CHAPTER TWO

Exploring age-related changes in inter-brain synchrony during verbal communication

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Abstract

Successful communication is key to health in older age. This is true in the narrow sense of being able to gain critical information, e.g., from health care providers, but also more broadly in being able to maintain social ties and pursue meaningful activities, which, in turn, are central to maintaining health and well-being. Compared to younger adults,

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older adults show both quantitative and qualitative changes in how information is processed and used over time to achieve comprehension. Such systematic age-related neural dissimilarities in processing dynamics and strategies raise fundamental questions about how the human brain supports cross-generational communication, especially in light of accumulating evidence linking interpersonal similarities in brain responses to communicative success. Yet despite its prevalence and tangible health-related importance, naturalistic intergenerational communication involving older adults is understudied. In this chapter, we lay out why filling this research gap is critical in advancing our understanding of naturalistic communication, with implications for both science and practice.

1. Introduction

Generational divides are front and center in public discourse. For example, older adults are often accused of being dismissive of young adults, resulting in various forms of pushbacks, ranging from protests to "OK Boomer" memes. Such intergenerational clashes, whether overblown or not, are widely studied from a social science perspective and are typically attributed to socio-cultural gaps (Beheshti, 2018). Less explored is whether and how neurophysiological factors may also contribute to intergenerational (mis)alignment; that is: whether and how age-related changes in processing dynamics can result in intergenerational communication pattern differences—ranging from speech rate to discourse-level comprehension—that may impede positive communicative outcomes.

The disconnect that can arise from differing communication patterns between interlocutors (of any age) is often highlighted in pop culture. For example, the Disney Pixar film Zootopia features a scene where the main character, a bunny police officer, pays a visit to the Zootopia DMV—operated by sloths (www.youtube.com/watch?v=HHKwnUa3txo). The scene comically illustrates how vast interpersonal differences in speech rates can lead to excruciating conversational breakdowns, demonstrating that successful communication goes beyond comprehending words and sentences: It involves the ability to adapt to and align with the language source at all levels of linguistic representation. Needless to say, interspecies conversations in a Disney movie are not representative of real-world human communication. But, albeit less dramatic, both quantitative (e.g., *when*, and *to what extent* are processes engaged) and qualitative (e.g., *what* processes are engaged) changes in language comprehension and production dynamics as a function of age have indeed been widely documented. Yet, few researchers to date have asked if these and other neuropsychological changes may have cascading implications for intergenerational communication outcomes.

This is a topic of high importance because communication skills are key to a happy and healthy life across the lifespan. For example, preschoolers who start to talk earlier have fewer tantrums (Manning et al., 2019), aggression in school-age children is linked to verbal reasoning skills (Kikas, Peets, Tropp, & Hinn, 2009), and linguistic abilities are predictive of professional success (e.g., McCluney, Durkee, Smith, Robotham, & Lee, 2021; Piopiunik, Schwerdt, Simon, & Woessmann, 2020). The most direct links between communication and health are found in healthcare settings themselves, where health outcomes have long been attributed not only to patient communication skills and health literacy (Berkman, Sheridan, Donahue, Halpern, & Crotty, 2011; Martin et al., 2011; Nutbeam, 2000; Rosenfeld et al., 2011) but also to effective patient–physician communication (Stewart, 1995). Contextual factors that affect linguistic communication, such as how familiar conversational partners are with one other, have also been shown to directly affect health-related decision-making. For example, primary care providers, with whom patients have an established relationship, have been more successful than other medical professionals at helping combat vaccine hesitancy during the covid-19 pandemic (Ratzan, Schneider, Hatch, & Cacchione, 2021), and improving communication in pediatric settings is critical in helping caregivers of children with autism spectrum disorder navigate treatment options (Evans, 2021; Levy et al., 2016). These examples underscore the importance of linguistic communication skills that allow people of all ages to flexibly adapt (or *accommodate*) to a wide range of conversational contexts, in familiar and unfamiliar settings, and involving both familiar and unfamiliar conversational partners of similar or different ages (Giles et al., 1991).

A better understanding of the neurobiological basis of conversations, and particularly the relationship between dyadic conversational coordination (also termed *alignment;* Pickering & Garrod, 2004) and communicative outcomes that may directly impact health-related outcomes, is arguably especially vital in the context of (intergenerational) interactions involving older adults. Older adults tend to have more regular encounters with healthcare professionals (Carr-Hill, Rice, & Roland, 1996), making them more likely than young and middle-aged adults to be confronted with intergenerational communicative contexts for which the outcomes may have consequences for their physical health. At the same time, older adults are often reported to differ from young adults in terms of the frequency, variation, and quality of daily social interactions (Zhaoyang, Sliwinski, Martire, & Smyth, 2018), and it has been argued that social isolation during the covid-19 pandemic has disproportionately affected older adults (Dahlberg, 2021; National Academies of Sciences, Engineering, and Medicine et al., 2020). While social isolation has been linked to dementia (Kuiper et al., 2015), it is important to note that research does not unequivocally point to communicative deficits in healthy older adults (e.g., Mesik, Ray, & Wojtczak, 2021). Still, older adults are generally more likely to find themselves interacting with younger people who may be processing language differently. Yet, as already alluded to above, prior work has largely left unexplored whether alignment is more challenging in the context of intergenerational communication, as might be suggested by well-documented age-related changes in language processing, which are discussed in more detail below.

What's more, although there exists a rich sociolinguistic literature on conversational intergenerational accommodation (Williams & Nussbaum, 2013), neuroscientists have only just begun addressing these and related questions in naturalistic dyadic contexts (see below). This knowledge gap stems from a combination of practical and historical factors. For example, most laboratory human neuroscience research is conducted on a homogeneous convenience sample of university students (Sears, 1986), which naturally leads to the undersampling of older adults in studies ranging from laboratory psychology to clinical trials (Van Marum, 2020). Additionally, neurolinguistics research is heavily skewed toward studying participants who are alone in a lab and asked to comprehend experimental stimuli that are "isolated"—well-controlled and limited to the phrase, word, or even syllable level, intentionally devoid of discourse context. This work has indisputably led to tremendous insights into the neurobiology of human language (e.g., Hickok & Small, 2015). But this fairly in-depth mechanistic understanding of how the human brain derives meaning through the (de)composition of linguistic units (Pylkkänen, 2019) has yet to be comprehensively linked back to what humans tend to use language for on a daily basis: to communicate and negotiate this meaning with others.

In what follows, we first discuss how recent methodological advances can be leveraged to better understand not only naturalistic linguistic comprehension, but also dyadic (and group) interactions. Then, we will discuss possible linking hypotheses between what is known about age-related changes in how the human brain supports language, and neural and communicative outcomes during real-world dynamic social interactions.

