What is the contribution of executive functions to communicative-pragmatic skills?

Insights from aging and different types of pragmatic inference

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ABSTRACT (max 250 words)

The role of executive functions in supporting the pragmatics of communication has been extensively examined in clinical populations, but is still under-explored in healthy aging. In this study we addressed the role of executive skills, including inhibition, working memory, and cognitive flexibility, in older adults' communicative-pragmatic abilities. Pragmatics was extensively assessed by measuring the understanding of figurative language, narrative texts, humor, and implicatures. A hierarchical regression analysis using composite scores evidenced a global effect of executive functions on communicative-pragmatic abilities, beyond demographic and theory of mind aspects. More fine-grained analyses showed that working memory was the strongest predictor of all pragmatic tasks. Specifically, comprehending narratives and humor seemed to capitalize primarily upon working memory, whereas figurative language and implicatures relied on working memory and to some extent cognitive flexibility. Conversely, inhibition did not stand out as a robust predictor of pragmatics. We argue that working memory allows for the simultaneous consideration of multiple pieces of information needed for pragmatic inferencing, and that only once working memory has played its role other executive aspects, such as cognitive flexibility and inhibition, might come into play. Overall, this study highlights the diverse role of executive skills in pragmatics in aging, and more generally contributes to shed light on pragmatic competence in older adults.

Keywords: communicative-pragmatic skills; pragmatics; implicature; inhibition; working memory; figurative language; aging; older adults

Introduction

One of the key aspects of quality of life is communication, as communicative activities allow people to maintain successful social relations and to pursue life goals (Agostoni et al., 2021; Snow & Douglas, 2017). From the cognitive point of view, communication is supported by the so-called pragmatic competence (Cummings, 2014). Pragmatic competence is a complex set of skills that can be defined as the ability to understand the interlocutor's needs in a conversation and to comprehend the speaker's meaning beyond the literal sense of words, as in the case of indirect requests, metaphors, humor, and irony (Grice, 1975; Sperber & Wilson, 1995), and more broadly as the ability to use language in different communicative contexts. The last years have witnessed an increased interest and debate on the cognitive underpinnings of pragmatic abilities, especially in clinical populations (Cummings, 2017). Executive functions have been at the center of this debate. Focusing in turn on different communicative-pragmatic domains, studies have suggested that, for instance, the impairment in understanding figurative language in neurological and psychiatric patients might be linked to reduced inhibitory processes (Amanzio et al., 2008; Schettino et al., 2010) and that humor appreciation in patients with damage to the right frontal lobe is related to problems in working memory (Shammi & Stuss, 1999). Other kinds of pragmatics inferences, for instance implicatures, were also linked to working memory and cognitive flexibility resources (De Neys & Schaeken, 2007; Kissine, 2012). Similarly, the comprehension of narrative texts after brain damages was correlated to executive and memory aspects (Ferstl et al., 2005).

In aging, on the one hand successful communication is vital for the maintenance of social relationships and to prevent isolation (Burke & Shafto, 2008); on the other hand the pragmatic abilities supporting communicative activities were shown to exhibit a decline compared to young adults (Messer, 2015). Age-related changes have been reported for a number of specific aspects involving pragmatic processing, including the comprehension of idioms (Grindrod & Raizen, 2019), metaphors (Mashal et al., 2011), and proverbs (Uekermann et al., 2008), as well as the comprehension of expository texts (De Beni et al., 2007) and humor (Uekermann et al., 2006). Also expressive pragmatics seems to show differences in older compared to younger adults, primarily because of off-topic speech verbosity, a phenomenon that is related to the pragmatic ability to provide the appropriate contribution in a conversation (Burke & Shafto, 2008; Ruffman et al., 2010).

Interestingly, these difficulties have often been related to a failure in executive functions, with emphasis on different executive aspects depending on the pragmatic aspect under investigation. As concerns metaphors, Morrone, Declercq, Novella, & Besche (2010) observed that difficulties in metaphor comprehension in aging pair with a decline in inhibitory processes, which causes interferences between metaphorical and literal meanings. In a similar vein, Champagne-Lavau, Monetta, & Moreau (2012) showed that metaphor comprehension is related to the weakening of inhibitory processes in older adults with low educational level, and not to working memory. Concerning another type of figurative language, namely proverbs, older adults showed poorer performance relative to young adults in choosing the correct interpretation from non-relevant options (Uekermann et al., 2008), and their performance was associated with an executive function deficit, specifically in working memory, set shifting, and inhibition. Also for the understanding of humor, studies showed that difficulties of older adults in choosing the funny endings among different options correlated with executive resources (Mak & Carpenter, 2007; Uekermann et al., 2006). Text comprehension too is affected by age, especially in relation to participants' working memory and metacognitive flexibility (De Beni et al., 2007). The working memory decline seems to affect also the retrieval of aspects of discourse that are taken for granted, that is, presupposed (Domaneschi et al., 2018; Domaneschi & Di Paola, 2019).

Other studies have elaborated further on the possible link between decline in pragmatic and general linguistic skills on the one hand and executive functions on the other hand, highlighting in particular the role of inhibitory mechanisms. One prominent model relevant to pragmatic processing is the suppression-inhibition account (Gernsbacher et al., 2001; Gernsbacher & Robertson, 1999), which argues that people understand figurative language by attenuating or suppressing irrelevant (literal) information. So, to understand metaphors such as "Lawyers are sharks" speakers need to suppress irrelevant properties of the encoded concept "shark", such as having fins and living in the ocean. Along these lines, difficulties in figurative understanding in older adults as well as in patients could be linked to poor inhibition of literal meanings (Amanzio et al., 2008; Morrone et al., 2010). Other findings relevant to pragmatics in aging and linked to inhibition concern inference formation during reading stories with unexpected passages. Older adults seem able to form the proper inferences, but, unlike young adults, have difficulty in abandoning the non-relevant ones (Hamm & Hasher, 1992), which was interpreted in the frame of age-related breakdowns in inhibitory mechanisms.

However, the inhibition hypothesis *per se* has proved elusive in accounting for linguistic decline in aging. For instance, pragmatic difficulties in speech production do not always correlate with inhibition difficulties (see Burke & Shafto, 2008 for a review). Moreover, it must be pointed out that executive functions represent a multidimensional construct comprising several cognitive processes (Buczylowska & Petermann, 2018). To account for this complexity, some scholars have argued that both unity and diversity should be given their place in the study of frontal functions (Duncan et al., 1997; Miyake & Friedman, 2012) and some have proposed a hierarchical organization of executive functions where working memory is primary and inhibitory control is derivative (Diamond, 2013). Specifically, inhibition serves the function of keeping irrelevant information out of the working memory space, and in turn working memory and inhibition support cognitive flexibility. In this scenario, it becomes pivotal to assess the relative contribution of the different executive function aspects to the pragmatics of communication in older adults.

When addressing the role of the different executive functions in pragmatics, one should consider also models of pragmatic functioning. For instance, Hyter (2017) argues that pragmatics has an interdependent relationship with executive functions (especially inhibition and mental flexibility) and social cognition (especially Theory of Mind, ToM). Working memory is seen as the glue that makes all these aspects cooperate in the service of social communication. Models of this type are mostly based on clinical populations, where problems in the pragmatics of language were shown to involve both executive functions and ToM abilities (Bambini, Arcara, Bechi, et al., 2016; Bosco, Parola, Sacco, Zettin, & Angeleri, 2017; Carotenuto et al., 2018; Martin & McDonald, 2003). Executive functions, thus, are probably just one of the domains related to pragmatics, with ToM representing another important one. Indeed, theoretical accounts of pragmatics highlighted that, in order to communicate successfully, speakers need to take into account intentions and beliefs of the communicative partners (Bara, 2010; Del Sette et al., 2020; Sperber & Wilson, 2002). Also for aging, studies have highlighted important relationships between pragmatics and ToM skills, focusing for instance on discourse production (Ruffman et al., 2010) and non-literal language such as humor (Bischetti et al., 2019). Therefore, in studying the role of executive functions in older adults' pragmatic profile one should not neglect the contribution of ToM skills.

Rationale of the present study

This study had two main aims. First, we aimed at investigating the predictive role of executive functions in older adults' global pragmatic skills. Importantly, we wanted to investigate the role of executive functions above and beyond the role of ToM, given that the literature has highlighted that mindreading skills contribute to pragmatics (Hyter, 2017; Martin

& McDonald, 2003). For the second aim we adopted a more fine-grained perspective, and we were interested in investigating the predictive role of different executive function components, specifically inhibition, cognitive flexibility, and working memory, in specific pragmatic tasks, namely figurative language, narratives, humor, and implicatures. More globally, with this study we also aimed at contributing to increase our knowledge on the cognitive status of pragmatic skills in aging and to foster the debate on the cognitive underpinnings of pragmatics (e.g., Bosco et al., 2018; Martin & McDonald, 2003) with data from older adults, a population till now poorly investigated.

