– 748.

Finke, R. A., Ward, T. B., & Smith, S. M. (1992). *Creative cognition: Theory, research and applications.* MIT Press.

Fjell, A. M., & Walhovd, K. B. (2010). Structural brain changes in aging: courses, causes and cognitive consequences. *Reviews in the Neurosciences*, 21(3), 187-222.

References

Flint, A. J. (2005). Generalised anxiety disorder in elderly patients. *Drugs & aging*, 22(2), 101-114.

Flood, M. (2006). Exploring the Relationships Between Creativity, Depression, and Successful Aging. *Activities, Adaptation & Aging*, 31(1). https://doi.org/10.1300/J016v31n03

Folstein, F.M., Folstein S.E., M. (1975). "MINI-MENTAL STATE". A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatry*, 12, 189–198.

Foos, P. W., & Boone, D. (2008). Adult age differences in divergent thinking: It's just a matter of time. *Educational Gerontology*, 34(7), 587–594. https://doi.org/10.1080/03601270801949393.

Forgeard, M., Corcoran, E., Beard, C., & Björgvinsson, T. (2020). Relationships between depression, self-reflection, brooding, and creative thinking in a psychiatric sample. *Psychology of Aesthetics, Creativity, and the Arts*, 14(3), 325–333. https://doi.org/10.1037/aca0000206

Fornazzari, L. R. (2005). Preserved painting creativity in an artist with Alzheimer's disease. *European Journal of Neurology*, 12(6), 419–424. https://doi.org/10.1111/j.1468-1331.2005.01128.x.

Forthmann, B., Bürkner, P.-C., Szardenings, C., Benedek, M., & Holling, H. (2019). A New Perspective on the Multidimensionality of Divergent Thinking Tasks. *Frontiers in Psychology*, 10(May), 1–9. https://doi.org/10.3389/fpsyg.2019.00985.

Forthmann, B., Gerwig, A., Holling, H., Çelik, P., Storme, M., & Lubart, T. (2016). The be-creative effect in divergent thinking: The interplay of instruction and object frequency. *Intelligence*, 57, 25–32. https://doi.org/10.1016/j.intell.2016.03.005.

Furnham, A., Crump, J., Batey, M., & Chamorro-Premuzic, T. (2009). Personality and ability predictors of the "Consequences" Test of divergent thinking in a large non-student sample. *Personality and Individual Differences*, 46(4), 536–540. https://doi.org/10.1016/j.paid.2008.12.007.

Fusi G., Ferrari E., Zanetti M., Crepaldi M., Bersanini C., Paladino A., Colatti L., Rozzini L., Antonietti A., & Ruconi ML. (2020a). A Comparison of Divergent Thinking Abilities Between

Healthy Elderly Subjects and MCI Patients: Preliminary Findings and Implications. *Frontiers in Psychology*. 11:738. doi: 10.3389/fpsyg.2020.00738.

Fusi, G., Lavolpe, S., Crepaldi, M., & Rusconi, M. L. (2020b). The Controversial Effect of Age on Divergent Thinking Abilities: A Systematic Review. *The Journal of Creative Behavior*. doi: 10.1002/jocb.461.

Fusi, G., Colombo B., Zanetti M., Crepaldi M., Rozzini L., & Rusconi ML (2021a). The effect of psychological symptoms on divergent thinking in healthy older adults. *Creativity Research Journal.*

Fusi, G., Crepaldi, M., Colautti, L., Palmiero, M., Antonietti, A., Rozzini, L., & Rusconi, M. L. (2021b). Divergent thinking abilities in frontotemporal dementia: A mini-review. *Frontiers in Psychology*, 1279.

Gates, N. J., Vernooij, R. W., Di Nisio, M., Karim, S., March, E., Martinez, G., & Rutjes, A. W. (2019). Computerised cognitive training for preventing dementia in people with mild cognitive impairment. *Cochrane database of systematic reviews*, (3).

Gauthier, S., Reisberg, B., Zaudig, M., Petersen, R. C., Ritchie, K., Broich, K., et al. (2006). Mild cognitive impairment. *Lancet* 367, 1262–1270.

Gazzaniga M.S., Ivry R.B., Mangun G.R. (2015). *Neuroscienze cognitive.* Zanichelli.

Gilhooly, K. J., Fioratou, E., Anthony, S. H., & Wynn, V. (2007). Divergent thinking: Strategies and executive involvement in generating novel uses for familiar objects. *British Journal of Psychology*, 98, 611–625. https://doi.org/10.1348/096317907X173421.

Goff, K. (2002). *Abbreviated Torrance test for adults*. Scholastic Testing Service.

Goldberg E. (2018). *Creativity: the human brain in the age of innovation.* Oxford University Press.

Gonen-Yaacovi, G., De Souza, L. C., Levy, R., Urbanski, M., Josse, G., & Volle, E. (2013). Rostral and caudal prefrontal contribution to creativity: A meta-analysis of functional imaging data.

Frontiers in Human Neuroscience, 7(AUG), 1–22. https://doi.org/10.3389/fnhum.2013.00465.

Grègoire, J. & Van der Linden, M. Effects of age on forward and backward digit spans. Aging, *Neuropsychology and Cognition*. 4, 140–149 (1997).

Gruszka, A., & Necka, E. (2002). Priming and acceptance of close and remote associations by creative and less creative people. *Creativity Research Journal*, 14, 193–205.

Guilford, J. P. (1957). Creative abilities in the arts. *Psychological Review*, 64(2), 110–118. https://doi.org/10.1037/h0048280.

Guilford, J. P. (1959). Three faces of intellect. *American psychologist,* 14(8), 469.

Guilford, J.P. (1967). The nature of human intelligence. *McGraw-Hill.*

Guilford, J. P. (1988). Some changes in the structure-of-intellect model. *Educational and Psychological Measurement*, 48(1), 1-4.

Guilford, J.P., Christensen, P.R., Merrifiedld, P.R., & Wilson, R.C. (1978). *Alternate uses: Manual of instructions and interpretation.* Sheridan Psychological Services.

Hagura, N., Haggard, P., & Diedrichsen, J. (2017). Perceptual decisions are biased by the cost to act. *Elife*, 6, e18422.

Harada, C. N., Love, M. C. N., & Triebel, K. L. (2013). Normal cognitive aging. *Clinics in geriatric medicine*, 29(4), 737-752.

Hart, R., & Wade, J. (2006). Divergent thinking in Alzheimer's and frontotemporal dementia. *Aging, Neuropsychology, and Cognition*, 13(3–4), 281–290. https://doi.org/10.1080/13825580490904246.

Head, D., Buckner, R. L., Shimony, J. S., Williams, L. E., Akbudak, E., Conturo, T. E., McAvoy M., Morris J.C. & Snyder, A. Z. (2004). Differential vulnerability of anterior white matter in nondemented aging with minimal acceleration in dementia of the Alzheimer type: evidence from diffusion tensor imaging. *Cerebral cortex*, 14(4), 410-423.

Hedden, T., & Gabrieli, J. D. E. (2004). Insights into the ageing mind: A view from cognitive neuroscience. *Nature Reviews Neuroscience*, 5(2), 87–96. https://doi.org/10.1038/nrn1323.

Hedden, T., Lautenschlager, G., & Park, D. C. (2005). Contributions of processing ability and knowledge to verbal memory tasks across the adult life-span. *The Quarterly Journal of Experimental Psychology Section* A, 58(1), 169-190.