2. Studying naturalistic dyadic interactions

2.1 The interactive turn: Hyperscanning

As discussed above, (social) neuroscientists have mostly studied individuals responding to pictures or movies of people rather than live human interactions. However, some neurophysiological correlates of social cognition are only observed when there is true social interaction (Tognoli, Lagarde, DeGuzman, & Kelso, 2007). It is thus unclear to what extent the neurobiological markers of social behavior can be reliably probed in the *absence* of real-time, naturalistic reciprocal social interaction (Matusz, Dikker, Huth, & Perrodin, 2019; Schilbach et al., 2013). To create more naturalistic study conditions, researchers are increasingly comparing brain activity *between* participants instead of using a stimulus-brain approach (Babiloni & Astolfi, 2014; Dumas, Lachat, Martinerie, Nadel, & George, 2011; Hari, Himberg, Nummenmaa, Hämäläinen, & Parkkonen, 2013; Hasson, Ghazanfar, Galantucci, Garrod, & Keysers, 2012; Hasson, Nir, Levy, Fuhrmann, & Malach, 2004; Sänger, Lindenberger, & Müller, 2011). In addition to comparing neural responses across people in data collected asynchronously (e.g., in fMRI research; Parkinson, Kleinbaum, & Wheatley, 2018; Stephens, Silbert, & Hasson, 2010; Dikker, Silbert, Hasson, & Zevin, 2014; Vodrahalli et al., 2018), social neuroscientists have leveraged technological advances that now make it possible to record neurophysiological data from multiple people simultaneously (so-called hyperscanning; Montague et al., 2002), which has led to a rich and exponentially growing field of research exploring the relationship between social factors and *inter-brain coupling*, or similarities in brain responses across people.

2.1.1 Quantifying inter-brain coupling

Inter-brain coupling, like intra-brain coupling, can be quantified in various ways (for an overview, see Ayrolles et al., 2021). Reasons to choose one metric over another can be purely computational in nature. For instance, some metrics are more likely to result in spurious correlations (Burgess, 2013) or to require the stationarity of the signals (Ayrolles et al., 2021). More broadly, recent work has suggested that inter-brain measures can capture behavior and communication outcomes (such as memory) better than intra-brain measures in certain cases, also most likely because of computational reasons such as signal-to-noise ratio (Balconi, Pezard, Nandrino, & Vanutelli, 2017; Ben-Yakov, Honey, Lerner, & Hasson, 2012; Davidesco et al., 2019;

Dumas, Chavez, Nadel, & Martinerie, 2012; Hasson, Furman, Clark, Dudai, & Davachi, 2008; Pan et al., 2020; Simony et al., 2016).

Recently, our group and others have also illustrated how different metrics may correspond to different psychobiological processes (Dikker et al., 2021; Dumas & Fairhurst, 2021). For example, some metrics capture instantaneous, time-locked, inter-brain coupling between dyads while others do not, and one might argue that non-instantaneous inter-brain coupling is less likely to arise from purely stimulus-related factors and thus be more likely to stem from socially relevant factors. Granger Causality and time-shifting approaches are used to address questions related to the directionality of mutual influence between dyads (Leong, Byrne, & Clackson, 2017). Given inherent delays between speakers and listeners, such directional approaches have been employed in particular in inter-brain coupling between speakers and listeners (Davidesco et al., 2019; Dikker et al., 2014; Liu et al., 2017; Stephens et al., 2010).

Crucially, these metrics are not mutually exclusive and can be combined to arrive at a more comprehensive understanding of conversational dynamics. But much remains to be investigated on this front: There is currently no consensus in the field with respect to which metric is most appropriate in which context (Ayrolles et al., 2021), and different approaches can lead to different results in the same dataset (Chen et al., 2021; Nozawa, Sasaki, Sakaki, Yokoyama, & Kawashima, 2016).

2.1.2 Inter-brain coupling during dynamic social interactions

As summarized in Fig. 1, in the decade or so since the emergence of hyperscanning, many factors have been found to predict *inter-brain coupling*, across dyads or groups: Listening to or watching the same stimulus (Bevilacqua et al., 2019; Dikker et al., 2017; Hasson et al., 2004; Nummenmaa et al., 2012; Parkinson et al., 2018); social coordination, like conversation or joint action (Dikker et al., 2021, 2014; Dumas, Nadel, Soussignan, Martinerie, & Garnero, 2010; Konvalinka et al., 2014; Pérez, Carreiras, & Duñabeitia, 2017; Pérez, Dumas, Karadag, & Duñabeitia, 2018; Stephens et al., 2010); and social intentions, like cooperation vs competition (Astolfi et al., 2010; Babiloni et al., 2007; Cui, Bryant, & Reiss, 2012; Czeszumski et al., 2022).

Crucially, individual differences and contextual factors may mediate these factors (Bevilacqua et al., 2019; Dikker et al., 2017; Dumas et al., 2012; Goldstein, Weissman-Fogel, Dumas, & Shamay-Tsoory, 2018; Lee, Miernicki, & Telzer, 2017; Petroni et al., 2017). For example, personality traits and (social) engagement are linked to inter-brain coupling

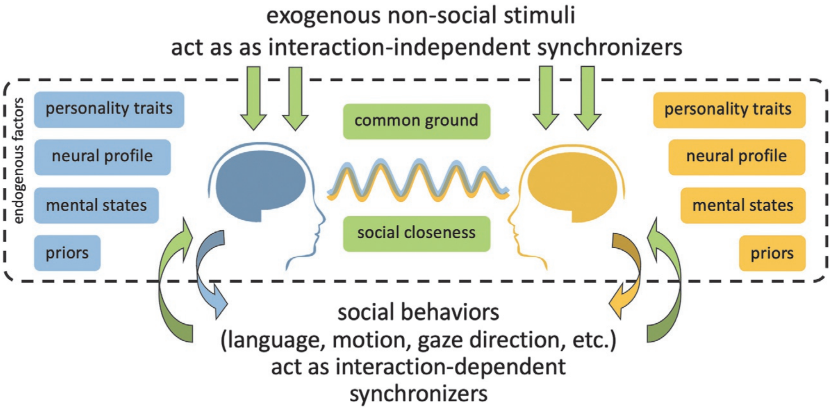

Fig. 1 A summary of possible sources of inter-brain coupling during social interaction in dyadic interaction. External non-social stimuli (top) and social behavior (bottom) provide exogenous sources of shared stimulus entrainment and interpersonal social coordination, respectively, leading to similar brain responses, i.e., inter-brain coupling. Social closeness and personality traits (e.g., affective empathy) both affect social engagement during the interaction, and thus the extent to which dyads' brain responses become synchronized. Each individual's mental state (e.g., focus) similarly affects their engagement with each other, intrinsically (endogenously) motivating participants to make an effort to connect to each other; and priors (knowledge about the other or the topic of conversation) will affect communicative expectations. Individual variation in "neural profiles" (basic oscillatory frequencies, etc.) may also predict baseline (dis)similarities in inter-brain coupling. *Adapted from Dikker, S., Michalareas, G., Oostrik, M., Serafimaki, A., Kahraman, H. M., Struiksma, M. E., & Poeppel, D. (2021). Crowdsourcing neuroscience: Inter-brain coupling during face-to-face interactions outside the laboratory. NeuroImage, 227, 117436..*

(Bevilacqua et al., 2019; Cohen, Henin, & Parra, 2017; Czeszumski et al., 2020; Dikker et al., 2017; Goldstein et al., 2018; Ki, Kelly, & Parra, 2016; Petroni et al., 2017), as are the nature and quality of the dyadic relationship. Social closeness has been shown to affect inter-brain coupling in a number of studies, even within groups or dyads who know each other well (Bevilacqua et al., 2019; Dikker et al., 2021, 2017; Parkinson et al., 2018), and some researchers report categorical differences in inter-brain coupling as a function of the nature of the relationship. For example, a recent fNIRS study (Long et al., 2021) found that romantic couples, but not friends, showed greater inter-brain coupling when discussing contentious over neutral topics. Another recent EEG hyperscanning study found that neurobehavioral coupling in dyads was affected by both their relationship (romantic couples, good friends, and strangers) and the ongoing social tasks (motor coordination, empathy giving; Djalovski, Dumas, Kinreich, & Feldman, 2021). Moreover, results revealed an interaction between those two factors, suggesting that the effects of human attachment on neurobehavioral coupling stem from a number of inter-dependent sources.