A number of decisions needed to be taken to shape the study. First, for the assessment of pragmatics, we used the Flemish version of the Assessment of Pragmatic Abilities and Cognitive Substrates (APACS) test, originally developed in Italian (Arcara & Bambini, 2016) and currently undergoing formal validation in Flemish. More specifically, we decided to focus on the comprehension section of APACS, because previous research showed that the strongest effect of age are observed on this part rather than on the production part of the test (Arcara & Bambini, 2016) and because the role of executive functions in pragmatic production is debated (Burke & Shafto, 2008). We complemented the APACS test with an Implicature task, created *ad hoc* on the basis of previous research (Janssens & Schaeken, 2013) and targeting different types of pragmatic inferences, not assessed in APACS.

On the executive function side, we included measurements of working memory, inhibition, and cognitive flexibility. The choice for our specific tests was motivated by guidelines in the literature. Diamond (2013) emphasizes that a good working memory test requires not only holding information in mind, but also processing. Therefore, we opted for the Working Memory Index derived from the Wechsler Adult Intelligence Scale (Wechsler, 1997b). Diamond (2013) also argues that fluency measures can be good tests of cognitive flexibility, since they require the flexibility to think beyond the answers that come up quickly.

There is indeed evidence that switching is an important component of fluency performance and fluency measures have been reported to be sensitive to age-effects (Abwender et al., 2001; Troyer et al., 1997). Hence we used the Word Fluency Test (Mulder et al., 2014). For inhibition, we opted for the Delis–Kaplan Executive Function System Color-Word Interference Test (Delis et al., 2008), which is developed as an improvement of the classic Stroop test (MacLeod, 1991), where prepotent responses have to be inhibited.

From the point of view of the analysis, to address Aim 1 we investigated the relationship between a global executive score and a global pragmatic comprehension score through multiple regressions. Based on the literature on aging that considered specific pragmatic aspects, as well as on evidence from the clinical literature, we hypothesized a relationship between pragmatics and executive functions, beyond the relationship between pragmatics and ToM. For Aim 2, we ran several analyses, including correlations, multiple regressions, and – to account for multicollinearity – a relative weight analysis. Here we hypothesized that different aspects of executive functions would be involved in different pragmatic tasks. Following the literature (e.g., De Beni et al., 2007; Morrone et al., 2010), we expected inhibition to play a major role in figurative language processing, and working memory to be primarily involved in the other pragmatic aspects.

Method

Participants

We enrolled 58 older adults. Exclusion criteria were cognitive deficit and severe hearing problems. As a screening tool for cognitive deficit, we used the Clock Drawing Test (Shulman et al., 1986), which is a short and easy to administer test moderately-to-highly correlated with other screening tests such as the Mini-Mental State Examination (Palsetia et al., 2018; Ricci et al., 2016) and with good diagnostic accuracy for detecting moderate and severe dementia (Ricci et al., 2016; Wolf-Klein et al., 1989). Cognitive deficit was defined as a score < 3 in the test. Severe hearing problems were informally assessed during the oral administration of the APACS test. These two criteria led to the exclusion of one participant and three participants, respectively. The remaining 54 participants (15 male and 39 female) were between 65 and 94 years old (*M* = 82, SD = 7.59). Based on the Belgian school system, the education level varied from lower secondary education (i.e., 9 years or less of education; 12 participants), to higher secondary education (i.e., 12 years of education; 16 participants) and higher education (i.e., more than 12 years of education; 26 participants). Twelve were still living in their own house, 42 were living in a residential care home (see Table 1 for more details).

This research was reviewed and approved by the ethical review board SMEC of the University of Leuven. Informed consent was obtained from all participants.

INSERT TABLE 1

Procedure

The participants were tested individually in their own home or in their room in the residential care home. We tested them in two sessions of approximately one hour each. There was never more than two weeks between the first and second taking-in time. At the start of the testing, the participant was asked to read and approve an informed consent. In the first session we assessed participants' pragmatic abilities (through the APACS and the Implicatures tests); in the second session we assessed participants' cognitive and ToM skills.

Tests

Pragmatics.

Pragmatics was evaluated with two tools: the Flemish version of the Assessment of Pragmatics Abilities and Cognitive Substrates (APACS) test (Arcara & Bambini, 2016) and with the Implicatures task.

APACS test, Comprehension section (APACS Comp).

The APACS test is a tool to assess expressive and receptive pragmatic skills that was developed and validated for the Italian speaking population (Arcara & Bambini, 2016) and used in various studies on pathological and healthy aging (e.g., Bambini, Arcara, Martinelli, et al., 2016; Bischetti et al., 2019; Montemurro et al., 2019). The APACS test was translated from Italian into Flemish based on a committee approach[1] and the Flemish version was preliminarily validated on a norm group in another ongoing study. Here we used only the APACS Comprehension (henceforth APACS Comp) section, which includes four tasks: [2]

i) Narratives. Six stories with increasing length were read aloud by the researcher. After each story, the participant was asked one question about the topic of the story, followed by either two or four yes/no questions about explicit and implicit aspects of the story, and finally, by two questions evaluating the comprehension of the figurative expressions embedded in the

[1] The committee approach is based on the collaborative work of bilingual individuals; this approach is particularly indicated for the translation of colloquial or idiomatic language where the literal translation might fail in capturing the intended meaning and when the local contexts must be taken into account (Douglas & Craig, 2007), as in the case of a test assessing verbal pragmatics. In this case, two bilingual individuals worked on the translation of the APACS from Italian to Flemish.

[2] Although the Flemish version of the APACS test is not formally validated yet, we can offer already some evidence with respect to its validity, based on the preliminary data from a normgroup of N = 90 (50 female and 40 male participants) with a mean age of 42.60 years. Focusing on the Comprehension section of the test, the mean values of the Flemish preliminary norm-group (see Table 2A in the main text) are in line with the normative data collected for the original Italian version (Narratives = 53.40, Figurative Language 1 = 14.77, Figurative Language 2 = 27.69, Humor = 6.51). Moreover, a factor analysis (maximum likelihood - varimax) on the preliminary sample revealed two factors, exactly like in the original Arcara and Bambini (2016) study. As in the latter study, one factor seems to reflect the capacity to interpret figurative meanings, considering that Narratives, Figurative Language 1 and 2 score high on this first factor, whereas the second factor correlates highly with Humor.

texts. The score for each story could range from 0 to 8 (for the first two stories) or from 0 to 10 (for the other four stories).

ii) Figurative Language 1. Participants were presented with a multiple-choice task testing the comprehension of 15 figurative language items (five idioms, five novel metaphors, and five proverbs). Each item was scored either 1 or 0 depending on accuracy.

iii) Humor. Participants were presented with a multiple-choice task and were requested to select the funny ending for 7 short stories. Each item was scored either 1 or 0 depending on accuracy.

iv) Figurative Language 2. This task was similar to Figurative Language 1 in that it evaluated the comprehension of 15 figurative language items (five idioms, five metaphors, and five proverbs), only this time with a verbal explanation response format. Each item was scored 2, 1 or 0 depending on accuracy (correct, partially correct, wrong).

In line with the instructions of the APACS test, the four tasks were administered orally, with the support of a booklet for Figurative Language 1 and Humor.

Implicature assessment.

The Implicatures task was developed *ad hoc* following previous works (Janssens & Schaeken, 2013). Because it focused on some types of pragmatic inference that are not included in the APACS, the Implicatures task was therefore very suitable as a further measurement of pragmatic thinking in addition to the APACS. Participants received 19 experimental stories (and four control stories), and had to explain the implied meaning. These stories were partly adapted from previous experimental work (Janssens & Schaeken, 2013), partly created de novo based on textbook examples. Some stories were short and contained implicature-eliciting terms, like "some", "but", and "even" (e.g., *"The milk is sour but Magda is very thirsty." Do you expect Magda will drink the milk?*); other stories were longer and the context had to be used to infer the intended meaning of the sentences (e.g., *Fiona tells her friend: "I'm coming* *to the reception tonight. Do you think July comes too?" Her friend answers: "Her car broke down." Do you think July comes to the party?*). Every correct answer was scored with 1, every incorrect answer with 0. An answer was considered as correct if it was in line with the implicature (e.g., in an indirect distancing contrast sentence with "but", the second phrase has more weight, consequently in the first example above the conclusion follows that Magda will drink the milk). Conversely, answers were considered as incorrect when the participant did not derive the implicit meaning (for instance, in the second example above, an answer simply saying that July will go to the party). A second rater independently coded all the responses, achieving a Cohen's *k* of .86, which indicates an almost perfect inter-rater reliability.

Administration modality followed the same procedure as in the APACS tasks (oral presentation of the items by the examiner accompanied by written presentation in a booklet).

Executive Functions.

Working Memory.

We used the Working Memory Index from the Dutch version (Wechsler, 1997a) of the Wechsler Adult Intelligence Scale – Third Edition (WAIS-III; Wechsler, 1997b). This Index is based on three subtests: Digit Span, Letter-Number Sequencing, and Arithmetic. For the subtest Digit Span, a correct answer was scored as 1, whereas a wrong or incomplete answer was scored as 0. For the subtest Letter-Number Sequencing, 1 point was given if the answer was correct and 0 was given when the answer was wrong. For the subtest Arithmetic, 1 point was given if the answer was correct and 0 was given when the answer was wrong or outside the time limit. The total score for the Working Memory Index was calculated as the sum of the scores in the single subtests.