Heilman, K.M., & Fleischer, I.S. (2018). Creativity and the aging brain. In Jung, R. E., & Vartanian, O. (Eds.). (2018). *The Cambridge handbook of the neuroscience of creativity*. Cambridge University Press.

Heinonen J., Numminen J., Hlushchuk Y., Antell H., Taatila V., & Suomala J. (2016). Default mode and executive networks areas: association with the serial order in divergent thinking. *PLoS One*, 11:e 0162234. 10.1371/journal.pone.0162234.

Henson, R. N. A. (2003). Neuroimaging studies of priming. *Progress in Neurobiology*. 70, 53–81. doi: 10.1016/S0301-0082(03)00086-8.

Henson, R. N. A., & Rugg, M. D. (2003). Neural response suppression, haemodynamic repetition effects, and behavioural priming. *Neuropsychologia*, 41(3), 263-270.

Hof, P. R., & Morrison, J. H. (2004). The aging brain: morphomolecular senescence of cortical circuits. *Trends in neurosciences*, 27(10), 607-613.

Holm-Hadulla, R. M., Roussel, M., & Hofmann, F. H. (2010). Depression and creativity—The case of the German poet, scientist and statesman JW v. Goethe. *Journal of Affective Disorders*, 127(1-3), 43-49.

Howard-Jones, P. A., Blakemore, S. J., Samuel, E. A., Summers, I. R., & Claxton, G. (2005). Semantic divergence and creative story generation: An fMRI investigation. Brain Research. *Cognitive Brain Research*, 25, 240–250.

Hudon, C., Escudier, F., De Roy, J., Croteau, J., Cross, N., Dang-Vu, T. T., Zomahoun, V., Grenier, S., Gagnon, J., Parent, A., Buneau, M., Belleville, S., & the consortium for the Early Identificaztion of Alzheimer's Disease - Quebec. (2020). Behavioral and Psychological Symptoms that Predict Cognitive Decline or Impairment in Cognitively Normal Middle-Aged or Older Adults: a Meta-Analysis. *Neuropsychology review.*

Ishii, S., Weintraub, N., & Mervis, J. R. (2009). Apathy: a common psychiatric syndrome in the elderly. *Journal of the American Medical Directors Association*, 10(6), 381-393.

Jack, C. R., Bennett, D. A., Blennow, K., Carrillo, M. C., Dunn, B., Haeberlein, S. B., Holtzman, D.M., Jagust, W., Jessen, F., Karlawish, J., Liu, E., Molinuevo J.L., Montine, T., Phelps, C., Rankin, K.P., Rowe, C.C., Sheltens, P., Siemers, E., Snyder, H.M., Sperling, R., … Silverberg, N. (2018). NIA-AA Research Framework: Toward a biological definition of Alzheimer’s disease. *Alzheimer’s and Dementia*, 14(4), 535–562. https://doi.org/10.1016/j.jalz.2018.02.018.

Jaquish, G.A. & Ripple, R. E. (1981). Cognitive Creative Abilities and Self-Esteem across the Adult Life-Span. *Journal of Human Development*, (c), 2–6.

Jauk, E. (2019). A bio-psycho-behavioral model of creativity. *Current Opinion in Behavioral Sciences*, 27(September), 1–6. https://doi.org/10.1016/j.cobeha.2018.08.012.

Jauk, E., Benedek, M., & Neubauer, A. C. (2014). The road to creative achievement: A latent variable model of ability and personality predictors. *European Journal of Personality*, 28(1), 95–105. https://doi.org/10.1002/per.1941.

Jean, L., Bergeron, M. E., Thivierge, S., and Simard, M. (2010). Cognitive intervention programs for individuals with mild cognitive impairment: systematic review of the literature. *American Journal of Geriatric Psychiatry* 18, 281–296. doi: 10.1097/jgp.0b013e3181c37ce9

Jefferies, E. (2013). The neural basis of semantic cognition: converging evidence from neuropsychology, neuroimaging and TMS. *Cortex* 49, 611e625.

Jung, R. E., & Vartanian, O. (Eds.). (2018). *The Cambridge handbook of the neuroscience of creativity*. Cambridge University Press.

Kapur, N. (1996). Paradoxical functional facilitation in brain-behavious research. *Brain*, 119, 1775–1790.

Karas, G., Sluimer, J., Goekoop, R., Van Der Flier, W., Rombouts, S. A. R. B., Vrenken, H., Sheltens P., Fox, N., & Barkhof, F. (2008). Amnestic mild cognitive impairment: Structural MR imaging findings predictive of conversion to Alzheimer disease. *American Journal of Neuroradiology*, 29(5), 944–949. https://doi.org/10.3174/ajnr.A0949.

Karp, A., Andel, R., Parker, M. G., Wang, H. X., Winblad, B., & Fratiglioni, L. (2009). Mentally stimulating activities at work during midlife and dementia risk after age 75: follow-up study from the Kungsholmen Project. *The American Journal of Geriatric Psychiatry*, 17(3), 227-236.

Kawagoe, T., Onoda, K., & Yamaguchi, S. (2017). Apathy and executive function in healthy elderly-resting state fMRI study. *Frontiers in Aging Neuroscience*, 9(MAY), 1–7. https://doi.org/10.3389/fnagi.2017.00124

Kaya, F., & Acar, S. (2019). The Impact of Originality Instructions on Cognitive Strategy Use in Divergent Thinking. *Thinking Skills and Creativity*, (June), 100581. https://doi.org/10.1016/j.tsc.2019.100581.

Kemper, S., & Kemtes, K. (1999). *Aging and message production and comprehension, in Cognition, aging, and self-reports*. eds N. Schwarz, D. C. Park, B. Knauper, and S. Sudman. Psychology Press, 229–244. doi: 10.4324/9780203345115_chapter_11.

Kenett, Y. N., Anaki, D., & Faust, M. (2014). Investigating the structure of semantic networks in low and high creative persons. *Frontiers in human neuroscience*, 8, 407.

Kenett, Y. N., Levy, O., Kenett, D. Y., Stanley, H. E., Faust, M., & Havlin, S. (2018). Flexibility of thought in high creative individuals represented by percolation analysis. *Proceedings of the National Academy of Sciences*, 115(5), 867-872.

Kim, K. E. (2006). Can We Trust Creativity Tests? A Review of the Torrance Tests of Creative Thinking (TTCT). *Creativity Research Journal*, 18(1), 3–14.

https://doi.org/10.1207/s15326934crj1801_2.

Kim, K. H. (2008). Meta-analyses of the relationship of creative achievement to both IQ and divergent thinking test scores. *The Journal of Creative Behavior*, 42(2), 106-130.

Kim, S. H., Seo, S. W., Yoon, D. S., Chin, J., Lee, B. H., Cheong, H. K., Hans, S.H., & Na, D. L. (2010). Comparison of neuropsychological and FDG-PET findings between early-versus late-onset mild cognitive impairment: A five-year longitudinal study. *Dementia and geriatric cognitive disorders*, 29(3), 213-223.

Kim, T. Y., Hon, A. H. Y., & Lee, D. R. (2010). Proactive personality and employee creativity: The effects of job creativity requirement and supervisor support for creativity. *Creativity Research Journal*, 22(1), 37–45. https://doi.org/10.1080/10400410903579536.

Kleibeuker, S.W., Koolschijn, P.C. MP., Jolles, D.D., De Dreu, C.K. W., & Crone, E.A. (2013). The neural coding of creative idea generation across adolescence and early adulthood. *Frontiers in Human Neuroscience*, 7, 905.