With respect to behavioral and communicative outcomes, inter-brain coupling has been linked to better team performance (Reinero, Dikker, & Van Bavel, 2021), successful comprehension (Stephens et al., 2010), memory retention (Hasson et al., 2008), and learning (Davidesco et al., 2019; Pan et al., 2020). Neurobehavioral coupling has also been shown to predict therapeutic alliance (Duggento et al., 2021; Ellingsen et al., 2020; Koole et al., 2020; Koole & Tschacher, 2016; Ramseyer & Tschacher, 2011), which has led some researchers to develop synchrony-based interventions such as hyperscanning neurofeedback (Chen, Kirk, & Dikker, 2021; Dikker et al., 2021; Duan et al., 2013; Moreau & Dumas, 2021; Müller, Perdikis, Mende, & Lindenberger, 2021; Pan & Cheng, 2020).

2.1.3 Hyperscanning linguistic interactions

The emergence of inter-subject correlation approaches has contributed to a transition, for some researchers, from "traditional" event-related laboratory neuroimaging research to naturalistic designs (Hasson et al., 2004). In fMRI research, much of the work has focused on narrative comprehension, where similarities across individuals listening to or watching the same narratives are correlated with features of the narrative structure (Nastase et al., 2021), recall (Hasson et al., 2008), or with individual differences in personality traits (Nummenmaa et al., 2012) or narrative interpretation (Sievers, Welker, Hasson, Kleinbaum, & Wheatley, 2020). Hyperscanning research, in contrast, directly probes interpersonal social interaction, and most studies involve some form of verbal communication (Czeszumski et al., 2022). However, very few have directly investigated the linguistic characteristics of the communicative exchange. In a typical study, for example, participants are assigned to either a collaborative or competitive task, and then the average inter-brain coupling across each of these interactions is compared, without much attention to the internal structure of the communication.

2.1.4 Intergenerational verbal interactions

Hyperscanning research has mostly involved intragenerational dyads, but there is also a growing body of work on intergenerational social interactions, Most, if not all, of these studies are geared toward understanding developmental questions, examining adult-child dyads where the adult is either a parent (Endevelt-Shapira, Djalovski, Dumas, & Feldman, 2021; Lee et al., 2017; Leong et al., 2017; Nguyen, Abney, Salamander, Bertenthal, & Hoehl, 2021; Nguyen, Schleihauf, et al., 2021; Wass et al., 2018), or a teacher (Bevilacqua et al., 2019; Davidesco et al., 2019; Davidesco, Matuk, Bevilacqua, Poeppel, & Dikker, 2021; Dikker et al., 2017). This work, spanning infants to high schoolers, has linked inter-brain coupling to the quality and nature of adult-child social interactions (Bevilacqua et al., 2019; Dikker et al., 2017; Jones et al., 2017; Nguyen, Abney, et al., 2021; Nguyen, Schleihauf, et al., 2021; Wass et al., 2018). In educational contexts, our work and that of others have shown that the teacher-student relationship affects inter-brain coupling as well as learning outcomes (Bevilacqua et al., 2019; Davidesco et al., 2019, 2021).

In sum, there has been an exponential growth in hyperscanning research over the past 5 years, and while many details still have to be hashed out, evidence is accumulating that inter-brain coupling is a correlate of successful communication for both intra- and intergenerational dyadic interactions. Yet, to our knowledge, no research to date has investigated inter-brain and inter-body coupling during dyadic interactions involving older adults, (60+) at either the intra- or inter-generational level. This is a striking gap given that questions about the interplay between language skills, communicative outcomes, social context, and familiarity are especially important for this age group. As a result, many questions about the neurobiology of successful communication in older adults remain unanswered.

3. Factors that may influence inter-brain coupling during linguistic exchanges with older adults

Laboratory work has identified a number of important ways that language processing changes across adulthood. At the level of broad outcomes, language remains well-preserved in older age. Different from patterns seen for executive function and memory, in the absence of vision or hearing impairment, older adults generally self-report little difficulty using language in many everyday situations, such as having conversations or reading books or newspapers (reviewed in Light & Burke, 1993). This is due in part to the fact that linguistic knowledge is well-preserved or even augmented with increasing age (Burns, 1993) and that language relies on well-practiced procedures responsible for the production and appreciation of syntax, prosodic forms, and basic aspects of word meaning (Kempler, 2005; Wingfield & Stine-Morrow, 2000). However, research into language processing mechanisms has shown that these outcomes are achieved in the face of notable age-related changes in the underlying processing dynamics. Strikingly, the implications of these changes for how and how successfully older adults communicate have rarely been considered even in a laboratory context, let alone in the context of more naturalistic exchanges. Below, we discuss a non-exhaustive set of examples wherein aging may affect aspects of language processing that are important for accommodation, alignment, and inter-brain coupling. We will use the term "coupling" to refer to dyadic similarities in neurophysiological responses, "alignment" to refer to dyadic coordination patterns in speech and language, and "accommodation" to refer to the (sub)conscious adjustment between speakers (or between a comprehender and the message) to improve alignment, which we hypothesize is related to coupling.

3.1 Changes in neural profiles

Aging has widespread effects on brain systems that support cognitive functioning (Bethlehem et al., 2022; Cabeza, Nyberg, & Park, 2016) including changes in white matter that affect the speed and strength of neural communication between areas (Head et al., 2004; Sullivan & Pfefferbaum, 2006), which can lead to qualitative shifts in the recruitment of brain areas (see review by Diaz, Rizio, & Zhuang, 2016). Age-related changes further have various implications for the temporal and rhythmic properties of neural responses, both in the presence and absence of audiovisual stimuli.

Age-related changes in the time course of response to external stimuli can begin early in processing. For example, studies have reported that older adults show less precision in neural responses to syllables (Anderson, Parbery-Clark, White-Schwoch, & Kraus, 2012), and Federmeier, Van Petten, Schwartz, and Kutas (2003) found age-related delays in sensory-evoked responses to sentence-initial auditory words: Frontal N1 responses were delayed by about 15 ms and P2 responses by about 25 ms in a group of healthy older adults compared to college-aged adults. These timing shifts, however, may be context-dependent. Woodward, Ford, and Hammett (1993) did not observe age-related delays on the N1 (although they did find P2 delays) to sentence-final words, which have more contextual support. Later aspects of processing often show even more dramatic age-related timing differences. For example, the N400, an ERP component linked to semantic access (see Federmeier, 2022), shows a gradual increase in latency of about 1.5–2 ms per year from age 20 to age 80 (Kutas & Iragui, 1998), such that delays of >50 ms are not uncommon when comparing college-aged adults to samples over age 55. At the same time, however, age-related timing differences are not always maintained over the course of processing, even for a single word, as the sensory delays observed in Federmeier et al. (2003) were not accompanied by delays in the subsequent (auditory) N400 response. Such patterns emphasize that similarity in timing at one point of measurement (e.g., a behavioral response) can mask dissimilarity in the timing of earlier processes which, in turn, likely herald differences in the nature or quality of the information that is being processed. More generally, findings like these highlight that the impact of aging on the timing of neural responses is complex, varying with modality and context among other factors, and needs to be studied across different conditions in order for its impact on alignment and coupling to be understood.