Inhibition.

The Dutch translation of the Delis–Kaplan Executive Function System (D-KEFS) Color-Word Interference Test (CWIT, Delis et al., 2008) was used. We presented three conditions: naming colors, reading words, and inhibition. In the first condition (naming colors), the participant was administered a sheet with red, blue, and green boxes and was asked to name the colors as quickly as possible. In the second condition (reading words), the participant received a sheet with words printed in black ink ("red", "blue", and "green") and was asked to read the words aloud as soon as possible. In the third condition (inhibition) the participant was administered a sheet with words printed in incongruent ink color (for example the word "red" printed in green ink). The participant had to state as soon as possible the color of the ink in which the letters were printed and not read the word. For this, the more automatic response, that is, the word reading, needed to be suppressed. The number of seconds required to complete the third condition minus the average of the number of seconds required to complete the first and the second conditions (i.e., the so-called "interference score") was taken as a measure of inhibitory capacity. The smaller this number, the better the inhibitory capacity.

Cognitive Flexibility.

We used the Word Fluency Test (WFT; Mulder, Dekker, & Dekker, 2014), which is a semantic word fluency task where the participant has to come up with as many words as possible for a given category within 60 seconds. We used the category "animals" and the category "professions". Extinct or non-existent animals and professions were considered as wrong answers and repetitions of answers within a category or across categories were considered as perseverative answers. Every correct answer was scored with 1 and every error or perseverative answer was scored with 0. The total score was calculated as the sum of the correct answers.

Theory of Mind.

The Reading the Mind in the Eyes Test (Baron-Cohen et al., 2001) was used. This test consists of 36 black-and-white photos, which only show the area around the eyes of the face. For each photo, the participant had to indicate the emotional state of each person. The participant was given the choice of four answer alternatives (for example, “playful”, “comforting”, “irritated”, “bored”). Each item was scored with 0 or 1. We opted for this test because it can be applied conveniently in the population of older adults (Moran, 2013). Compared to other ToM tasks (e.g., the *Faux-pas*), the Reading the Mind in the Eyes Test is more closely related to the detection of emotions in daily life. Moreover, this task depends less on executive skills compared to some other ToM tasks. These two characteristics make the task ideal for use with older adults (Mahy et al., 2014) and for our specific purpose, that is, investigating the role of executive functions in pragmatics *controlling* for ToM.

Data preparation

For the variable education level, two dummy variables were created: "lower secondary education" and "higher secondary education" with "higher education" as reference category. For gender, a dummy variable was used whereby "man" was given the code 0 and "woman" the code 1. We obtained an APACS Comp composite score by transforming the original tasks’ scores obtained in the four APACS Comp tasks in proportions, and averaging these proportions (see Arcara & Bambini, 2016). Moreover, we obtained a “figurative language combined score” by calculating the average of the proportions of the tasks Figurative Language 1 and Figurative Language 2. Finally, we obtained a total “executive functioning score” by calculating the average of the Z scores obtained in Working Memory, Inhibition, and Cognitive Flexibility.

Data analysis

Before addressing the main aims of the study, we provided the descriptive statistics concerning the performance in the assessment tests (APACS Com, Implicature, EF and ToM) and we performed preliminary analyses on the scores in the pragmatic tests (median, skewness, kurtosis, Q1 and Q3), in order to enable a better grip on the data and to make the comparison with the data obtained with the original Italian APACS test (Arcara & Bambini, 2016) easier. Moreover, to explore the effect of age, we also tested the difference in performance between the current sample of older adults and the norm group of the Flemish APACS by means of non-parametric Mann-Whitney U tests. Finally, we compared the pragmatic performance of the "home" and the "residential care home" group, to control for potential systematic differences.

Then, in order to investigate the relationship between pragmatics, Executive Functions (EF), and ToM (Aim 1), we first ran Pearson correlations and partial correlations between the different variables. Then, we tested the potential contribution of demographic variables, ToM, and EF for both the APACS and the Implicatures assessment by means of a hierarchic multiple regression analysis. Because our focus was on EF, the demographic variables were introduced in the first step, ToM in the second, and the EF in the third step. In other words, the hierarchic multiple regression aimed at measuring the effect of EF on top of demographic and ToM skills.

In order to obtain more detailed information on the role of EF on our different pragmatic tasks (Aim 2), we ran several analyses. Preliminarily, we explored Pearson correlations between the total EF score and the different pragmatic tasks. Then, Pearson correlations between the different EF were calculated. Next, we calculated bivariate correlations between the different pragmatic tasks (Narratives, figurative language combined, Humor from the APACS and Implicatures) and the different EF (Working Memory, Inhibition, and Cognitive Flexibility). Furthermore, we ran a multiple regression analysis with the different EF as predictors and the different pragmatic tasks as outcome.

However, a multiple regression analysis takes insufficiently into account the high intercorrelations between the predictors. Consequently, it is only possible to infer which domain makes the largest unique contribution, but not the largest total contribution (Barni, 2015). To account for multicollinearity, we additionally performed a relative weight analysis of the EF predictors for every aspect of pragmatic functioning (Johnson, 2000). The relative weight analysis was shown to give extremely good estimates of the relative importance of predictor variables when those predictor variables are correlated (LeBreton et al., 2004). More specifically, while in a multiple regression analysis multicollinearity makes the partitioning of variance among multiple correlated predictors difficult, the relative weight analysis enables a more accurate partitioning of variance among correlated predictors (Johnson, 2000). This relative weight analysis was proposed by Johnson (2000) as a heuristic method for estimating the proportionate contribution that each predictor in a multiple regression makes to R^2, taking into account both its unique contribution and its contribution resulting from the combination with other variables. This contribution is also commonly referred to as "relative importance". The method is applied here in the intended context, that is, when there is no inherent ordering of the variables.

Additionally, we performed three extra exploratory analyses with respect to the Age variable. In Analysis 1 we correlated (with Pearson correlations) Age with the different individual EF and APACS tasks, thus complementing the correlations between all the main measures employed in the study. In Analysis 2, we took into account the uneven distribution of the variable Age in our sample and we dived the participants into five bins with increasing age and of about the same number of participants; then, age as an ordinal variable was correlated (with Spearman's rank order correlations) with all pragmatic and EF tasks. In Analysis 3 we explored the Pearson correlations between pragmatic tasks and EF tasks separately for each age bin. Results of these analyses are briefly commented in the main text and presented in more details in the Supplementary Material.

In all the above analyses, if applicable, the significance level was set at $\alpha = .05$.

Data Availability Statement

Results

Preliminary analysis: performance in the assessment tests

Table 2A presents mean and standard deviation obtained by the sample of older adults in the pragmatic assessment (APACS Comp and Implicatures), as well as the median, the skewness, the kurtosis, Q1 and Q3. Values revealed a left-tailed distribution which is however still in the minus 1-plus 1 range and less pronounced than the distribution reported in the validation study of the Italian original APACS test (Arcara & Bambini, 2016).

INSERT TABLE 2A

The four APACS Comp tasks correlated with each other: Narratives with Figurative Language 1 (r = .541, p < .001), with Figurative Language 2 (r = .653, p < .001), and with Humor (r = .538, p < .001); Figurative Language 1 with Figurative Language 2 (r = .399, p = .003), and with Humor (r = .470, p < .001); and Figurative Language 2 with Humor (r = .499, p < .001). These correlations are in line with the correlations reported in the validation study of the original Italian APACS (Arcara & Bambini, 2016), where correlations of .40 and higher were also observed.

Table 2A also reports the performance of a normgroup on the Flemish version of the APACS, collected in an ongoing normative study, including 90 healthy participants (50 female and 40 male participants) with a mean age of 42,60 years.

Concerning the role of age, when we compared the group of older adults with the normgroup tested with the Flemish APACS, the non-parametric Mann-Whitney U tests showed that for all subtests and the composite score, the normgroup performed better than the older adults (Narratives: Mann-Whitney $U = 4286.5$, $p < .001$; Figurative Language 1: Mann-Whitney $U = 3540.5$, $p < .001$; Humor: Mann-Whitney $U = 2933.5$, $p = .029$; Figurative Language 2: Mann-Whitney $U = 3712$, $p < .001$; APACS Comp: Mann-Whitney $U = 3844$, $p < .001$).

Concerning the comparison between the ‘home’ and ‘residential care home’ group on APACS Comp, Implicatures, and the three tasks of the APACS Comp, the outcomes of these tests were not significant, indicating that the pragmatic functioning of the participants who were living at home and those living in a residential care home was comparable (Narratives: 47.75 vs. 43.72, $U = 164.5$, n.s.; Figurative Language: 0.84 vs. 0.81, $U = 209$, n.s.; Humor: 5.58 vs. 5.39, $U = 228.5$, n.s.; APACS Comp: 82.91 vs. 79.11, $U = 200$, n.s.; Implicatures: 14.83 vs. 13.75, $U = 211$, n.s.).