Koster, A., Penninx, B. W., Bosma, H., Kempen, G. I., Newman, A. B., Rubin, S. M., Satterfield, S., Atkinson, H.H., Ayonayon, H.N., Rosano, C., Yaffe, K., Harris, T.B., Rook, Van Eijk, J., & Kritchevsky, S. B. (2005). Socioeconomic differences in cognitive decline and the role of biomedical factors. *Annals of epidemiology*, 15(8), 564-571.

Kounios J., & Beeman M. (2014). The cognitive neuroscience of insight. *Annual review of psychology*, 65:71-93.

Kowatari, Y., Lee, S. H., Yamamura, H., Nagamori, Y., Levy, P., Yamane, S., & Yamamoto, M. (2009). Neural networks involved in artistic creativity. *Human Brain Mapping*, 30, 1678–1690.

Kral, V. A. (1962). Senescent forgetfulness: benign and malignant. *Canadian Medical Association Journal*, 86(6), 257.

Kröger, E., Andel, R., Lindsay, J., Benounissa, Z., Verreault, R., & Laurin, D. (2008). Is complexity of work associated with risk of dementia? The Canadian Study of Health and Aging. *American* *journal of epidemiology*, 167(7), 820-830.

Kukull, W. A., Higdon, R., Bowen, J. D., McCormick, W. C., Teri, L., Schellenberg, G. D., van Belle, G., Jolley, L., & Larson, E. B. (2002). Dementia and Alzheimer disease incidence: a prospective cohort study. *Archives of neurology*, 59(11), 1737-1746.

Lau, A. L., Chi, I., Cummins, R. A., Lee, T. M., Chou, K. L., & Chung, L. W. (2008). The SARS (Severe Acute Respiratory Syndrome) pandemic in Hong Kong: Effects on the subjective wellbeing of elderly and younger people. *Aging and mental health*, 12(6), 746-760.

Lee, C. S., & Therriault, D. J. (2013). The cognitive underpinnings of creative thought: A latent variable analysis exploring the roles of intelligence and working memory in three creative thinking processes. *Intelligence*, 41(5), 306–320. https://doi.org/10.1016/j.intell.2013.04.008.

Lenze, E. J., Mulsant, B. H., Shear, M. K., Schulberg, H. C., Dew, M. A., Begley, A. E., Pollok B. G. & Reynolds III, C. F. (2000). Comorbid anxiety disorders in depressed elderly patients. *American Journal of Psychiatry*, 157(5), 722-728.

Leon, S. A., Altmann, L. J. P., Abrams, L., Gonzalez Rothi, L. J., & Heilman, K. M. (2014). Divergent Task Performance in Older Adults: Declarative Memory or Creative Potential? *Creativity Research Journal*, 26(1), 21–29. https://doi.org/10.1080/10400419.2014.873657.

Li, S. C., & Baltes, P. B. (2006). Cognitive developmental research from lifespan perspectives: the challenge of integration. *Lifespan cognition: Mechanisms of change*, 344-363.

Li, H., Li, J., Li, N., Li, B., Wang, P., & Zhou, T. (2011). Cognitive intervention for persons with mild cognitive impairment: a meta-analysis. *Ageing Research Review* 10, 285–296. doi: 10.1016/j.arr.2010.11.003

Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P. A., Clarke, M., Devereaux, P.J., Kleijnen, J., & Moher, D. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. J*ournal of Clinical Epidemiology*, 62(10), e1–e34.

https://doi.org/10.1016/j.jclinepi.2009.06.006.

Liberati, G., Raffone, A., & Belardinelli, M. O. (2012). Cognitive reserve and its implications for rehabilitation and Alzheimer's disease. *Cognitive Processing*, 13(1), 1–12. https://doi.org/10.1007/s10339-011-0410-3.

Lindauer, M. (1998). Artists, art and arts activities: What do they tell us about aging? In C. Adams-Price (Ed.), *Creativity and successful aging: Theoretical and empirical approaches* (pp. 237–250). Springer.

Lohner, V., Brookes, R. L., Hollocks, M. J., Morris, R. G., & Markus, H. S. (2017). Apathy, but not depression, is associated with executive dysfunction in cerebral small vessel disease. *PLoS One*, 12(5).

Luppa, M., Sikorski, C., Luck, T., Ehreke, L., Konnopka, A., Wiese, B., Weyerer, S., König, H.H. & Riedel-Heller, S. G. (2012). Age-and gender-specific prevalence of depression in latest-life–systematic review and meta-analysis. *Journal of affective disorders*, 136(3), 212-221.

MacDonald, A.W., Cohen, J.D., Strenger, V.A., & Carter, C.S. (2000). Dissociating the role of dorsolateral prefrontal and anterior cingulate cortex in cognitive control. *Science*, 9, 1835–1838.

Madore, K.P., Jing, H. G., & Schacter, D. L. (2016). Divergent creative thinking in young and older adults: Extending the effects of an episodic specificity induction. *Memory and Cognition*, 44(6), 974–988. https://doi.org/10.3758/s13421-016-0605-z.

Madore, Kevin P, Addis, D. R., & Schacter, D. L. (2015). Creativity and Memory: Effects of an Episodic Specificity Induction on Divergent Thinking. *Psychological Science*, 26(9), 1461–1468. https://doi.org/10.1177/0956797615591863.Creativity.

Madore, K. P., Thakral, P. P., Beaty, R. E., Addis, D. R., & Schacter, D. L. (2019). Neural mechanisms of episodic retrieval support divergent creative thinking. *Cerebral Cortex*, 29(1), 150-166.

Manly, J. J., Schupf, N., Tang, M. X., & Stern, Y. (2005). Cognitive decline and literacy among ethnically diverse elders. *Journal of geriatric psychiatry and neurology*, 18(4), 213-217.

Marek, S., & Dosenbach, N. U. (2018). The frontoparietal network: function, electrophysiology, and importance of individual precision mapping. *Dialogues in clinical neuroscience*, 20(2), 133.

Marin, R. S., Biedrzycki, R. C., & Firinciogullari, S. (1991). Reliability and validity of the apathy evaluation scale. *Psychiatry Research*, 38(2), 143–162. https://doi.org/10.1016/0165-1781(91)90040-V.

Mattsson, N., Zetterberg, H., Hansson, O., Andreasen, N., Parnetti, L., Jonsson, M., … Blennow, K. (2009). CSF biomarkers and incipient Alzheimer disease in patients with mild cognitive impairment. *JAMA - Journal of the American Medical Association*, 302(4), 385–393. https://doi.org/10.1001/jama.2009.1064.

Maurer, K., & Prvulovic, D. (2004). Paintings of an artist with Alzheimer's disease: visuoconstructural deficits during dementia. *Journal of Neuralal Transmission*, 111, 235–245. doi: 10.1007/s00702-003-0046-2

McRae, K., & Jones, M. (2013). *Semantic Memory*. Vol. 206. Oxford University Press.

McCrae, R. R, Arenberg, D. and C. P. T. (1987). Declines in divergent thinking with age: cross-sectional, longitudinal, and cross-sequential analyses. *Psychology and Aging*, 2(2), 130–137. https://doi.org/10.1037/0882-7974.2.2.130.

Measso, G., Cavarzeran, F., Zappala, G., Lebowitz, B. D., Crook, T. H., Pirozzolo, F. J., Amaducci, L.A., Massari, D. & Grigoletto, F. (1993). The mini-mental state examination: Normative study of an Italian random sample. *Developmental neuropsychology*, 9(2), 77-85.