Older adults also exhibit shifts in cerebral oscillatory patterns (Duffy, McAnulty, & Albert, 1993). Such resting-state biological rhythms have been linked to social behavior in a meaningful way. For example, similarities in resting-state fMRI activity between children and their caregivers are predictive of their relationship (Lee et al., 2017) and real-life school friends show greater neuroanatomic similarity (D'Onofrio, Norman, Sudre, White, & Shaw, 2021). Fig. 2 illustrates a few ways in which individual differences in biological rhythms may affect dyadic inter-brain coupling (sync) in both quantitative (Fig. 2B) and qualitative ways (Fig. 2C).

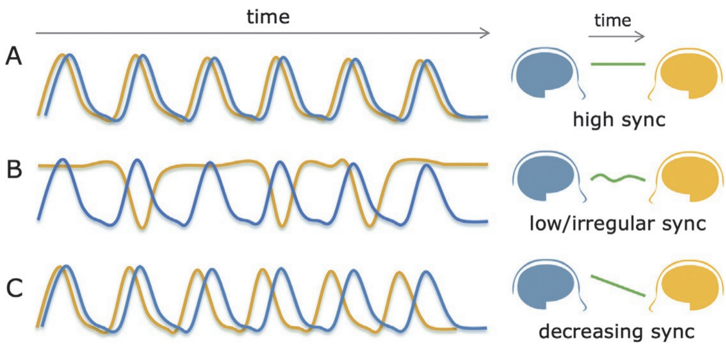

Fig. 2 Individual differences in neural profiles may lead to different inter-brain coupling patterns. (A) Similarities in endogenous oscillatory patterns within a dyad lead to high inter-brain coupling (high sync). (B) (Slight) individual discrepancies in peak frequency of oscillatory patterns (e.g., age-related alpha peak frequency changes) will lead to interpersonal drift and, consequently, a decrease in inter-brain coupling over time (decreasing sync). (C) Non-systematic differences between the neural profiles of dyads will lead to low, or irregular inter-brain coupling (low/irregular sync).

Figure 2B illustrates how age-related oscillatory shifts thus could lead to "interpersonal" drifts. Preliminary evidence from our group suggests that such age-related differences in inter-brain coupling can indeed be detected. In a large-scale study on naturalistic dyadic face-to-face interactions collected from pairs of museum and festival visitors across different sites and countries (Dikker et al., 2021), we found site-specific differences with respect to the frequency range where inter-brain coupling predicted interaction-related features. For example, as shown in Fig. 3, inter-brain coupling was correlated with relationship duration at 10–11 Hz for participants at a 3-day music festival in the Netherlands, whereas this correlation was significant at ~8 Hz for visitors of an art museum in Athens, Greece. One possible explanation could lie in age differences between the two groups: Alpha peak frequency is typically lower for older than for younger adults (e.g., Duffy et al., 1993; Tröndle et al., 2021), and the music festival is known to attract a younger demographic than the art museum.

Figure 2C illustrates a more "messy" scenario, where idiosyncratic neural profiles lead to inconsistent dyadic inter-brain coupling patterns over time (Li, Lindenberger, & Sikström, 2001; Voytek et al., 2015). Such patterns may result from either a single qualitative difference or from an accumulation of neurobehavioral factors. Autism, for example, has been associated with idiosyncratic distortions of resting-state neural patterns (Hahamy, Behrmann, & Malach, 2015), and inter-brain coupling is shown to be

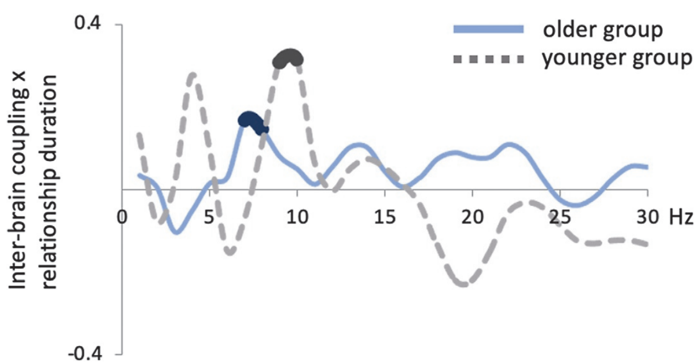

Fig. 3 Correlations between inter-brain coupling and relationship duration by age group. During face-to-face communication, the frequency at which inter-brain coupling was correlated with relationship duration was lower for museum visitors in Athens (blue line; 7–8 Hz; r(302) = 0.1776; $P = 0.0019$), an older demographic than music festival visitors in the Netherlands (dashed line; 9–10 Hz: r(56) = 0.3107, $P = 0.0198$). (Exact age range is unknown).

modulated by the severity of autistic symptoms (Wang et al., 2020). The "misattunement hypothesis" attributes autism-related alterations in social cognition not to a single mechanism but rather to an interpersonal mismatch in neurobehavioral patterns that stem from a complex interplay of factors at multiple levels of description (Bolis, Balsters, Wenderoth, Becchio, & Schilbach, 2017).

3.2 Deriving meaning

3.2.1 Lexico-semantic processing

We know the most about age-related changes in language processing from studies that have focused on processing outside of a social/conversational context and that have often used single words or isolated sentences. This body of work has shown that the structure of the language network remains fairly stable across age. Older adults generally match or outperform education-matched younger adults on vocabulary measures (Salthouse, 1993), produce similar patterns of semantic associations (Burke & Peters, 1986), and show similar effects of orthographic neighborhood size (Payne & Federmeier, 2018). However, older adults differ in the dynamics with which activation levels are adjusted in that stable network during online processing. This can be seen even at the single word level, as, for example, in alterations in repetition and semantic priming effects on the N400 (Jongman & Federmeier, 2022; Kutas & Iragui, 1998). More notable changes are attested for sentence comprehension, especially when successful comprehension requires the effective deployment of cognitive control mechanisms to maintain, select, or revise incoming information, as, for example during ambiguity resolution (Lee & Federmeier, 2011; Stites, Federmeier, & Stine-Morrow, 2013; see also review by Stine-Morrow, Miller, & Hertzog, 2006). However, age-related differences are apparent even for the comprehension of simple sentences, as older adults manifest reductions in the incremental accrual of context information (Payne & Federmeier, 2018) and in the ability to make use of weakly constraining context information (Wlotko & Federmeier, 2012). One particularly striking pattern is that older adults often fail to show patterns in ERP associated with the use of predictive preactivation. Older adults do not show predictive effects on articles that match upcoming nouns (DeLong, Groppe, Urbach, & Kutas, 2012) or N400 facilitations for unexpected words with predicted features (Federmeier, McLennan, Ochoa, & Kutas, 2002). They also do not show anterior positivities to prediction violations (Wlotko, Federmeier, & Kutas, 2012). Thus, whereas younger adults often seem to comprehend in a mode that emphasizes active anticipation of and preparation for likely upcoming information, older adults instead often seem to adopt a more "passive" comprehension strategy, which is less attentionally-demanding (see review by Federmeier, 2022).