Finally, Table 2B displays the scores observed in ToM and EF assessment tasks.

INSERT TABLE 2B*

The role of demographic variables, ToM, and EF on APACS Comp and Implicatures

Table 3 presents the Pearson correlations between the different variables. There is a significant correlation between EF and APACS Comp (r (52) = .68, $p < .001$) and between EF and Implicatures (r (52) = .62, $p < .001$). Also, ToM significantly correlated with both APACS Comp (r (52) = .45, $p < .001$) and Implicature (r (52) = .41, $p < .01$). ToM and EF also correlated significantly with each other (r (52) = .36, $p < .01$). Finally, we also observed a significant correlation between the two pragmatic tasks (APACS Comp and Implicatures) (r (52) = .80, $p < .001$).

Age correlated with all measures, that is, EF, APACS Comp, Implicatures, and ToM. Extra analyses considering Age on the one hand and the individual EF and pragmatic tasks on the other hand confirmed the pattern of diffuse correlations (see Supplementary Material, Analysis 1). When Age was considered as an ordinal variable with 5 equal age-bins, however, significant correlations were observed only with some EF tasks, and not with the pragmatic tasks (see Supplementary Material, Analysis 2).

INSERT TABLE 3

Subsequently, a partial correlation was calculated between EF and APACS Comp and between EF and Implicatures, partialling out the effect of ToM on these variables. The results showed that both the relationship between EF and APACS Comp and the relationship between EF and Implicatures were still significant (r (51) = .62, $p < .001$ and r (51) = .55, $p < .001$, respectively).

With a hierarchical multiple regression analysis it was investigated whether APACS Comp and Implicatures can be predicted by EF after controlling for Age, Gender, Level of Education and ToM. The demographic variables Age, Gender, and Educational Level were included in the first step of the hierarchical regression procedure. In Step 2 the additional contribution of ToM was investigated and in Step 3 the influence of EF. Results are displayed in Table 4 and described below first for APACS Comp and then for Implicatures.

INSERT TABLE 4

APACS Comp. The hierarchical multiple regression analysis showed that in Step 1, the model with only the demographic variables was significant (F (4, 49) = 5.91, $p < .001$). Age, Gender and Educational Level together accounted for 32.53% of the variance in APACS Comp. Only Educational Level was a significant predictor of APACS Comp, while Age and Gender were not significant. People who have completed higher education score higher on APACS Comp compared to people with only lower secondary education ($\beta = -0.46$, $t\,(49) = -3.48$, $p = .001$) and to people with only higher secondary education ($\beta = -0.29$, $t\,(49) = -2.25$, $p < .05$). The addition of the variable ToM in the prediction of APACS Comp significantly increased the explained variance by 11.06% ($F\,(1, 48) = 9.41$, $p = .004$). The higher the person's ToM score, the higher the score on APACS Comp ($\beta = 0.38$, $t\,(48) = 3.07$, $p = .004$). The dummy variable lower secondary education remains significant in the prediction of APACS Comp in comparison with higher education ($\beta = -0.37$, $t\,(48) = -3.00$, $p = .004$). Finally, with the addition of the variable EF, the proportion of explained variance in APACS Comp significantly increased by 11.71% ($F\,(1, 47) = 12.31$, $p = .001$). When the score on EF increases, the score on APACS Comp also increases ($\beta = 0.48$, $t\,(47) = 3.51$, $p = .001$). ToM remains a significant predictor of APACS Comp in this third model ($\beta = 0.29$, $t\,(47) = 2.56$, $p = .01$). After adding all variables, 55.30% of the variance was explained in APACS Comp.

Implicatures. The hierarchical multiple regression analysis showed that the model with only the demographic variables was significant ($F\,(4, 49) = 5.94$, $p < .001$). Age, Gender, and Education Level together explained 32.66% of the variance. As was the case for APACS Comp, only Education Level was a significant predictor, while Age and Gender were not significant. People who have completed higher education score higher on Implicatures compared to people with only lower secondary education ($\beta = -0.55$, $t\,(49) = -4.15$, $p < .001$) and to people with only higher secondary education ($\beta = -0.29$, $t\,(49) = -2.23$, $p < .05$). The addition of ToM significantly increased the proportion of explained variance by 8.38% ($F\,(1, 48) = 6.82$, $p = .01$). When the score on ToM is higher, the score on Implicatures will also be higher (β = 0.33, t (48) = 2.61, p = .01). The dummy variable lower secondary education remains significant in the prediction of Implicatures compared to higher education (β = -0.47, t (48) = -3.70, $p < .001$). With the addition of EF, the proportion of explained variance increased significantly by 9.15% (F (1, 47) = 8.63, p = .005). When the score on EF increases, so does the score on Implicatures (β = 0.43, t (47) = 2.94, p = .005). The dummy variable lower secondary education and ToM remain significant predictors for understanding implicatures in this third model (respectively β = -0.30, t (47) = -2.26, $p < .05$ and β = 0.25, t (47) = 2.10, $p < .05$). After adding all variables, the proportion of explained variance in Implicatures was 50.19%.

The role of each of the domains of EF for the different aspects of APACS Comp and Implicatures

The total EF score correlated significantly with all pragmatic tasks (all ps < .001), namely Narratives (.54), Figurative Language (.69), Humor (.53), and Implicatures (.63).

When considering the Pearson correlations between the different EF, all correlations were significant, ranging from moderate to strong (see Table 5).

INSERT TABLE 5

In what follows, for every aspect of pragmatic functioning, an overview is given of the results of the Pearson correlations, multiple regression analysis, and the relative weight analysis (see Table 6 for results of the three analyses, and Figure 1 for a graphical representation of the results of the relative weight analysis).

INSERT TABLE 6

IINSERT FIGURE 1

Narratives. Narratives correlated significantly with Working Memory (.62) and Cognitive Flexibility (.46), but not with Inhibition (.22). The EF together explained a significant proportion of variance in Narratives (F (3.50) = 11.15, p < .001, R^2 = .40). However, only Working Memory was a significant predictor (β = .54, t (50) = 3.97, p < .001). The relative weight analysis, on the other hand, shows that both Working Memory and Cognitive Flexibility are significant predictors: 68.62% of the explained variance can be attributed to Working Memory and 27.16% to Cognitive Flexibility.

Figurative Language. Figurative Language correlated significantly with all three EF: Working Memory (.62), Inhibition (.36) and Cognitive Flexibility (.65). The EF together explained a significant proportion of variance in figurative language use (F (3.50) = 17.73, p < .001, R^2 = .52). Both Working Memory (β = .37, t (50) = 3.05, p = .004) and Cognitive Flexibility (β = .43, t (50) = 3.38, p = .001) were significant predictors. This corresponds to the results of the relative weight analysis: 43.15% of the explained variance can be attributed to Working Memory and 47.62% to Cognitive Flexibility.

Humor. Humor correlated significantly with all three EF: Working Memory (.61), Inhibition (.27) and Cognitive Flexibility (.65). The EF together explained a significant proportion of variance (F (3.50) = 9.95, p < .001, R^2 = .37). However, only Working Memory was a significant predictor (β = .57, t (50) = 4.15, p < .001). This corresponds to the results of the relative weight analysis: 75.23% of the explained variance in Humor can be attributed to Working Memory.

Implicatures. Implicatures correlated significantly with all three EF: Working Memory (.64), Inhibition (.27) and Cognitive Flexibility (.59). The EF together explained a significant proportion of variance (*F* (3.50) = 15.97, $p < .001$, $R^2 = .49$). Both Working Memory ($\beta = .47$, t (50) = 3.75, p < .001) and Cognitive Flexibility ($\beta = .36$, *t* (50) = 2.73, $p = .009$) were significant predictors. This corresponds to the results of the relative weight analysis: 54.59% of the explained variance can be attributed to Working Memory and 40.38% to Cognitive Flexibility.

Finally, the extra analyses exploring age-related changes in the relationship between pragmatic tasks and EF tasks revealed several significant Pearson correlations between Working Memory and pragmatic tasks across all age bins and a similar pattern – although less widespread – for Cognitive Flexibility, whereas the role of Inhibition was less pronounced (see Supplementary Material, Analysis 3).

Discussion

The first aim of this work was to investigate the relationship between receptive pragmatic abilities and executive functions in older adults, on top of other skills such as ToM. The second aim was to zoom in on the interplay between pragmatics and executive functions, to focus on specific pragmatic tasks and different executive function aspects. To pursue these aims, we combined an extensive assessment of pragmatic skills, considering the main communicative tasks used in the literature (figurative language, humor, and narrative comprehension as assessed in the Flemish version of the APACS test, as well as implicatures as assessed in an *ad hoc* test), with the assessment of three crucial components of executive functions, namely working memory, inhibition, and cognitive flexibility. The analyses were structured in order to meet the two aims, the first more general and the second more specific.