Mednick S.A. (1962). The associative basis of creativity. *Psychological Review*, 69: 220-32.

Meléndez, J. C., Alfonso-Benlliure, V., Mayordomo, T., & Sales, A. (2016). Is Age Just a Number? Cognitive Reserve as a Predictor of Divergent Thinking in Late Adulthood. *Creativity Research Journal*, 28(4), 435–441. https://doi.org/10.1080/10400419.2016.1229983.

Mell, J. C., Howard, S. M., & Miller, B. L. (2003). Art and the brain: The influence of frontotemporal dementia on an accomplished artist. *Neurology*, 60, 1707– 1710.

Mendelsohn, G., & Griswold, B. (1964). Differential use of incidental stimuli in problem solving as a function of creativity. *Journal of Abnormal and Social Psychology*, 68, 431–436.

Mendes, A., Câmara, J., Caires, A. L., Garcês, S., & Pocinho, M. (2020). Creativity and cognitive reserve in old age: an exploratory study in the Portuguese population. *Revista PSICOLOGIA*, 34(1), 229-235.

Miller, Z. A., & Miller, B. L. (2013). Artistic creativity and dementia. *Progress in Brain Research*, 204, 99–112. https://doi.org/10.1016/B978-0-444-63287-6.00005-1.

Miyake, A., Emerson, M. J., & Friedman, N. P. (2000). Assessment of executive functions in clinical settings: Problems and recommendations. *Seminars in Speech and Language*, 21, 169–183.

Miyake, A., & Friedman, N. P. (2012). The nature and organization of individual differences in executive functions: Four general conclusions. *Current Directions in Psychological Science*, 21, 8–14.

Morrow-Howell, N., Galucia, N., & Swinford, E. (2020). Recovering from the COVID-19 Pandemic: A Focus on Older Adults. *Journal of Aging & Social Policy*. Doi:10.1080/08959420.2020.1759758

Mullally, S. L., & Maguire, E. A. (2014). Memory, imagination, and predicting the future: a common brain mechanism?. *The Neuroscientist*, 20(3), 220-234.

Nichols, E., Szoeke, C. E., Vollset, S. E., Abbasi, N., Abd-Allah, F., Abdela, J., Aichour M.T., Akinyemu R.O., Alahdab, F., Asgedom, S.W., Awasthi, A., Barker-Collo, S.L., Baune, B.T., Béjot, Y., Belachew, A.B., Bennett, D.A., Biadgo, B., Bijani, A., Sayeed M.S., Brayne, C., ….& Murray, C.J.L. (2019). Global, regional, and national burden of Alzheimer's disease and other dementias, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016. *The Lancet Neurology*, 18(1), 88-106.

Nijstad, B. A., De Dreu, C. K. W., Rietzschel, E. F., & Baas, M. (2010). The dual pathway to creativity model: Creative ideation as a function of flexibility and persistence. *European Review of Social Psychology*, 21(1), 34–77. https://doi.org/10.1080/10463281003765323.

Noonan, K.A., Jefferies, E., Visser, M., & Lambon Ralph, M.A. (2013). Going beyond inferior prefrontal involvement in semantic control: evidence for the additional contribution of dorsal angular gyrus and posterior middle temporal cortex. *Journal of Cognitive Neuroscience*, 25, 1824e1850.

Nucci, M., Mondini, S., & Mapelli, D. (2012). Cognitive Reserve Index (CRI). Un questionario per la valutazione della riserva cognitiva. *Giornale italiano di psicologia*, 1, 155–174.

Nusbaum, B. E. C., & Silvia, P. J. (2011). Are intelligence and creativity really so different? Fluid intelligence, executive processes, and strategy use in divergent thinking. *Intelligence*, 39((1)), 36-45.

Nusbaum, E.C., Silvia, P.J., & Beaty, R.E. (2014). Ready, set, create: What instructing people to "be creative" reveals about the meaning and mechanisms of divergent thinking. *Psychology of Aesthetics, Creativity, and the Arts*, 8, 423.

Ovando-Tellez, M. P., Bieth, T., Bernard, M., & Volle, E. (2019). The contribution of the lesion approach to the neuroscience of creative cognition. *Current Opinion in Behavioral Sciences*, 27(November), 100–108. https://doi.org/10.1016/j.cobeha.2018.10.011.

Ouvrard, C., Meillon, C., Dartigues, J. F., Ávila-Funes, J. A., & Amieva, H. (2016). Psychosocioeconomic precariousness, cognitive decline and risk of developing dementia: A 25-year study. *Dementia and geriatric cognitive disorders*, 41(3-4), 137-145.

Palmiero, M. (2015). The effects of age on divergent thinking and creative objects production: a cross-sectional study. *High Ability Studies*, 26(1), 93–104. https://doi.org/10.1080/13598139.2015.1029117.

Palmiero, M., Di Giacomo, D., & Passafiume, D. (2012). Creativity and dementia: A review. *Cognitive Processing*, 13(3), 193–209. https://doi.org/10.1007/s10339-012-0439-y.

Palmiero, M., Di Giacomo, D., & Passafiume, D. (2014). Divergent Thinking and Age-Related Changes. *Creativity Research Journal,* 26(4), 456–460. https://doi.org/10.1080/10400419.2014.961786.

Palmiero, M., Di Giacomo, D., & Passafiume, D. (2016a). Can Creativity Predict Cognitive Reserve? *Journal of Creative Behavior,* 50(1), 7–23. https://doi.org/10.1002/jocb.62.

Palmiero, M., Fusi, G., Crepaldi, M., Borsa, V. M., & Rusconi, M. L. (2022). Divergent thinking and the core executive functions: a state-of-the-art review. *Cognitive Processing.* https://doi.org/10.1007/s10339-022-01091-4.

Palmiero, M., Nori, R., & Piccardi, L. (2017). Verbal and visual divergent thinking in aging. *Experimental Brain Research,* 235(4), 1021–1029. https://doi.org/10.1007/s00221-016-4857-4.

Palmiero, M., Piccardi, L., Nori, R., Palermo, L., Salvi, C., & Guariglia, C. (2016b). Creativity and mental imagery. *Frontiers in psychology,* 7, 1280.

Palmiero, M., Piccardi, L., Nori, R., Palermo, L., Salvi, C., & Guariglia, C. (2019). Creativity: Education and rehabilitation. *Frontiers in Psychology,* 10, 1500.

Pakkenberg, B., Pelvig, D., Marner, L., Bundgaard, M. J., Gundersen, H. J. G., Nyengaard, J. R., & Regeur, L. (2003). Aging and the human neocortex. *Experimental gerontology,* 38(1-2), 95-99.

Parisi, J. M., Stine-Morrow, E. A. L., Noh, S. R., & Morrow, D. G. (2009). Predispositional engagement, activity engagement, and cognition among older adults. *Neuropsychology, Development, and Cognition. Section B, Aging, Neuropsychology and Cognition*, 16(4), 485–504. https://doi.org/10.1080/13825580902866653.

Parmelee, P. A., Katz, I. R., & Lawton, M. P. (1993). Anxiety and its association with depression among institutionalized elderly. *The American Journal of Geriatric Psychiatry,* 1(1), 46-58.

Park, D. C., Lautenschlager, G., Hedden, T., Davidson, N. S., Smith, A. D., & Smith, P. K. (2002). Models of visuospatial and verbal memory across the adult life span. *Psychology and* *aging,* 17(2), 299.