These age-related changes in the use of predictive preactivation are particularly important in the context of communication dynamics and accommodation because one impact of preactivation is to fundamentally shift the time course with which information becomes and stays available. When younger adults are predicting, they preactivate information about likely upcoming words (DeLong et al., 2012; Dikker & Pylkkanen, 2011; Dikker & Pylkkänen, 2013; Dikker, Rabagliati, & Pylkkänen, 2009; Van Berkum, Brown, Zwitserlood, Kooijman, & Hagoort, 2005), in a manner that is timed to anticipate the presentation of that word (Dikker & Pylkkänen, 2013; Hubbard & Federmeier, 2021). When the prediction is successful, the processing of that predictable word is then reduced at the time that it is actually encountered (Rommers & Federmeier, 2018a)—with downstream consequences for how well it will later be remembered (Hubbard, Rommers, Jacobs, & Federmeier, 2019). When, instead, predictions are violated, additional processes are brought online to allow revision and to deal with the conflicting representation of the erroneously preactivated information (as seen in the anterior positivity and increases in frontal theta power; Federmeier, 2007; Rommers, Dickson, Norton, Wlotko, & Federmeier, 2017), which lingers and also affects later memory (Hubbard et al., 2019; Rommers & Federmeier, 2018b). Thus, when listening to the same sentence, comprehenders who are preactivating information and those who are not will be using different neural systems over time and will be activating even the same information with different time courses, creating a basic misalignment of their processing states.

3.2.2 Linguistic encoding during naturalistic comprehension

Although differences in comprehension outcomes have been reported between younger and older adults, how this relates to the encoding of specific levels of linguistic information remains a major unknown. Language is hierarchically structured, comprising speech units that build in size and complexity (e.g., phoneme, syllable, morpheme, word, phrase, sentence). In young adults listening to continuous speech, such as an audiobook, neural responses encode features across the entire hierarchy (Gwilliams, 2020). One hypothesis, already discussed above in the context of lexical-semantic preactivation, is that younger and older adults recruit different processing strategies, implicating the generation of different linguistic features to resolve comprehension. For instance, if sensory processing is compromised in an older adult, they may compensate by more heavily relying on higher-order language features (e.g., sentence structure, grammatical predictions) in order to aid interpretation of the features that are closer to the sensory input (e.g., phoneme and syllable identity). In this case, there would be a larger difference between the encoding of higher and lower order features in the older adult as compared to the younger adult (Payne & Silcox, 2019).

An alternative hypothesis is that younger and older adults recruit the same set of neural processes, and therefore generate the same set of linguistic features, but in a different temporal order. In younger adults, it has been found that higher-order features such as sentence structure are encoded earlier than lower-order features such as speech sounds (Gwilliams, 2020). This "reverse hierarchy" arises because a higher-order structure is predictable over longer timescales than a lower-order structure. One possibility is that, if the older adult predicts upcoming speech to a lesser extent, their processing instead unfolds under a compositional feedforward hierarchy, whereby smaller sensory units are processed before larger abstract ones. This would entail a fundamental disconnect between the order of operations occurring in the younger and older brain.

A final hypothesis we offer is that, in the younger and older brain, the same operations occur, and in the same order, but with a temporal delay. This means that in the older adult it might take X ms longer for a linguistic representation to be generated. This would then have cascading effects later in the processing chain, culminating in an overall large processing delay (Gwilliams & King, 2020).

By testing the encoding of a suite of hierarchical linguistic representations during naturalistic listening, it will be possible to discriminate between these different hypotheses and ultimately associate different processing strategies with listener age and comprehension ability.

3.2.3 Predictability and discourse coherence

Younger and older adults may not only differ in the use of predictive preactivation during language comprehension, but the speech of younger and older adults may also vary in its predictability. Discourse coherence refers to the degree to which the overall topic under discussion is preserved across conversations. The more coherent a discourse, the more that the speaker is maintaining a theme of conversation and the more likely that the listener will be able to understand the meaning intended by the speaker. Although younger and older adults are remarkably similar in a variety of conversational discourse abilities (Pereira et al., 2019), older adults have been found to produce less globally coherent discourse, especially when recounting personal experiences (Pereira et al., 2019; Wright, Koutsoftas, Capilouto, & Fergadiotis, 2014). If the speech of older adults includes more tangential asides and is less globally coherent, it may be more difficult for a listener to actively predict upcoming information in the discourse. As a result, an intergenerational conversation may be marked by differences not only in the overall propensity of each of the interlocutors to predict, but also by differences in the predictability of the content of the conversation. As a result, neural activity between younger and older interlocutors may be more coupled if both conversational partners adopt processing strategies that "passive"—i.e., reactive to the input as it comes, with less investment of attention toward anticipation and preactivation (see discussion in Federmeier, 2022).

Few studies have directly examined how linguistic predictability affects inter-brain coupling between speakers and listeners. In one fMRI study, Stephens et al. (2010) found that communicative outcomes (in this case, memory of a story) were correlated with speaker-listener inter-brain coupling during storytelling. Crucially, this relationship between inter-brain coupling and communicative success was most prominent for neural activity in the listener that preceded the speaker's brain activity, a finding that the authors attributed to listeners successfully predicting the speaker's utterance. Hyperscanning studies involving naturalistic verbal interactions have also suggested that prediction plays a role in inter-brain synchrony (e.g., Dai et al., 2018). More direct evidence for the role of lexical-semantic preactivation in speaker-listener neural coupling comes from an fMRI study that compared high and low cloze-probability utterances and found that speaker-listener inter-brain coupling was indeed affected by sentence-level predictability, both before and during the predicted word (Dikker et al., 2014).

3.3 Keeping up with discourse

3.3.1 Speech tracking

Our brains track the temporal structure of (auditory) information in our environment, a process that has been linked to various behavioral outcomes (Lakatos, Karmos, Mehta, Ulbert, & Schroeder, 2008). Studies suggest that this neural *entrainment* to the speech envelope may be important for language comprehension (Zion Golumbic et al., 2013), where brain-to-speech coupling at frequencies under 8 Hz is linked to segmenting the continuous speech stream into meaningful linguistic units (phonemes, syllables, words, and phrases). Brain-to-speech coupling is mediated by a number of factors, with emerging evidence revealing a complex interaction between tracking and comprehension. While it was long assumed that increased attention to the speech signal leads to increased tracking, which in turn leads to comprehension advantages, more recent studies suggest that the relationship between tracking and comprehension is more nuanced, at times generating seemingly contradictory findings. For example, non-native listeners exhibit tighter entrainment of the speech envelope but lower comprehension rates (Reetzke, Gnanateja, & Chandrasekaran, 2020), whereas in older adults higher entrainment has instead been linked to *better* comprehension (Decruy, Vanthornhout, & Francart, 2019). This study also reported a general increase in envelope tracking as a function of age, with older adults showing the highest entrainment to the speech envelope.

Speech tracking during language production (e.g., Magrassi, Aromataris, Cabrini, Annovazzi-Lodi, & Moro, 2015) also changes with age. For example, Kemper and colleagues (Kemper, Hoffman, Schmalzried, Herman, & Kieweg, 2011) modeled age-related changes in speech planning, speech production, and speech output monitoring, and found that older adults experience increased costs associated with each of these stages. Post-production cost was especially high for long, informative, or high-rate utterances. It is not unlikely that this underlies the finding that older adults tend to produce not only less fluent, but also less complex language (e.g., Kemper, Herman, & Lian, 2003).

This increased cost associated with language production may also be partly responsible for the fact that speech rate slows down as a function of aging (Linville, 2001). In fact, this age-related speech attribute is so consistent that if listeners are asked to infer the age of a speaker, they associate slower speech with old age above and beyond any other cue (Harnsberger, Shrivastav, Brown, Rothman, & Hollien, 2008; Skoog Waller, Eriksson, & Sörqvist, 2015).