Before considering the main findings of the paper, we will discuss the outcome of some preliminary analyses that were performed in order to enable a better grip of the data and to strengthen the validity of the pragmatic assessment tools used in the study. First, although the distribution of the data obtained in the different pragmatic tasks was left-tailed, the rather low range of the skewness scores (actually less pronounced than in the Italian normative study of the APACS test in Arcara and Bambini, 2016) and the spread in the data indicate that performance was not at ceiling. Similar to the original Italian study, the four APACS Comp tasks correlated with each other. This confirms that the four tasks measure the same larger domain of receptive pragmatic skills, as part of the APACS Comp composite score. However, it is important to stress that follow-up research with the APACS test has shown that, within the pragmatic comprehension domain, clinical populations might exhibit different profiles, with greater impairment in some receptive pragmatic tasks than others. For instance, adults with dyslexia performed poorly in the verbal explanation of figurative language expressions as assessed in Figurative Language 2 task, while their scores in the other pragmatic tasks was in the normal range (Cappelli et al., 2018); conversely, individuals with Parkinson's Disease have greater difficulties with stories as evaluated in the Narrative task, while performing as the control group in figurative language tasks (Montemurro et al., 2019). Overall, these data are indicative of individual differences in our samples and of a certain degree of differentiation across pragmatic tasks.

Considering now the results regarding the first aim of the study, that is, the role of executive functions on the general pragmatic competence in aging, the correlations and the hierarchical multiple regressions showed that pragmatic skills (as assed both with APACS Comp and Implicatures) were predicted by the total executive functions score, also when controlling for demographic factors and ToM. This finding is important for at least two reasons. First, it contributes to the understanding of the cognitive underpinnings of pragmatics in aging, highlighting the role of executive functions – on top of ToM skills. There is a large literature devoted to the role of executive functions and ToM in the pragmatic skills of clinical populations (Cummings, 2017; Martin & McDonald, 2003; Parola, Berardinelli, & Bosco, 2018), debating on which of the two (executive or ToM aspects) might be more prominent (Champagne-Lavau & Stip, 2010). Our data speak in favor of the idea that executive functions do play a role, irrespective of the role played by ToM skills. Although we are not in the position of claiming which one is primary, our findings are indicative of a strong alliance between cognitive and socio-cognitive aspects in supporting pragmatics. Second, and more generally, our results contribute to the debate about the status of pragmatics as a cognitive domain. In particular, the findings of the prominent role of executive functions pose problems for those accounts that tend to equate pragmatic abilities with ToM skills (for reviews, see Bosco et al., 2018; Del Sette et al., 2020). Conversely, our findings support models where pragmatics has interdependent relationships with multiple domains, including both executive and ToM aspects (Bambini, Arcara, Bechi, et al., 2016; Bosco et al., 2017; Hyter, 2017).

Now we will address the second aim, zooming in on the different pragmatic aspects and the different executive function aspects, namely working memory (as assessed with the Working Memory Index derived from the WAIS-III), inhibition (as assessed with the Color-Word Interference Test), and cognitive flexibility (as assessed with the Word Fluency Test). We will discuss the role of the different executive functions for each pragmatic domain separately. Then, we will move to more general considerations on executive functions in pragmatics and on the specific role of inhibition.

For the *Narratives* task, which assesses the ability to understand the main aspects of a text and to infer implicit information from it, the series of analyses evidenced a role of working memory and, to a smaller extent, cognitive flexibility, while the role of inhibition was negligible. This is consistent with our hypothesis and is largely compatible with previous evidence on aging and text comprehension that indicates a major role of working memory in predicting text comprehension abilities (De Beni et al., 2007). It has been argued that working memory resources allow for the maintenance of information in memory while the text unfolds, thus supporting the construction of a coherent representation of the text (Kintsch & van Dijk, 1978).

It is important to acknowledge that the prominent working memory effect observed for the Narratives task might be at least partly due to the oral administration modality of this task. Indeed, studies that have examined narrative comprehension by manipulating the modality have found that older adults perform better in comprehension questions when they can review the passages, a finding that is explained in terms of reduced working memory costs (Borella et al., 2007). However, the involvement of working memory seems to characterize narrative comprehension in aging in general, being strictly involved in tracking events and characters (Borella, Ghisletta, & de Ribaupierre, 2011; Martin et al., 2018; Noh & Stine-Morrow, 2009). Therefore, we believe that the working memory effect that we observed also reflects the genuine involvement of cognitive resources in the process of making sense of a text. Moreover, the APACS Narratives task includes not only comprehension questions about explicit contents, but also questions about implicit aspects of the story (for instance, in a story about a robbery, the participant has to infer that it happened in a jewelry, given that stolen jewels and the noise of a broken window are mentioned in the narrative), as well as questions about figurative expressions. Answering questions about implicit and non-literal aspects capitalizes on the ability to make pragmatic inferences and thus to consider multiple perspectives from the text in order to derive an answer. This might explain the involvement of cognitive flexibility, since correct answers require not only to take into account the literal perspective but also to make a shift in perspective and to consider alternative and more elaborated interpretations. Consistent with this explanation, a previous study using the APACS test in patients with schizophrenia evidenced, for the Narratives Task, verbal fluency (the same test used here to measure cognitive flexibility) and verbal memory as the strongest predictors (Bosia et al., 2016).

For the *Figurative Language* measure, the pattern of results was more diverse than for Narratives. Consistent with our prediction, which was based on the Inhibition account of figurative language (Gernsbacher & Robertson, 1999; Morrone et al., 2010), the correlational analysis evidenced a relationship between figurative language understanding and inhibition scores. However, this correlation was only moderate, and the role of inhibition did not emerge in the further analyses (multiple regressions and relative weight analysis). Conversely, all analyses supported a comparable weight of both working memory and cognitive flexibility. Our findings, thus, seem to be in contrast with the idea of a suppression deficit (Gernsbacher et al., 2001) proposed to explain difficulties in figurative language in clinical conditions (Cacciari et al., 2006; Papagno, 2001) and in aging (Morrone et al., 2010; Uekermann et al., 2008). Rather, our findings seem more in line with a series of behavioral studies on typical young adults that have evidenced the important role of working memory in metaphor comprehension (Chiappe & Chiappe, 2007; Columbus et al., 2015).

A possible reconciliation of the idea of the importance of inhibition with the evidence of the role of working memory and cognitive flexibility can be found by looking at the processing of figurative language more closely. In figurative language comprehension, aspects of the literal meanings are activated to some extent (Weiland et al., 2014), and the figurative meaning is often accessed not directly, but rather through a process that considers alternative meaning options in order of accessibility, depending on the contextual support (Wilson & Carston, 2007). Hence, in order to derive a figurative interpretation, one needs to maintain multiple meanings in the memory space and to show the flexibility not only to attend to the literal ones, but also to consider, compare and weigh alternative meanings before suppressing the irrelevant ones. This makes the working memory and cognitive flexibility resources essential and somehow primary, whereas inhibition appears as derivative. In other words, we argue that when working memory (and cognitive flexibility) fails, then there might be no literal representation to inhibit.

The analyses performed on the *Humor* comprehension task also pointed to a major role of working memory. A weak association between humor comprehension and inhibition emerged in the correlational analysis, but was negligible in the further analyses. Similarly, cognitive flexibility significantly correlated with Humor but was not a significant predictor and its weight was marginal. The role of executive functions in humor understanding has been often evoked across behavioral studies and studies measuring the brain response. The link between the two domains is accounted for in light of the widely-accepted dual-step humor processing model, which points to a sequential process unfolding through incongruity detection and resolution (Canal et al., 2019; Suls, 1972). In order to solve a joke, hearers/readers have to detect an incongruity that violates the current expectations, and then to solve it, by finding a scenario that reconciles the clash in a funny way. This process crucially involves following a story by tracking its characters and events and handling multiple scenarios in memory, as well as the flexible shift between them in order to find the scenario that solves the joke. Consistent with this idea, humor comprehension engages prefrontal and medial cortices devoted to executive control (Vrticka et al., 2013). Humor tasks such as the one included in APACS, where participants are required to select the funny ending among three options, might further increase the executive load. Indeed, studies on aging have highlighted that poor humor performance in aging is related to executive control (Mak & Carpenter, 2007; Uekermann et al., 2006). Our study is consistent with this literature, but it adds something novel, because it contributes to zoom in on what aspects of executive functions might be especially involved in the aging population, something that was left vague in previous studies. Here we argued that inhibition and cognitive flexibility might have some role in the elaboration of the alternative scenarios evoked by humorous stimuli, but their role is derivative to the one of working memory. Similar to what we argued for figurative language, working memory is key in humor to track the story context and to provide the multiple scenarios upon which further operations apply, including flexibly pondering each of these scenarios and inhibiting the irrelevant ones.