Park, D. C., Polk, T. A., Mikels, J. A., Taylor, S. F., & Marshuetz, C. (2001). Cerebral aging: Integration of brain and behavioral models of cognitive function. *Dialogues in Clinical Neuroscience,* 3, 151–165.

Park, D. C., & Reuter-Lorenz, P. (2009). The adaptive brain: aging and neurocognitive scaffolding. *Annual review of psychology*, 60, 173-196.

Passafiume, D., De Federicis, L. S., Di Giacomo, D., and Carlino, N. (2010). Do performances in verbal and visuospatial tasks change across the life span and in pathological aging? Poster Presented at the XXVIII European Workshop on Cognitive Neuropsychology, Brixen.

Paterniti, S., Verdier-Taillefer, M. H., Dufouil, C., & Alpérovitch, A. (2002). Depressive symptoms and cognitive decline in elderly people: Longitudinal study. *British Journal of Psychiatry,* 181(NOV.), 406–410. https://doi.org/10.1192/bjp.181.5.406.

Pedrabissi, L. & Santinello, M. (1989). *STAI State-Trait Anxiety Inventory Forma Y Manuale.* Organizzazioni Speciali.

Petersen, R. C. (2004). Mild cognitive impairment as a diagnostic entity. *Journal of Internal Medicine,* 256(3), 183–194. https://doi.org/10.1111/j.1365-2796.2004.01388.x.

Petersen, R. C. (2016). Mild cognitive impairment. *Continuum Journal,* 22(April), 404–418. https://doi.org/7.

Petersen, R. C., Doody, R., Kurz, A., Mohs, R. C., Morris, J. C., Rabins, P. V., Ritchie, K., Rossor, M., Thal, L., & Winblad, B. (2001). Current concepts in mild cognitive impairment. *Archives of neurology,* 58(12), 1985-1992.

Petersen, R. C., Smith, G. E., Waring, S. C., Ivnik, R. J., Tangalos, E. G., & Kokmen, E. (1999). Mild cognitive impairment: clinical characterization and outcome. *Archives of neurology, 5*6(3), 303-308.

Petersen, R. C., Stevens, J. C., Ganguli, M., Tangalos, E. G., Cummings, J. L., & DeKosky, S. T. (2007). Appendix C: Practice parameter: Early detection of dementia: Mild cognitive impairment (an evidence-based review): Report of the quality standards subcommittee of the American academy neurology. *CONTINUUM Lifelong Learning in Neurology*, 13(2), 222–231. https://doi.org/10.1212/01.CON.0000267233.84626.08.

Piffer, D. (2012). Can creativity be measured? An attempt to clarify the notion of creativity and general directions for future research. *Thinking Skills and Creativity*, 7(3), 258-264.

Posner, M. I. (1988). Structures and functions of selective attention. In T. Boll & B. Bryant (Eds.), Master lectures in clinical neuropsychology and brain function: Research, measurement, and practice (pp. 171–202). *American Psychological Association.*

Potvin, O., Forget, H., Grenier, S., Préville, M., & Hudon, C. (2011). Anxiety, depression, and 1-year incident cognitive impairment in community-dwelling older adults. *Journal of the American Geriatrics Society*, 59(8), 1421–1428. https://doi.org/10.1111/j.1532-5415.2011.03521.x

Prakash, R. S., Voss, M. W., Erickson, K. I., & Kramer, A. F. (2015). Physical activity and cognitive vitality. *Annual review of psychology*, 66, 769-797.

Qian, J., Wolters, F. J., Beiser, A., Haan, M., Ikram, M. A., Karlawish, J., Langbaum J.B., Neuhaus J.M., Reiman, E.M., Roberts, J.S., Seshadri, S., Tariot, P.N., McCarty Woods, B., Betensky A., & Blacker, D. (2017). APOE-related risk of mild cognitive impairment and dementia for prevention trials: an analysis of four cohorts. *PLoS medicine*, 14(3).

Qiu, C., Karp, A., von Strauss, E., Winblad, B., Fratiglioni, L., & Bellander, T. (2003). Lifetime principal occupation and risk of Alzheimer's disease in the Kungsholmen project. *American journal of industrial medicine*, 43(2), 204-211.

Radel, R., Davranche, K., Fournier, M., & Dietrich, A. (2015). The role of (dis)inhibition in creativity: Decreased inhibition improves idea generation. *Cognition*, 134, 110–120. https://doi.org/10.1016/j.cognition.2014.09.001.

Raffaglio, M. (2011). *Mature people: una risorsa da valorizzare.* Economia & management: la rivista della Scuola di Direzione Aziendale dell'Università L. Bocconi, (1), 49-66.

Raichle, M. E. (2015). The Brain's Default Mode Network. *Annual Review of Neuroscience*, 38(1), 433–447. https://doi.org/10.1146/annurev-neuro-071013-014030.

Raimo, S., Trojano, L., Spitaleri, D., Petretta, V., Grossi, D., & Santangelo, G. (2016). The relationships between apathy and executive dysfunction in multiple sclerosis. *Neuropsychology,* 30(6), 767.

Rankin, K. P. , Liu, A. A. , Howard, S. , Slama, H. , Craig, E. H. , Shuster, K. , & Miller, B. L. (2007). A Case-Controlled Study of Altered Visual Art Production in Alzheimer's and FTLD. *Cognitive Beahavior Neurology*, 20(1), 48–61. https://doi.org/10.1097/WNN.0b013e31803141dd.

Rawlings, D. (1985). Psychoticism, creativity, and dichotic listening. P*ersonality and Individual Differences,* 6, 737–742.

Raz, N., Gunning, F. M., Head, D., Dupuis, J. H., McQuain, J., Briggs, S. D., Loken, W., Thornton, E., & Acker, J. D. (1997). Selective aging of the human cerebral cortex observed in vivo: differential vulnerability of the prefrontal gray matter. *Cerebral cortex,* 7(3), 268-282.

Raz, N., Lindenberger, U., Rodrigue, K. M., Kennedy, K. M., Head, D., Williamson, A., Dahle, C., Gerstorf, D., & Acker, J. D. (2005). Regional brain changes in aging healthy adults: General trends, individual differences and modifiers. *Cerebral Cortex*, 15, 1676–1689.

Reese, H. W., Lee, L. J., Cohen, S. H., & Puckett, J. M. (2001). Effects intellectual variables, ages, and gender on divergent thinking in adulthood. *International Journal of Behavioral Development*, 25(6), 491–500. https://doi.org/10.1080/01650250042000483.

Reiter-Palmon, R., Forthmann, B., & Barbot, B. (2019). Scoring divergent thinking tests: A review and systematic framework. *Psychology of Aesthetics, Creativity, and the Arts,* 13(2), 144–152. https://doi.org/10.1037/aca0000227.

Resnick, S. M., Pham, D. L., Kraut, M. A., Zonderman, A. B., & Davatzikos, C. (2003). Longitudinal magnetic resonance imaging studies of older adults: a shrinking brain. *Journal of*

Neuroscience, 23(8), 3295-3301.

Reuter-Lorenz, P. A., & Cappell, K. A. (2008). Neurocognitive aging and the compensation hypothesis. *Current Directions in Psychological Science,* 17(3), 177–182. https://doi.org/10.1111/j.1467-8721.2008.00570.x.

Reuter-Lorenz, P. A., & Park, D. C. (2014). How does it STAC up? Revisiting the scaffolding theory of aging and cognition. *Neuropsychology review,* 24(3), 355-370.