To our knowledge, language comprehension research has not directly asked how the ability to comprehend or align with spoken information changes with the age of the speaker. Some indirect evidence that slow speech rates may benefit comprehension by older adults comes from studies comparing older and younger adults in how they comprehend language presented at different rates, often under adverse listening conditions (such as noisy or multispeaker contexts, or impoverished speech). A series of studies conducted in the 1980s (reviewed in Kemper & Anagnopoulos, 1989), suggested that speech rate affects speech comprehension in older adults.

For example, at normal or fast speech rates, older adults are still able to accurately segment speech, but they remember less of what they heard (Wingfield & Stine, 1986). More recently, Wingfield, Peelle, and Grossman (2003) presented syntactically complex and simple clauses at different speech rates and found that older adults had more difficulty comprehending, and Mesik et al. (2021) found that older adults show stronger cortical-tracking of word-level features than young adults (again under adverse listening conditions), although their overall comprehension score was higher than that of younger adults.

3.3.2 Turn-taking in dynamic discourse

Thus far, we have discussed mostly findings from studies wherein communication is unidirectional: participants take on the role of the listener or, more rarely, the speaker. Needless to say, dyadic interaction most often takes the form of a dialog, where speakers and listeners swap roles at fairly short intervals (in the order of seconds). Turn-taking behavior plays a key role in dyadic conversation both to facilitate mutual comprehension, but also to foster interpersonal relationships more broadly (Menenti, Pickering, & Garrod, 2012; Pickering & Garrod, 2004, 2021).

The typical gap or offset of a turn is about 200 ms. It has been suggested that this rapid timing can only be achieved if speakers and listeners actively predict both linguistic content and the timing of the turn (Levinson, 2016), and if comprehension and production processes temporarily overlap (Jongman, 2021). Wilson and Wilson (2005) further suggest that shared neural entrainment to the speech rhythm by both the speaker and the listener supports tightly locked turn-taking and helps prevent speakers and listeners from starting to talk at the same time. Upcoming turns can be anticipated based on word-by-word lexico-semantic predictability, with highly predictable words more likely to coincide with the end of a turn (Garrod & Pickering, 2015). Given the documented age-related changes in both timing and prediction, then, one might expect age-related turn-taking differences. To our knowledge, however, while turn-taking behavior has been studied in early development (Holler, Kendrick, Casillas, & Levinson, 2015), variation in turn-taking in older adults is not well-documented.

In hyperscanning research, several studies have reported a relationship between turn-taking and interpersonal neurophysiological coupling (Nguyen, Schleihauf, et al., 2021; Pan et al., 2020; Wohltjen & Wheatley, 2021). For example, Nguyen, Schleihauf, et al. (2021) found that turn-taking, but no other qualitative measures, predicted inter-brain coupling over the course of a conversation in parent–child dyads; and a recent study has shown that the rise and fall of pupil synchrony align with turn-taking behavior (Wohltjen & Wheatley, 2021). This work highlights the importance not only of studying dynamic interactions, but also of examining the dynamics of inter-brain coupling within utterances.

3.4 Accommodation

The findings reviewed thus far underscore that verbal communication recruits multiple mechanisms at multiple levels of representation and that aging affects both how and the extent to which different mechanisms are used during comprehension. Importantly, linguistic communication processes and outcomes are subject to individual differences at all ages, due to factors ranging from verbal fluency and literacy (Federmeier, Kutas, & Schul, 2010; Huettig, Singh, & Mishra, 2011; Ng, Payne, Steen, Stine-Morrow, & Federmeier, 2017; Ng, Payne, Stine-Morrow, & Federmeier, 2018; Stites et al., 2013), to gender, socio-economic status, and regional features. Comprehension patterns can also shift within individuals, even within a single experimental session, in response to a wide range of task demands (Brothers, Swaab, & Traxler, 2015; Brothers, Swaab, & Traxler, 2017; Fischer-Baum, Dickson, & Federmeier, 2014; Lau, Holcomb, & Kuperberg, 2013; Payne & Federmeier, 2017; Wlotko & Federmeier, 2015). For example, Brothers et al. (2017) showed that behavioral and neurophysiological signatures of prediction increased when young adults were encouraged to predict but decreased when the stimulus set included many unpredictable sentence endings, which thus rendered prediction less useful as a strategy. Similarly, older adults, who are overall less likely to exhibit signatures of predictive preactivation, have been shown to do so under some conditions (Dave et al., 2018; DeLong et al., 2012). These adaptations to the task and stimulus set occur at even smaller time scales: Examination of trial-by-trial variability in sentence processing by both younger and older adults (Jongman & Federmeier, 2022; Jongman, Xu, & Federmeier, n.d.; Payne & Federmeier, 2017) has revealed that prediction is differentially engaged across items, even within the same individual and the same task. Importantly, then, processing strategies are not fixed, but can be adapted—a process that could potentially be leveraged to aid alignment and allow more successful coupling.

Sociolinguists have extensively studied how individuals may adapt (accommodate) their language use in conversational settings. In addition to coordinating turns, conversational partners can flexibly adapt their communication to accommodate a wide range of their partner's communicative behaviors ranging from low-level features (Giles, 1973; Giles, Coupland, & Coupland, 1991) such as speech rate (Szabo, 2019) to syntactic structure (Gries, 2005; Hardy, Messenger, & Maylor, 2017). Strategically converging attributes of one's speech to be more like a conversational partner may be an effective strategy to convey the motivation to gain social approval or improve the communicative efficiency of the interaction. Across a variety of contexts, it has been found that when a speaker perceives that their communication partner sounds more similar to themself, the partner is perceived to be more predictable and supportive (Coupland, 2010). For example, in the English and French bilingual context of Montreal, speakers of English view speakers of French more favorably if they converge toward English, and vice versa, even though the convergence necessarily means that one communication partner is speaking in their less dominant language (Giles et al., 1991).

Although convergence to a partner's speech is often viewed favorably, the intentions of the converging speaker can impact how attempts to converge are interpreted by the communication partner. "Overaccommodation" refers to cases in which a speaker's attempt to converge is perceived by their conversation partner as unnecessary and possibly demeaning or mocking (Giles, Mulac, Bradac, & Johnson, 1987). Overaccommodation viewed as a key issue in the context of intergenerational communication, which can differ from communication between interlocutors of a similar age not only due to possible differences in competence of the communication partners, but also from *perceived* differences in competence. For example, physical attributes of the elder communication partner such as gray hair, wrinkles, and repetitive speech may prime younger communication partners to overaccommodate their speech by slowing their speech rate, speaking louder, or making simpler lexical choices in the interaction, even when these accommodations are unnecessary (e.g., Chen, Joyce, Harwood, & Xiang, 2017; Ryan, Giles, Bartolucci, & Henwood, 1986). These speech accommodations, often referred to as *elderspeak* in the literature (cf., Samuelsson, Adolfsson, & Persson, 2013), are similar to speech adaptations made by adults in speech to young children, but when used with a competent older adult can have a negative effect on self-esteem and psychological well-being (Chen et al., 2017; Hummert, 1994) as well as negative health outcomes (Williams & Herman, 2011). Additionally, overaccommodating speech from a younger adult conversing with an older adult may constrain the older adult's set of possible responses, thereby leading to a negative feedback loop in which the elderly interlocutor only engages in simple communication, which in turn reinforces stereotypes in the younger conversation partner (Ryan et al., 1986).

Intergenerational communication marked by overaccommodation and simplified speech may create linguistic and social misalignment, which, in turn, may result in lower inter-brain coupling between the younger and older interlocutors. To the extent that neural coupling is critical for communicative success, it is important to identify the characteristics of speech between younger and older communication partners that afford successful accommodation, as compared to perceived overaccommodation, in order to better understand the circumstances under which intergenerational communication can unfold most effectively.