We complemented the assessment of pragmatic skills with the *Implicatures* task, which targeted other types of implicatures not included in the APACS Comp. While the APACS test included different types of pragmatic inferences and focused on conversational implicatures linked to figurative uses of language, here implicatures were either triggered by linguistic elements such as "but" and "even" (which pragmatically imply a contrast and some type of unexpectedness or surprise, respectively, see Janssens & Schaeken, 2016) or generated on a purely conversational basis. Interestingly, the Implicatures task was strongly correlated with the APACS Comp ($r = .80$), suggesting that the two tests tap on the same pragmatic competence in a broad sense. This is important to highlight, because the pattern of results in terms of involvement of executive resources in the Implicatures task is similar to the one observed for another APACS task, namely figurative language. Implicatures seem to be associated with all executive functions, but working memory and cognitive flexibility are the most important predictors (with a comparable weight), whereas inhibition is negligible. Accounts of implicatures have largely documented that their derivation capitalizes on working memory resources to compare alternative representations of scalar statements (De Neys & Schaeken, 2007; Dieussaert et al., 2011; Heyman & Schaeken, 2015; Marty et al., 2013; Marty & Chemla, 2013). Antoniou, Cummins, & Katsos (2016) tested participants between 18 and 46 years old with scalar implicatures with "some" and observed that both age and working memory significantly predicted the performance (respectively negatively and positively), but inhibition did not. Cognitive flexibility is also important, to guarantee that the different potential interpretations are considered. For "some", one should not only consider the lower-bound, literal meaning (e.g., the interpretation of "some" as "some and possibly all"), but also switch perspective and consider the more pragmatic upper-bound meanings (e.g., “some” is “some but not all”). Kissine (2012), for instance, argued that difficulties in cognitive flexibility are a key executive dysfunction associated with Autism Spectrum Disorder (Hill, 2004; Ozonoff et al., 2005) and play a crucial role in the pragmatic struggles of this population.

To summarize, the results of the multiple regressions and the relative weight analysis concerning Aim 2 suggest that, in the aging population, the role of executive functions in pragmatic skills varies depending on the specific type of pragmatic inference to be derived. The comprehension of oral narrative stories and of stories involving humorous endings seems to be primarily related to working memory skills, whereas understanding figurative language and implicatures involves the joint cooperation of working memory and cognitive flexibility resources. Inhibition, by contrast, does not stand out as a robust predictor of pragmatic skills.

Considered against previous accounts that have linked older adults’ inefficient pragmatic and inferential processes to suppression (Champagne-Lavau et al., 2012; Hamm & Hasher, 1992; Morrone et al., 2010), our data seem to indicate that the role of inhibition in pragmatics should be recalibrated. Given that the derivation of all pragmatic inferences – of any type – requires handling multiple information in memory, working memory is the necessary basis upon which further operations might be taken. These operations might involve inhibition, presumably in the case of figurative language and other implicatures, when alternative irrelevant meanings need to be suppressed. However, the role of inhibition in pragmatics seems subordinate to the one of working memory, in line with the view that working memory is primary and inhibitory control derivative (see Diamond, 2013 for a review).

Broadening the discussion to the architecture of executive functions, the overall picture emerging from these data confirms the unity and diversity hypothesis of executive functions (Miyake & Friedman, 2012). On the one hand, our data clearly showed multicollinearity among the different executive function measures, as reflected in the significant correlations between the different scores: hence there is clearly unity. On the other hand, the different executive functions exhibited different relative weights regarding pragmatic functioning. This is indicative of some diversity in terms of a different role in supporting communication and pragmatics.

A final point of discussion concerns the role of age in pragmatics skills. Although this was not the focus of the present study, our data are informative regarding age-related changes in pragmatics as well as age-related changes in the relationship between pragmatics and executive skills. First of all, our sample performed significantly worse than the normgroup in all pragmatic tasks and composite scores, suggesting a decline in pragmatics with aging. Moreover, as shown in the correlation analysis (Table 3), we observed a significant association between Age on the one hand and APACS Comp, Implicatures, and the Executive Function Score on the other hand. However, the hierarchical multiple regression analysis with only the demographic variables showed that Age was not a significant predictor of APACS Comp nor of Implicatures. In the Supplementary Material, we investigated this issue further and described three extra analyses on the potential role of age. In general, Age was negatively correlated with all pragmatics tasks (the total score on APACS Comp, the individual APACS tasks, and Implicatures) and with all executive function tasks (Working Memory, Inhibition, and Cognitive Flexibility), confirming the age-related trends in the literature. However, more fine-grained analyses with five more or less equal age-groups in our sample put this picture somewhat into perspective: while we observed the expected significant correlation of Age with the executive function tasks, our pragmatic tasks seemed less purely driven by the variable Age and more by a complex interaction between different cognitive and social functions. Moreover, the general relation between the different pragmatics tasks and the executive function tasks seemed to be more or less present in each of the five different age-groups in our sample, with working memory and cognitive flexibility being often correlated positively with the different pragmatic tasks, while the specific role of inhibition was clearly less pronounced. This extra analysis on the role of age seems thus to confirm the main claim of this work, namely that working memory and to some extent cognitive flexibility play a primary role in supporting older adults' pragmatic skills, whereas inhibition is less key.

We are certainly aware that our study has a number of limitations which it is important to acknowledge. The first one concerns the interpretation of the study findings. An important caveat with respect to our analysis of the role of executive functions and age is that the nature of our investigation was correlational. Multiple regressions do not uncover the causal relationships between variables but basically disentangle the structure of the underlying correlations. Causality presupposes prediction (If A causes B, then one can predict B on the basis of A), but causality is more than prediction. Therefore, our data are indicative of the link with executive functions and their predictive role with respect to pragmatics, but cannot be interpreted in a causal fashion. Future manipulative experimental research might enable to make straight causal claims: for instance, research that uses a dual-task methodology might reveal the explicit causal role of working memory in pragmatic skills.

Another important limitation concerns the selection of the tests to measure executive functions. The literature on executive functions has pointed out the difficulty of selecting adequate tests to evaluate the executive function component of interest, given the presence of task-specific idiosyncratic demands (Chan et al., 2008; Miyake & Friedman, 2012). The measures selected here might thus reflect, in addition to the specific executive skill of interest, also task-specific non-executive demands, such as language and semantic memory (for the measure of cognitive flexibility) or speed (for the measure of inhibition). Therefore, our conclusions about the role of the different executive functions in pragmatics might be partly influenced by non-executive function aspects. For instance, the performance in verbal fluency tasks has been showed to involve linguistic aspects as well as working memory aspects (Morere et al., 2012; Shao et al., 2014). With specific reference to older adults, the speed of the first response was related to vocabulary size and lexical access speed, whereas the number of produced words was associated with updating skills (Shao et al., 2014). Thus, our findings on the role of cognitive flexibility in some pragmatic tasks might reflect also linguistic aspects, which indeed is in line with evidence on the importance of vocabulary skills in figurative language processing (Kalandadze et al., 2018), as well as working memory aspects. Also, we argue for a key role of working memory and a limited role of inhibition in pragmatic processing in older adults, but we must acknowledge that the absence of inhibition effects in our study might be due to our choice of using a single measure of inhibition, and specifically one that is known to load also on speed (de Assis Faria et al., 2015). It would be important, thus, to replicate the current study by using other measures of cognitive functions, and possibly more than one for each construct of interest. In a similar vein, it would be relevant to extend the investigation to other pragmatic domains. Although our measurement of pragmatic comprehension seems quite comprehensive and reliable, it leaves out the pragmatic aspects of discourse production, such as off-topic verbosity. Given the mixed results that the study of pragmatic production has generated in the literature on aging with respect to the role of inhibition (Burke & Shafto, 2008), it would be highly relevant to see what is the contribution of different executive functions to expressive pragmatics.

Furthermore, a limitation can be found in the use of the Clock Drawing Test to assess the cognitive status. While this test has the advantage of being a quick and simple general screening test suitable for the detection of cognitive loss in older adults (Ricci et al., 2016; Wolf-Klein et al., 1989), its utility as screening instrument for mild cognitive impairment is questionable (Ehreke et al., 2009; Powlishta et al., 2002). Therefore, we cannot completely rule out the presence of mild cognitive impairment in our sample. This limitation should be carefully considered especially in light of the demographic characteristics of our sample, composed mainly of older old adults. The composition of our sample deserves to be especially highlighted. On the one hand, having a sample with a majority of older old adults is a strength, because this is an underserved population with respect to the documentation of pragmatic skills. Indeed, most of the studies on pragmatics in aging were conducted on samples of individuals who typically range up to the mid 70s. Considering its rapid growth, and considering the importance of pragmatics for social life (Agostoni et al., 2021; Messer, 2015), investigating older old adults has also a societal value, besides a scientific interest. On the other hand, the specific focus on older old adults limits the generalizability of the results. In this respect, it might be interesting to replicate our research in a group of younger old adults, to see if the same pattern of results is observed.

On the applicative level, our findings provide indications for training programs targeting communication and pragmatics. Although we did not test a control group, the comparison with the normative data coming from the ongoing APACS validation study indicates that the aging population performed poorly in the pragmatic tasks. This evidence, coupled with considerations on the importance of pragmatics for psychosocial life, should promote the interest towards training programs that especially aim at improving pragmatic skills (Parola & Bosco, 2018). Given the evidence of the important role of executive and specifically working memory skills in pragmatics that we have highlighted in this study, exercises on executive abilities might produce benefits also for communication. Previous literature showed that memory trainings produce gains in language comprehension (Carretti et al., 2013) and daily life tasks (Cavallini et al., 2015) and there is recent evidence that older adults' pragmatic skills can be promoted both by a specific pragmatic training and by a general cognitive training (Bambini et al., 2020). The joint combination of pragmatic and executive training tasks might thus be key to ensure life-long success in the vital domain of social communication.