Richards, M., & Sacker, A. (2003). Lifetime antecedents of cognitive reserve. *Journal of Clinical Experimental Neuropsychology,* 25, 614–624. doi: 10.1076/jcen.25.5.614.14581

Rieck, J. R., Rodrigue, K. M., Boylan, M. A., & Kennedy, K. M. (2017). Age-related reduction of BOLD modulation to cognitive difficulty predicts poorer task accuracy and poorer fluid reasoning ability. *NeuroImage,* 147, 262–271.

Ripple, R. E., & Jaquish, G. A. (1981). Fluency, flexibility, and originality in later adulthood. *Educational Gerontology,* 7(1), 1–10. https://doi.org/10.1080/0360127810070101.

Ritchie, K., & Touchon, J. (2000). Mild cognitive impairment: conceptual basis and current nosological status. *The Lancet*, 355(9199), 225-228.

Roberts R.P. & Addis D.R. (2018). A common mode of processing governing divergent thinking and future imagination. In Jung R.E. & Vartarian O. *The Cambridge Handbook of the Neuroscience of Creativity* (pag. 588- 619). Cambridge University Press.

Roe, C. M., Fagan, A. M., Grant, E. A., Marcus, D. S., Benzinger, T. L., Mintun, M. A., Holtzman, D.M., & Morris, J. C. (2011). Cerebrospinal fluid biomarkers, education, brain volume, and future cognition. *Archives of neurology,* 68(9), 1145-1151.

Rogalski, E., Stebbins, G. T., Barnes, C. A., Murphy, C. M., Stoub, T. R., George, S., Ferrari C., Shah R.C. & deToledo-Morrell, L. (2012). Age-related changes in parahippocampal white matter integrity: a diffusion tensor imaging study. *Neuropsychologia*, 50(8), 1759-1765.

Romaniuk, J. G., & Romaniuk, M. (1981). Creativity across the life span: A measurement perspective. *Human Development,* 24(6), 366–381. https://doi.org/10.1159/000272732.

Rosen, D.S., Kim, Y.E., Mirman, D., & Kounios, J. (2017). All you need to do is ask? The exhortation to be creative improves creative performance more for nonexpert than expert jazz musicians. *Psychology of Aesthetics, Creativity, and the Arts,* 11, 420.

Roskos-Ewoldsen, B., Black, S. R., & Mccown, S. M. (2008). Age-related changes in Creative Thinking. *Journal of Creative Behavior*, 42(1), 33–59. https://doi.org/10.1002/j.2162-6057.2008.tb01079.x.

Rossmann, E., & Fink, A. (2010). Do creative people use shorter associative pathways? *Personality and Individual Differences,* 49(8), 891-895.

Ruggiero, F., Cortese, F., Lavazza, A., D'Urso, G., Di Nuzzo, C., Marceglia, S., Pravettoni, G., Priori, A., & Ferrucci, R. (2019). Do neurodegenerative diseases affect creativity? Divergent thinking in frontotemporal dementia and parkinson's disease. *Creativity Research Journal,* 31(1), 102-109.

Ruggiero, F., Lavazza, A., Vergari, M., Priori, A., & Ferrucci, R. (2018). Transcranial direct current stimulation of the left temporal lobe modulates insight. *Creativity Research Journal*, 30, 143–151. doi:10.1080/ 10400419.2018.1446817.

Runco, M. A. (2004). Everyone has creative potential. In R. J. Sternberg, E. L. Grigorenko, & J. L. Singer (Eds.), Creativity: From potential to realization (p. 21–30). *American Psychological Association.* https://doi.org/10.1037/10692-002.

Runco, M. A. (2008). Commentary: Divergent thinking is not synonymous with creativity. *Psychology of Aesthetics, Creativity, and the Arts,* 2(2), 93–96. https://doi.org/10.1037/1931-3896.2.2.93

Runco, M. A., Abdulla, A. M., Paek, S. H., Al-Jasim, F. A., & Alsuwaidi, H. N. (2017). Which Test of Divergent Thinking Is Best? *Creativity. Theories – Research - Applications,* 3(1), 4–18. https://doi.org/10.1515/ctra-2016-0001.

Runco, M. A., & Acar, S. (2012). Divergent Thinking as an Indicator of Creative Potential. *Creativity Research Journal,* 24(1), 66–75. https://doi.org/10.1080/10400419.2012.652929.

Runco, M. A., & Jaeger, G. J. (2012). The Standard Definition of Creativity. *Creativity Research Journal,* 24(1), 92–96. https://doi.org/10.1080/10400419.2012.650092.

Rusmaully, J., Dugravot, A., Moatti, J. P., Marmot, M. G., Elbaz, A., Kivimaki, M., Sabia, S., & Singh-Manoux, A. (2017). Contribution of cognitive performance and cognitive decline to associations between socioeconomic factors and dementia: A cohort study. *PLoS medicine,* 14(6).

Ruth, J. E., & Birren, J. E. (1985). Creativity in adulthood and old age: Relations to intelligence, sex and mode of testing. *International Journal of Behavioral Development,* 8(1), 99–109. https://doi.org/10.1177/016502548500800107.

Sacco, K. (2012). *Le neuroimmagini.* Idelson-Gnocchi.

Sahlas, D. J. (2003). Dementia with Lewy bodies and the neurobehavioral decline of Mervyn Peake. *Archives of Neurology,* 60, 889–892. doi: 10.1001/archneur.60.6.889

Sala-Llonch, R., Bartrés-Faz, D., & Junqué, C. (2015). Reorganization of brain networks in aging: a review of functional connectivity studies. *Frontiers in psychology,* 6, 663.

Salthouse, T. A. (2010). Selective review of cognitive aging. *Journal of the International Neuropsychological Society,* 16(5), 754–760. https://doi.org/10.1017/S1355617710000706.

Santangelo, G., Siciliano, M., Pedone, R., Vitale, C., Falco, F., Bisogno, R., … Trojano, L. (2015). Normative data for the Montreal Cognitive Assessment in an Italian population sample. *Neurological Sciences,* 36(4), 585–591. https://doi.org/10.1007/s10072-014-1995-y.

Sasser-Coen, J.R. (1993). Qualitative changes in creativity in the second half of life: A life-span developmental perspective. *The Journal of Creative Behavior,* 27, 18–27.

Satz, P. (1993). Brain reserve capacity on symptom onset after brain injury: a formulation and review of evidence for threshold theory. *Neuropsychology,* 7(3), 273.

Sawyer, R. K. (2011). The cognitive neuroscience of creativity: A critical review. *Creativity Research Journal*, 23(2), 137–154. https://doi.org/doi.org/10.1080/10400419.2011.571191.

Scarmeas, N., Levy, G., Tang, M. X., Manly, J., & Stern, Y. (2001). Influence of leisure activity on the incidence of Alzheimer's disease. *Neurology,* 57(12), 2236-2242.

Scarmeas, N., & Stern, Y. (2003). Cognitive reserve and lifestyle. *Journal of clinical and experimental neuropsychology,* 25(5), 625-633.

Schacter, D. L., Addis, D. R., Hassabis, D., Martin, V. C., Spreng, R. N., & Szpunar, K. K. (2012). The future of memory: remembering, imagining, and the brain. *Neuron,* 76(4), 677-694.

Schacter, D. L., Benoit, R. G., & Szpunar, K. K. (2017). Episodic future thinking: Mechanisms and functions. *Current opinion in behavioral sciences,* 17, 41-50.