3.5 Specific predictions for inter-brain coupling in intergenerational conversations

While the research discussed above is by no means exhaustive, an overall pattern emerges that both cortical timing and shared (linguistic) predictions, which are known correlates of inter-brain coupling in dyads, undergo significant age-related changes. This raises the question how these features may affect interpersonal neurophysiological coupling in intergenerational communication and how such challenges may be overcome.

3.5.1 Global patterns

Age-related slowing of both sensory-evoked responses and endogenous oscillations may tend to lead to global differences in inter-brain coupling for intergenerational dyads, compared to their intragenerational counterparts. For example, above we suggested that age-related changes in alpha peak frequency should result in lower intergenerational inter-brain coupling during rest. It is intriguing to speculate that intergenerational dyads might then try to use turn-taking as a strategy to "reset" drifting alignments over time. This scenario, depicted in Fig. 4A, is likely too simplistic because turns are not the only "phase-resetting" events during a dialog. In fact, it has been suggested that endogenous rhythms are subject to interpersonal convergence during dialog via event-related entrainment at the syllabic level (Wilson & Wilson, 2005). Thus, we might expect that any intergenerational drifts in oscillatory profiles are mitigated by speech entrainment. Still, as suggested by the data presented in Fig. 3, the average age of a study population may affect the neural frequency at which inter-brain coupling is predictive of global features of an interaction (such as mood, social closeness).

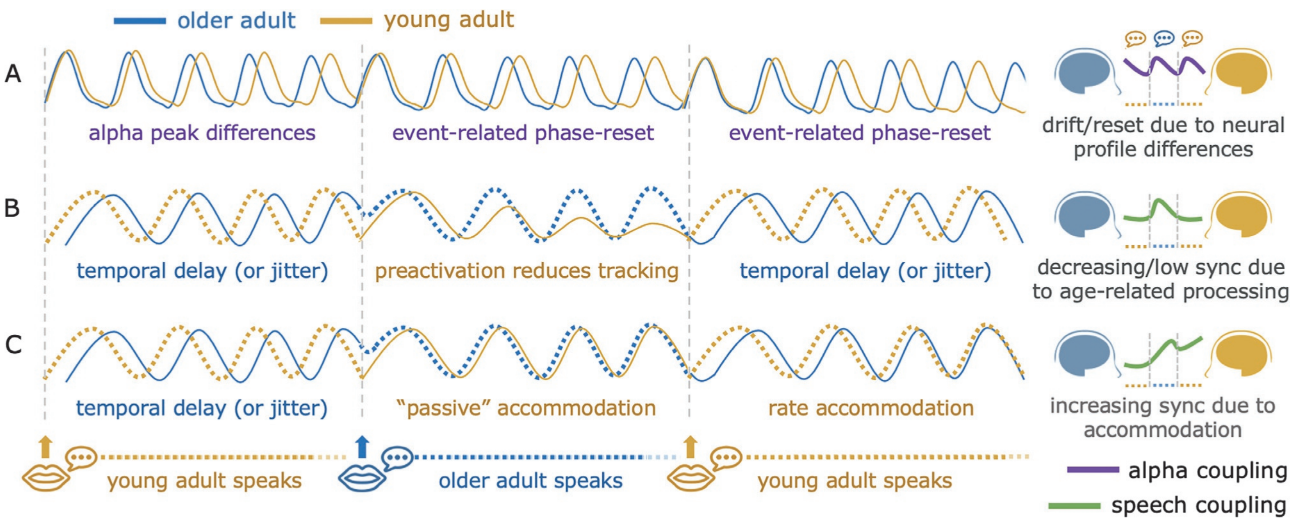

Fig. 4 Schematic scenarios of intergenerational inter-brain coupling during conversation in older adults. Three hypothetical scenarios illustrating how individual speech and brain activity in a young adult (orange) and an older adult (blue) dynamically progresses throughout a dyadic interaction over the course of three turns (“young adult speaks” > “older adult speaks” > “young adult speaks”; left panel), leading to different inter-brain coupling dynamics (right panel). (A) Age-related alpha peak differences lead to inter-individual drift, which is temporarily reset via events (here: turn-taking events). This leads to systematic rises and falls in inter-brain synchrony throughout a conversation (purple line in right panel). (B) A temporal delay or jitter in speech tracking in the older adult (turn 1 and turn 3), and differences in preactivation vs passive processing (turn 2) lead to low inter-brain coupling in turns 1 and 3, and a decay inter-brain coupling over the course of turn 2, respectively (green line in right panel). (C) Accommodation on the part of the young adult may consist of adopting a passive processing style (turn 2) and/or speech rate accommodation (turn 3), leading to an upward trend in inter-brain coupling throughout turns 1–3 (green line in right panel). Icon: Speak by Adrien Coquet from NounProject.com.

As a result, interbrain-behavior relationships may be less easy to detect in intergenerational dyads, depending on whether the inter-brain coupling metric captures possible cross-frequency coupling.

3.5.2 Dynamic and multilayered fluctuations of inter-brain coupling

There are good reasons to suspect that differences between intra- and intergenerational dyadic inter-brain coupling will dynamically vary over the course of an interaction, even within a single turn. For example, in young adult dyads, we might expect inter-brain coupling to gradually increase over the course of a turn as a function of an increase in predictability and thus increased speaker-listener alignment in language representation and timing (Pickering & Garrod, 2004). On the other hand, entrainment to the speech envelope, a known predictor of inter-brain coupling, has been shown to decrease with linguistic predictability (Molinaro et al., 2021). Thus, neural effects of expectancy on envelope tracking on the one hand, and representational similarity on the other, lead to opposite predictions about the time course of inter-brain coupling: while accumulating predictability should lead to *lower* shared tracking, it should lead to *higher* representational convergence. Recall, however, that there is no one way to compute inter-brain coupling. In fact, recent efforts to disentangle entrainment to the speech envelope from "purely" dyadic coupling in linguistic exchanges (Pérez et al., 2017) found that inter-brain coupling between speakers and listeners in the delta and theta band was best explained by entrainment to the audio signal, whereas inter-brain coupling in alpha and beta bands appeared to emerge directly from the interaction. Relatedly, the dataset referenced above (Dikker et al., 2021), showed that dyads who showed higher inter-brain coupling in power at 7–8 Hz (quantified as projected power correlations; Hipp, Hawellek, Corbetta, Siegel, & Engel, 2012), also exhibited higher (non-instantaneous) inter-brain coupling of oscillatory activity at 20 Hz (quantified as Imaginary Coherence; Nolte et al., 2004). These effects might be due to a co-occurrence effect where age-related changes in both alpha peak frequency and beta oscillations are both observed but are not functionally linked. Other "types" of coupling might instead be interdependent. For example, alpha peak frequency drifts may motivate intergenerational dyads to behaviorally (over)compensate during conversations (more turn-taking, more joint action), boosting dyadic coupling during interactions. Hints that such processes might indeed be at play come from recent research showing that inter-brain coupling and behavioral synchrony can be anti-correlated. Djalovski et al. (2021) found that, compared to strangers, romantic couples exhibited the highest behavioral synchrony and lowest inter-brain coupling.