Declarations

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Authors’ contributions

The project was ideated by WS and VB. Study design was performed by WS and LVL. Data collection was performed by LVL. Data analysis was done by LVL, KD, and WS. Data visualization was performed by KD. Data interpretation and manuscript writing were done by VB and WS: specifically, VB is mainly responsible for Introduction and Discussion and WS is mainly responsible for the Methods and Results sections.

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Tables

Table 1: Demographic characteristics of the sample

Age	Gender		Education			Living	
	Man	Woman	LE	ME	HE	Home	RCH
65-74 (N = 11)	3	8	0	2	9	7	4
75-84 (N = 20)	5	15	5	7	8	3	17
85-94 (N = 23)	7	16	7	7	9	2	21
Total (N = 54)	15	39	12	16	26	12	42

Note: LE is lower secondary education, ME is higher secondary education, and HE is higher education; RCH is Residential Care Home.

Table 2A: Scores in the pragmatic assessment (APACS Comp and Implicatures)

Test	**Mean (SD)**	**Min-Max scores of the participants**	**Median**	**Skewness**	**Kurtosis**	**Q1**	**Q3**	**Mean score of the norm group**
APACS Comp (score range: 0-100)	80.37 (12.14)	52-97	82	-0.79	-0.19	76.25	88.75	0.91
Narratives (score range: 0-56)	44.89 (6.66)	27-55	46	-0.87	0.34	42	49.75	52.36
Figurative Lang. 1 (score range: 0-15)	13.60 (1.41)	9-15	14	-1.13	1.21	13	15	14.59
Figurative Lang. 2 (score range: 0-30)	21.89 (5.13)	9-29	23.5	-0.71	-0.35	18	27.75	26.12
Humor (score range: 0-7)	5.44 (1.57)	1-7	6	-0.91	0.02	5	7	6.06
Implicatures (score range: 0-23)	14.13 (3.27)	7-21	13.5	0.09	-0.58	12	17	-

Note: The table reports mean and standard deviation, min-max scores of the participants, median, skewness, kurtosis, first quartile and third quartile for the different pragmatic tasks. For the tasks included in APACS Comp, we also report the scores of a norm group of 90 healthy Flemish adults (unpublished data from the validation study of the Flemish version of the APACS test).

Table 2B: Scores in the EF and ToM assessment

Test	**Mean (SD)**	**Min-Max scores of the participants**
Working Memory		
Digit Span (max score: 14)	5.26 (1.88)	2-12
Letter-Number Sequencing (max score: 21)	6.65 (3.41)	0-13
Arithmetic (max score: 22)	11.19 (4.19)	6-21
Inhibition	52.17 (28.50)	15-135
Cognitive Flexibility	36.41 (10.43)	14-65
ToM (max score: 36)	19.78 (4.71)	9-30

Table 3: Overview of the Pearson correlations between Age and scores in ToM, EF, and pragmatics (APACS Comp and Implicatures)

Variable	1	2	3	4	5
1. Age	-				
2. ToM	-.28*	-			
3. EF	-.52***	.36**	-		
4. APACS Comp	-.36**	.45***	.68***	-	
5. Implicatures	-.28*	.41**	.62***	.80***	-

Note: * $p < .05$. ** $p < .01$. *** $p < .001$.

Table 4: Results of the Hierarchical Multiple Regression Analyses for both APACS Comp and Implicatures

	APACS Comp		Implicatures	
Predictor	*β*	ΔR^2	*β*	ΔR^2
Step 1		.33***		.33***
Age	-.23		-.12	
Gender	-.08		-.05	
Lower secondary education	-.46**		-.55**	
Higher secondary education	-.29*		-.29*	
Step 2		.11**		.08*
ToM	-.38**		-.33*	
Step 3		.12**		.09**
EF	.48**		.43**	
Total R^2		.55***		.50***

Note: * $p < .05$. ** $p < .01$. *** $p < .001$.

Table 5: Overview of the Pearson correlations between the different EF

Variable	1	2	3
1. Working Memory	-		
2. Inhibition	.38**	-	
3. Cognitive Flexibility	.57***	.48***	-

Note: ** $p < .01$. *** $p < .001$.

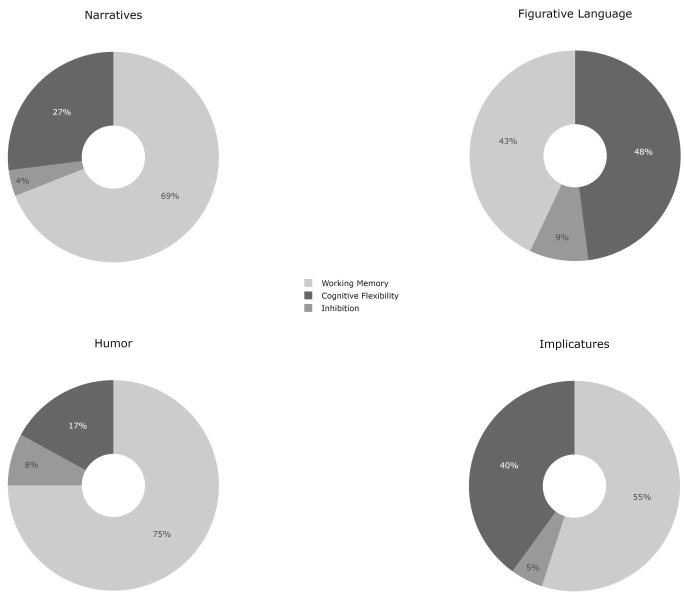
Table 6: Results of the Pearson correlations, multiple regression analysis, and Relative Weight Analysis for Narratives, Figurative Language, Humor, and Implicatures

Variable	*r*	*β*	*p*	Relative Weight [95% CI]	Scaled Relative Weight (%)
Narratives					
Working Memory	.62***	.54	< .001	0.2751 [0.1346, 0.4254]	68.62
Inhibition	.22	-.07	.56	0.0169 [-0.0701, 0.0811]	4.22
Cognitive Flexibility	.46***	.19	.19	0.1089 [0.0178, 0.2447]	27.16
Figurative Language					
Working Memory	.62***	.37	.004	0.2225 [0.1073, 0.3459]	43.15
Inhibition	.36**	.02	.90	0.0476 [-0.0147, 0.1601]	9.23
Cognitive Flexibility	.65***	.43	.001	0.2455 [0.1256, 0.3844]	47.62
Humor					
Working Memory	.61***	.57	< .001	0.2812 [0.1359, 0.4688]	75.23
Inhibition	.27*	.04	.79	0.0285 [-0.0470, 0.1269]	7.64
Cognitive Flexibility	.39**	.04	.78	0.0640 [-0.0376, 0.1750]	17.13
Implicatures					
Working Memory	.64***	.47	< .001	0.2671 [0.0708, 0.3786]	54.59
Inhibition	.27*	-.08	.50	0.0246 [-0.0762, 0.0786]	5.03
Cognitive Flexibility	.59***	.36	.009	0.1976 [0.0395, 0.3236]	40.38

Note: * $p < .05$. ** $p < .01$. *** $p < .001$.

Figure Caption

Figure 1: Scaled Relative Weights of the different EF for each pragmatic task (Narratives, Figurative Language, Humor, and Implicatures)



Supplemental Material for the article: *What is the contribution of executive functions to communicative-pragmatic skills? Insights from aging and different types of pragmatic inference*

Three extra exploratory analyses with respect to the variable Age

In order to investigate the relationship between age on the one hand and pragmatics and executive functions on the other hand in more detail, we performed three extra exploratory analyses.

Analysis 1

First, we explored Pearson correlations between age and the different pragmatic and EF scores. Figure S1 presents the different correlations and shows that age had a significant negative correlation with all pragmatics tasks (the total score on APACS, i.e., APACS Comp, Implicatures, and the individual APACS tasks) and with all executive function tasks (Working Memory, Inhibition, and Cognitive Flexibility). This picture confirms the age-related trends observed in the literature with respect to the executive functions and is also in line with observations with respect to language in older adults.