Schacter, D.L., Norman, K.A., & Koustaal, W. (1998). The cognitive neuroscience of constructive memory [Review, 157 refs.]. *Annual Review of Psychology*, 49, 289–318.

Schaie, K. W. (1996). *Intellectual Development in Adulthood: The Seattle Longitudinal Study.* Cambridge University Press.

Sherman, D. S., Mauser, J., Nuno, M., and Sherzai, D. (2017). The decacy of cognitive intervention in mild cognitive impairment (MCI): a meta-analysis of outcomes on neuropsychological measures. *Neuropsycology Review*, 27, 440–484. doi: 10.1007/s11065-017-9363-3

Serrano, C., Allegri, R. F., Martelli, M., Taragano, F., & Rinalli, P. (2005). Visual art, creativity and dementia. *Vertex* 16, 418–429.

Shi, L., Sun, J., Xia, Y., Ren, Z., Chen, Q., Wei, D., Yang, W. & Qiu, J. (2018). Large-scale brain network connectivity underlying creativity in resting-state and task fMRI: cooperation between default network and frontal-parietal network. *Biological psychology*, 135, 102-111.

Schmidtke, K., & Hermeneit, S. (2008). High rate of conversion to Alzheimer's disease in a cohort of amnestic MCI patients. *International Psychogeriatrics*, 20(1), 96–108. https://doi.org/10.1017/S1041610207005509.

Schneider-Garces, N. J., Gordon, B. A., Brumback-Peltz, C. R., Shin, E., Lee, Y., Sutton, B. P., Maclin, E.L., Gratton, G., & Fabiani, M. (2010). Span, CRUNCH, and beyond: working memory capacity and the aging brain. *Journal of cognitive neuroscience*, 22(4), 655-669.

Schoevers, R. A., Deeg, D. J. H., Van Tilburg, W., & Beekman, A. T. F. (2005). Depression and generalized anxiety disorder: co-occurrence and longitudinal patterns in elderly patients. *The American Journal of Geriatric Psychiatry*, 13(1), 31-39.

Seeley, W. W., Matthews, B. R., Crawford, R. K., Gorno-Tempini, M. L., Foti, D., Mackenzie, I. R., & Miller, B. L. (2008). Unravelling Boléro: Progressive aphasia, transmodal creativity and the right posterior neocortex. *Brain*, 131(1), 39–49. https://doi.org/10.1093/brain/awm270.

Seger, C. A., Desmond, J. E., Glover, G. H., & Gabrieli, J. D. (2000). Functional magnetic resonance imaging evidence for right-hemisphere involvement in processing unusual semantic relationships. *Neuropsychology*, 14, 361–369.

Sharma, S., & Babu, N. (2017). Interplay between Creativity, Executive Function and Working Memory in Middle-Aged and Older Adults. *Creativity Research Journal*, 29(1), 71–77. https://doi.org/10.1080/10400419.2017.1263512.

Sheldon, S., McAndrews, M. P., & Moscovitch, M. (2011). Episodic memory processes mediated by the medial temporal lobes contribute to open-ended problem solving. *Neuropsychologia*, 49(9), 2439–2447. https://doi.org/10.1016/j.neuropsychologia.2011.04.021.

Silvia, P.J., Winterstein, B.P., Willse, J.T., Barona, C.M., Cram, J.T., Hess, K.I., Martiez, J.L., & Richard, C.A. (2008). Assessing creativity with divergent thinking tasks: exploring the reliability and validity of new subjective scoring methods. *Psychology of Aesthetics, Creativity, and the Arts*, 2, 68–85. https://doi.org/10.1037/1931-3896.2.2.68.

Snowdon, D. A. (1997). Aging and Alzheimer's disease: lessons from the Nun Study. *The Gerontologist*, 37(2), 150-156.

Snyder, A. (2009). Explaining and inducing savant skills: Privileged access to lower level, less-processed information. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364(1522), 1399–1405. https://doi.org/10.1098/rstb.2008.0290.

Snyder, H.T., Hammond, J.A., Grohman, M.G., & Katz-Buonincontro, J. (2019). Creativity measurement in undergraduate students from 1984–2013: A systematic review. *Psychology of Aesthetics, Creativity, and the Arts,* 13, 133–143. https://doi.org/10.1037/aca 0000228.

Sperling, R. A., Aisen, P. S., Beckett, L. A., Bennett, D. A., Craft, S., Fagan, A. M., Iwatsubo, T., Jack, C.R., Kaye, J., Montine, T.J., Park, D.C., Reiman, E.M., Rowe, C.C., Siemers, E., Stern, Y., Yaffe, K., Carrillo, M.C., Thies, B., Morrison-Bogorad, M., Wagster, M.V., & Phelps, C. H. (2011). Toward defining the preclinical stages of Alzheimer's disease: Recommendations from the National Institute on Aging-Alzheimer's Association workgroups on diagnostic guidelines for Alzheimer's disease. *Alzheimer's and Dementia*, 7(3), 280–292. https://doi.org/10.1016/j.jalz.2011.03.003.

Spielberger, C.D., Gorsuch, R.L., Lushene, R., Vagg, P.R. & Jacobs, G.A. (1983) *Manual for the State-Trait Anxiety Inventory*. Consulting Psychologists Press.

Spreng, R. N., & Turner, G. R. (2019). The Shifting Architecture of Cognition and Brain Function in Older Adulthood. *Perspectives on Psychological Science,* 14(4), 523–542. https://doi.org/10.1177/1745691619827511.

Spreng, R. N., & Schacter, D. L. (2012). Default network modulation and large-scale network interactivity in healthy young and old adults. *Cerebral Cortex,* 22, 2610–2621.

Sprini, G., & Tomasello, S. (1989). *Torrance tests of creative thinking (Test di pensiero Creativo).* Giunti O. S Organizzazioni Speciali.

Staff, R. T., Murray, A. D., Deary, I. J., and Whalley, L. J. (2004). What provides cerebral reserve?. *Brain* 127, 1191–1199. doi: 10.1093/brain/awh144

Stern, Y. (2002). What is cognitive reserve? Theory and research application of the reserve concept. *Journal of the International Neuropsychological Society*, 8(May), 448–460.

Stern, Y. (2011). Cognitive reserve. *Brain Disorders in Critical Illness: Mechanisms, Diagnosis, and Treatment*, 9781107029(2009), 49–58. https://doi.org/10.1017/CBO9781139248822.009.

Stern, Y., Arenaza-Urquijo, E. M., Bartrés-Faz, D., Belleville, S., Cantilon, M., Chetelat, G., Ewers M., Franzmeier, N., Kempermann, G., Kremen, W.S., Okonkwo, O., Scarmeas, N., Soldan, A., Udeh-Momoh, C., Valenzuela, M., Vemuri, P., & Vuoksimaa, E. (2018). Whitepaper: Defining and investigating cognitive reserve, brain reserve, and brain maintenance. *Alzheimer's & Dementia.*

Stern, Y., Barnes, C. A., Grady, C., Jones, R. N., & Raz, N. (2019). Brain reserve, cognitive reserve, compensation, and maintenance: operationalization, validity, and mechanisms of cognitive resilience. *Neurobiology of aging*, 83, 124-129.

Stern, Y. (2014). Cognitive reserve: Implications for assessment and intervention. *Folia Phoniatrica et Logopaedica*, 65(2), 49–54. https://doi.org/10.1159/000353443

Stern, Y., Gurland, B., Tatemichi, T. K., Tang, M. X., Wilder, D., & Mayeux, R. (1994). Influence of education and occupation on the incidence of Alzheimer's disease. *Jama*, 271(13), 1004-1010.

Sydney, J. M. A., & Adlard, P. A. (2019). Ageing and cognition. *Subcellular Biochemistry*, 91, 107–122. https://doi.org/10.1007/978-981-13-3681-2_5

Takeuchi, H., & Kawashima, R. (2019). Implications of large-sample neuroimaging studies of creativity measured by divergent thinking. *Current Opinion in Behavioral Sciences*, 27, 139-145.

Takeuchi, H., Yasuyuki, T., Hashizume, H., Sass, Y., Nagase, T., Nouchi, R., & Kawashima, R. (2012). The association between resting functional connectivity and creativity. *Cerebral Cortex*, 22, 2921–2929.

Torrance, E. P. (1998). *The Torrance tests of creative thinking norms—technical manual figural (streamlined) forms A & B.* Scholastic Testing Service, Inc.

Tuokko, H. A., & Hultsch, D. F. (2020). *Mild cognitive impairment: International perspectives.* Psychology Press.

Turner, G. R., & Spreng, R. N. (2015). Prefrontal engagement and reduced default network suppression co-occur and are dynamically coupled in older adults: The default-executive coupling hypothesis of aging. *Journal of Cognitive Neuroscience*, 27, 2462–2476.

Vallar G. & Papagno C. (2018). *Manuale di neuropsicologia.* Il mulino.

van Buren, B., Bromberger, B., Potts, D., Miller, B., & Chatterjee, A. (2013). Changes in painting styles of two artists with Alzheimer's disease. *Psychology of Aesthetics, Creativity, and the Arts*, 7, 89–94. doi: 10.1037/a0029332

van der Linde, R.M., Stephan, B.C., Savva, G.M., Dening, T., & Brayne, C. (2012). Systematic reviews on behavioural and psychological symptoms in the older or demented population. *Alzheimer's Research & Therapy* 4, 28 (2012). https://doi.org/10.1186/alzrt131

Vartanian, O., Beatty, E. L., Smith, I., Forbes, S., Rice, E., & Crocker, J. (2018a). Measurement matters: the relationship between methods of scoring the Alternate Uses Task and brain activation. *Current Opinion in Behavioral Sciences*, 27, 109–115. https://doi.org/10.1016/j.cobeha.2018.10.012.

Vartanian, O., Jobidon, M.-E., Bouak, F., Nakashima, A., Smith, I., Lam, Q., & Cheung, B. (2013). Working memory training is associated with lower prefrontal cortex activation in a divergent thinking task. *Neuroscience*, 236, 186–194.

Vartanian, O., Martindale, C., & Kwiatkowski, J. (2007). Creative potential, attention, and speed of information processing. *Personality and Individual Differences*, 43, 1470–1480.

Vartanian, O., Martindale, C., & Matthews, J. (2009). Divergent thinking ability is related to faster relatedness judgments. *Psychology of Aesthetics, Creativity, and the Arts*, 3, 99–103.

http://doi.org/10.1037/a0013106.

Vartanian, O., Wertz, C. J., Flores, R. A., Beatty, E. L., Smith, I., Blackler, K., Lam, Q., Jung, R. E. (2018b). Structural correlates of Openness and Intellect: Implications for the contribution of personality to creativity. *Human Brain Mapping*, 39(7), 2987–2996. https://doi.org/10.1002/hbm.24054.

Verhaeghen, P. (2003). Aging and vocabulary scores: A meta- analysis. *Psychology and Aging*, 18, 332–339.

Volle, E. (2018). Associative and controlled cognition in divergent thinking: Theoretical, experimental, neuroimaging evidence, and new directions. In Jung R.E. & Vartarian O. *The Cambridge Handbook of the Neuroscience of Creativity* (pag. 588- 619). Cambridge University Press.

Wallach, M. A. (1970). Creativity. In P. H. Mussen (Ed.), Manual of child psychology (Vol. 1, pp. 1211–1272). *Wiley and Sons.*

Wallach, M.A., & Kogan, N. (1965). Modes of thinking in young children. Holt, Rinehart and Winston.

Wang M., Hao N., Ku Y., Grabner R. H., & Fink A. (2017). Neural correlates of serial order effect in verbal divergent thinking. *Neuropsychologia* 99 92–100. 10.1016/j.neuropsychologia.2017.03.001.

Wechsler, D. (2008). Wechsler Adult Intelligence Scale–Fourth Edition (WAIS–IV). NCS Pearson.

Wei, D., Yang, J., Li, W., Wang, K., Zhang, Q., & Qiu, J. (2014). Increased resting functional connectivity of the medial prefrontal cortex in creativity by means of cognitive stimulation. *Cortex*, 51, 92–102.

Welling, H. (2007). Four mental operations in creative cognition: The importance of abstraction. *Creativity Research Journal*, 19(2–3), 163–177. https://doi.org/10.1080/10400410701397214.

Williams, F. (1994). TCD. Test della creatività e del pensiero divergente. *Edizioni Erickson.*

World Health Organization. (1993). The ICD-10 classification of mental and behavioural disorders: diagnostic criteria for research(Vol. 2). *World Health Organization.*

Wu, T. Q., Miller, Z. A., Adhimoolam, B., Zackey, D. D., Khan, B. K., Ketelle, R., Rankin, K.P., & Miller, B. L. (2015). Verbal creativity in semantic variant primary progressive aphasia. *Neurocase,* 21(1), 73–78. https://doi.org/10.1080/13554794.2013.860179.

Wu, X., Yang, W., Tong, D., Sun, J., Chen, Q., Wei, D., Zhang, Q., Zhang, M., & Qiu, J. (2015). A meta-analysis of neuroimaging studies on divergent thinking using activation likelihood estimation. *Human Brain Mapping*, 36(7), 2703–2718. https://doi.org/10.1002/hbm.22801.

Yanhong, O., Chandra, M., & Venkatesh, D. (2013). Mild cognitive impairment in adult: A neuropsychological review. *Annals of Indian Academy of Neurology,* 16(3), 310–318. https://doi.org/10.4103/0972-2327.116907.

Yoruk, S., & Runco, M. A. (2014). The neuroscience of divergent thinking. *Journal for Neurocognitive Research*, 56(1), 1–16.

Yuen, G. S., Bhutani, S., Lucas, B. J., Gunning, F. M., AbdelMalak, B., Seirup, J. K., Klimstra S.A. & Alexopoulos, G. S. (2015). Apathy in late-life depression: common, persistent, and disabling. *The American Journal of Geriatric Psychiatry*, 23(5), 488-494.

Zabelina, D. L. (2018). Attention and creativity. In R. E. Jung & O. Vartanian (Eds.), The Cambridge handbook of the neuroscience of creativity (p. 161–179). *Cambridge University Press*. https://doi.org/10.1017/9781316556238.010

Zabelina, D. L., Friedman, N. P., & Andrews-Hanna, J. (2019). Unity and diversity of executive functions in creativity. *Consciousness and Cognition*, 68(September), 47–56. https://doi.org/10.1016/j.concog.2018.12.005.

Zabelina, D. L., & Robinson, M. D. (2010). Creativity as flexible cognitive control. *Psychology of Aesthetics, Creativity, and the Arts,* 4(3), 136–143. https://doi.org/10.1037/a0017379.

Zaidel, D. W. (2014). Creativity, brain, and art: Biological and neurological considerations. *Frontiers in Human Neuroscience*, 8(JUNE), 1–9. https://doi.org/10.3389/fnhum.2014.00389.