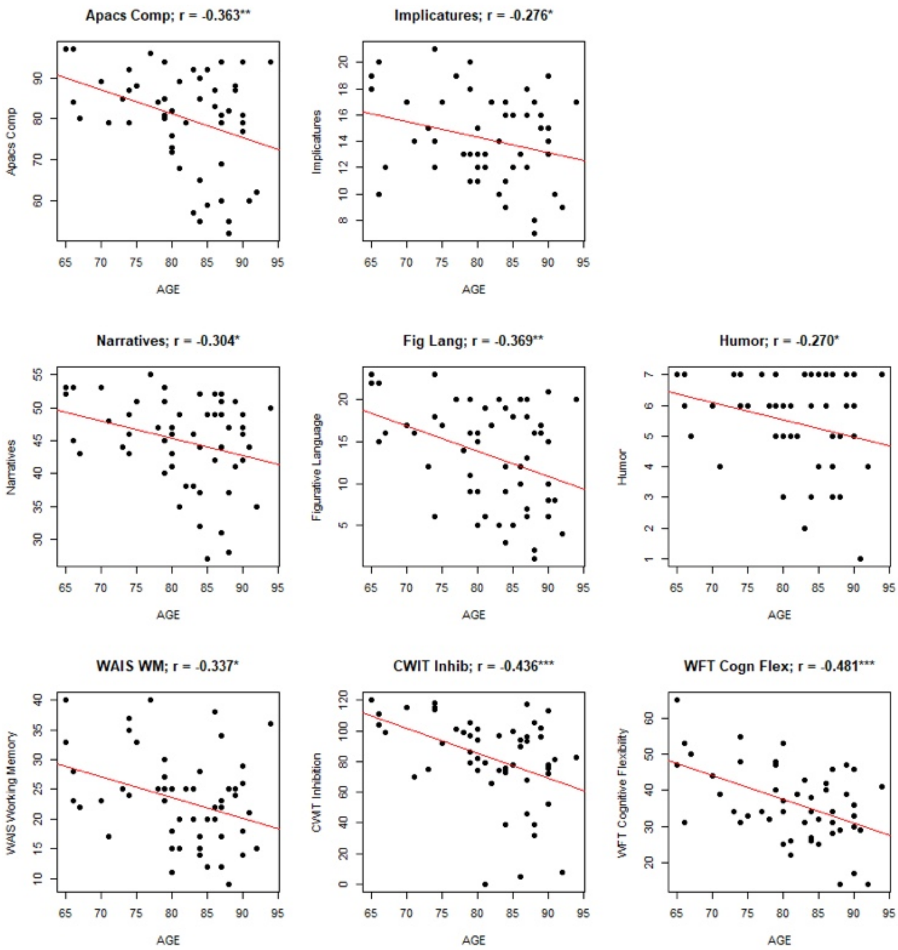


Figure S1: The correlations between age and all pragmatics measures (APACS Comp, Implicatures, and the scores in the three individual APACS tasks, i.e., Narratives, Figurative Language, and Humor) and all executive function tasks (Working Memory as assessed with the Working Memory Index from the Dutch version of the WAIS-III, i.e., WAIS WM, Inhibition as assessed with the Color-Word Interference Test, i.e., CWIT Inhib, and Cognitive Flexibility as assessed with the Word Fluency Test, i.e., WFT Cogn Flex).

Analysis 2

Second, since the participants were not evenly distributed according to variable Age (given the majority of older old adults in our study), we performed a second analysis where we explored Spearman's rank order correlations between the different pragmatic and EF scores and the variable Age, whereby the latter continuous variable was transformed into an ordinal variable: the participants were divided into five bins with increasing age and of about the same number of participants (see Table S1 for the descriptive statistics). Table S2 presents the different correlations and shows that this ordinal variable age had a significant negative correlation with Inhibition and Cognitive Flexibility, and a marginally significant negative correlation with Working Memory. However, none of the correlations with the pragmatic tasks reached the significance level of $p < .05$. This seems to imply on the one hand that our data show the expected relationship between age and the executive function tasks, and on the other hand that our pragmatic tasks are less purely driven by the variable Age but more by a complex interaction between different cognitive and social functions.

Table S1: The descriptive statistics of the five age-groups used in the second and third supplementary analyses (number of participants, mean age, mean standard error, and the lower and upper 95%).

Age-Ordinal	N	Mean age	Mean SE	Lower 95%	Upper 95%
1	11	69.5	.635	68.27	70.82
2	11	78.7	.635	77.45	80.00
3	11	83.3	.635	81.99	84.55
4	11	87.0	.635	85.72	88.28
5	10	90.5	.666	89.16	91.84

Table S2: The Spearman correlations between age as an ordinal variable with equal age-bins and all pragmatic tasks (APACS Comp, Implicatures, and the score the three individual APACS tasks, i.e., Narratives, Figurative Language, and Humor) and all executive function tasks (Working Memory, Inhibition, and Cognitive Flexibility).

Pragmatic and EF tasks	Spearman's rho	*p*
APACS Comp	-0.244	.075
Implicatures	-0.183	.185
Narratives	-0.226	.100
Figurative Language	-0.264	.054
Humor	-0.168	.223
Working Memory	-0.260	.057
Inhibition	-0.425 ***	.001
Cognitive Flexibility	-0.381 **	.004

* $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$

Analysis 3

Third, to investigate the observed pattern between the different pragmatic tasks and the executive function tasks in the main article, but now for each of the different age-groups constructed for the second analysis, we explored Pearson correlations between the different pragmatic scores and the EF scores for each of the five age-groups. Table S3 presents the different correlations. Given the small number of participants (about 11) in each of the age-bins, these correlations have to be interpreted with caution. Nevertheless, it seems to us that the picture arising from them is very strong and clearly in line with the analyses presented in the main article.

Working Memory often correlated positively with the different pragmatic tasks: more precisely, 13 correlations had a *p*-value below .05 and 5 correlations additionally had a p-value of .1 or less. In each of the five age-bins, Working Memory correlated significantly with one or more of the pragmatic scores, except for the third age-bin (where no significant correlation was observed at all). In other words, the importance of Working Memory for pragmatics seems to be present in almost all the age-bins of our sample of older adults.

Cognitive Flexibility sometimes correlated positively with the different pragmatic tasks: more precisely, 9 correlations had a *p*-value below .05 and 2 correlations additionally had a *p*-value of .1 or less. In three of the five age-bins (the first, fourth and fifth), Cognitive Flexibility correlated significantly with one or more of the pragmatic scores. In other words, also Cognitive Flexibility seems to have a prominent role in different age-bins of our sample of older adults.

As in the general analysis, the role of Inhibition was clearly less pronounced. Of the correlations with the pragmatic tasks, only 3 correlations had a *p*-value below .05, 3 correlations additionally had a *p*-value of .1 or less, and in two of the age-bins (the second and fifth) we observed a significant correlation. In other words, Inhibition seems not to be such a robust predictor of pragmatic skills as the two other executive functions.

Table S3: Pearson correlations between on the one hand all pragmatics tasks (APACS Comp, Implicatures, and the scores in the three individual APACS tasks, i.e., Narratives, Figurative Language, and Humor) and on the other hand the three executive function tasks (Working Memory, Inhibition, and Cognitive Flexibility) for each of the five ordinal age-bins.

		Age-Ordinal 1	Age-Ordinal 2	Age-Ordinal 3	Age-Ordinal 4	Age-Ordinal 5
		r (*p*)	*r* (*p*)	*r* (*p*)	*r* (*p*)	*r* (*p*)
APACS Comp	Working Memory	.727* (*.011*)	.709* (*.015*)	.464 (*.151*)	.885*** (*< .001*)	.656* (*.040*)
	Inhibition	.526 (*.096*)	.563 (*.071*)	.013 (*.971*)	-.004 (*.992*)	.548 (*.101*)
	Cognitive Flexibility	.697* (.017)	-.051 (*.881*)	.311 (*.352*)	.765** (*.006*)	.736* (*.015*)
Implicatures	Working Memory	.580 (*.062*)	.595 (.054)	.521 (*.100*)	.666* (*.025*)	.659* (*.038*)
	Inhibition	.283 (*.398*)	.661* (*.027*)	.194 (*.567*)	-.261 (*.439*)	.469 (*.171*)
	Cognitive Flexibility	.729* (*.011*)	.242 (*.474*)	.375 (*.256*)	.450 (*.165*)	.805** (*.005*)
Narratives	Working Memory	.379 (*.251*)	.665* (*.026*)	.503 (*.114*)	.696* (*.017*)	.503 (*.139*)
	Inhibition	.357 (*.281*)	.456 (*.159*)	-.099 (*.773*)	-.248 (*.462*)	.678* (*.031*)
	Cognitive Flexibility	.586 (*.058*)	-.140 (*.682*)	.272 (*.418*)	.494 (*.122*)	.610 (*.061*)
Figurative Lang	Working Memory	.614* (*.044*)	.300 (*.370*)	.570 (*.067*)	.715* (*.013*)	.679* (*.031*)
	Inhibition	.354 (*.285*)	.802** (.003)	-.104 (*.761*)	.175 (*.607*)	.563 (*.090*)
	Cognitive Flexibility	.837***(.001)	.203 (*.549*)	.379 (*.250*)	.656* (*.028*)	.880*** (*< .001*)
Humor	Working Memory	.534 (*.091*)	.681* (*.021*)	.271 (*.420*)	.883*** (*< .001*)	.460 (*.181*)
	Inhibition	.480 (*.135*)	-.004 (*.990*)	.187 (*.581*)	-.072 (*.833*)	.300 (*.399*)
	Cognitive Flexibility	.110 (*.746*)	-.255 (.449)	.217 (*.522*)	.788** (*.004*)	.409 (*.240*)

* $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$