We might thus expect that inter-brain coupling is affected by a complex interplay of the age-related changes reviewed above. Fig. 4B illustrates one possible way in which linguistic preactivation, speech tracking, and the timing of event-related neural responses may affect intergenerational inter-brain coupling dynamics within a turn, and shows that predictions vary depending on who is speaking versus listening (the older vs young adult).

3.5.3 Timing

Age-related neural timing differences are likely to affect inter-brain coupling in intergenerational dyadic interactions in various ways. Fig. 4B illustrates the hypothesis that older adults show a temporal shift, or delay, in tracking and encoding speech compared to younger adults ("young adult speaks", turns 1 and 3). Alternative possibilities are that such a delay is only observed at the beginning of a turn (recall that the N1 response is delayed for older adults relative to young adults for the first word, but not the last word of a sentence; Woodward et al., 1993); or that temporal reordering of linguistic encoding or lower encoding precision (Anderson et al., 2012) in older adults leads to lower overall inter-brain coupling or "jittered" inter-brain coupling.

3.5.4 Preactivation

If the tendency to engage in predictive preactivation differs across an intergenerational dyad, lower coupling may be seen toward the end of a turn (Fig. 4B, "older adult speaks"). This decline may be observed in the beta frequency range, reflecting differences in whether and how predictions are generated and comprehended (Lewis, Schoffelen, Schriefers, & Bastiaansen, 2016; Wang et al., 2012). In contrast, intragenerational older adult dyads may not show a decrease in coupling over the course of a turn: Despite accumulating predictability they may not exhibit a gradual attenuation in brain-to-speech tracking (Molinaro et al., 2021), resulting in a more constant level of entrainment-related inter-brain coupling.

3.5.5 Accommodation

Fig. 4C shows how accommodation on the part of the young adult may lead to increased inter-brain coupling over time. If young adults are able to pick up on different preactivation strategies in their older adult conversational partner, they may be able to adapt their own comprehension strategy to be less predictive—more "passive" (discussed above). Additionally, young adults may adapt their speech to better align with the preferred rate of the older adult (Fig. 4C, third turn). Together, accommodation may lead to an increase in inter-brain coupling over the course of the conversation (Fig. 4C, right panel).

It is important to stress that the scenarios displayed in Fig. 4 are simplistic and non-exhaustive. For example, increased speech envelope tracking in older adults could lead to *greater* overall inter-brain coupling for intergenerational dyads compared to young adult dyads. Additionally, prediction and preactivation has been shown to affect the speaker's neural signal as well, but in exactly the opposite way as the listener's, with *enhanced* rather than reduced activation for previously preactivated words (Dikker et al., 2014; Tian & Poeppel, 2012). Furthermore, the lag between production and comprehension is not taken into account: We would expect a delay of about 200 ms, at least in young adult listeners (Davidesco et al., 2019). Additionally, some research suggests that, at least in certain contexts, older adults are *more* likely to accommodate their speech rate (either by speeding up or slowing down) than young adults are (Szabo, 2019). It is an open question whether this also applies to comprehension strategies—e.g., whether older adults might engage in more predictive preactivation to accommodate to younger adult linguistic processing.

In sum, along the lines of the misattunement hypothesis referenced above (Bolis et al., 2017), one might expect a complex, but systematic interaction between different levels of representation to lead to differences in inter-brain coupling in intra vs intergenerational dyads that may vary by frequency and inter-brain coupling metric. A mix of inter-brain coupling dynamics may arise, depending on the degree to which the speakers are successful at achieving similar strategies and accommodating more generally. How and under which conditions these processes come online is subject to future investigation.

4. Discussion

4.1 Communicative outcomes

We began this chapter by arguing that understanding intergenerational language comprehension may be vital in explaining, and ultimately improving, health-related outcomes. We suggested that intergenerational communication involving older adults might be compromised by age-related neurobiological changes, and in prior sections we reviewed a subset of such changes as they relate to timing and prediction.

We cited research showing that, although some decline is reported for highly demanding listening conditions, comprehension is generally well-preserved in older adults. This work suggests that older adults often reach the same comprehension goals, albeit in different ways. However, although such research has been useful for telling us what circumstances or abilities predict better/worse language comprehension by older adults, most of this work has been done in the context of an individual comprehending in isolation. As we argued above, findings from single-individual laboratory research may not extend to social settings, let alone dynamic social exchanges, where successful communication involves the implicit negotiation of topics, timing, and turn-taking, among other factors. Indeed, emerging research supports the idea that the people involved in a communicative exchange and the environmental context in which that exchange takes place are not merely a backdrop to comprehension, but core features with critical implications for comprehension success (Brown-Schmidt, Yoon, & Ryskin, 2015). Moreover, even if comprehension can perhaps be successful despite difficulties with alignment and coupling as a function of the age(s) of the people involved in an interaction, immediate comprehension metrics are not the only outcome of communication. Different patterns of processing dynamics during communication can have downstream consequences for what people remember about the exchange and for a given dyad's ability to communicate further and feel socially connected. For example, even subtle, imperceivable disruptions of the temporal dynamics of a conversation (e.g., through video conferencing) can degrade the pleasantness of a conversation (Powers, Rauh, Henning, Buck, & West, 2011), disrupt turn-taking (Wilson & Wilson, 2005), or send unintentional social signals of disinterest or subordination. These factors, in turn, can harm both trust and social closeness, with possible negative impacts on learning (Bevilacqua et al., 2018), as well as joint (Bang et al., 2014) and health-based decision-making (Stewart, 1995).

Taken together, although clever experimental designs have been instrumental in isolating key language processing mechanisms, one might argue that the complex dynamics of dyadic conversations render them the ideal sandbox to study how the aging human brain supports the kind of interactive network dynamics that are critical for communication and for social interaction more generally (cf. Falandays, Batzloff, Spevack, & Spivey, 2020). In fact, the most effective "brain training" for healthy cognitive aging appears to be regularly recruiting the combination of processes needed to navigate multiperson social engagements (Huxhold, Fiori, & Windsor, 2013): All the sudoku puzzles in the world cannot compete with an afternoon of chit-chatting and playing Dominos on the sidewalk. Conversely, targeting age-related variation in dyadic conversations as a hypothesis space may help deepen our basic understanding of how "low-level" neurobiological factors may matter (and how) in explaining "high-level" communicative outcomes.

4.2 Questions and predictions

At minimum, the data we have reviewed here suggest that signatures of alignment and inter-brain coupling will show age-related differences (e.g., in the frequency bands that matter). To be able to take these into account and bring the right measures to bear in studies looking at communication involving older adults, we need more empirical work looking at inter-brain coupling in older adulthood and methodological refinements that allow us to better capture age-related changes as they come online during naturalistic dyadic interactions. Such refinements may include a better mapping of inter-brain coupling metrics to psychological constructs and a better consensus about analysis procedures (Ayrolles et al., 2021), examining inter-brain coupling dynamics within as opposed to across verbal exchanges, and developing analysis approaches that capture the complex interaction of linguistic processes at multiple levels of representation (Gwilliams & King, 2020).

One core question is whether there are age-related shifts in (the ability to achieve) inter-brain coupling. Older adults may have a harder time aligning and coupling due to factors including increased variability in neural firing (neural "noise"), difficulty sustaining dynamic patterns, sensory changes that result in lost fidelity of the signals that are important for alignment, and/or difficulties with attention and executive control that are critical for regulating neural patterns that are critical for accommodation to a conversation partner or adaptive behavior to a communicative context. If the coupling is reduced for dyads involving older adults, we further need to understand what consequences that might have for comprehension, memory, and social functioning. For example, if the coupling is reduced, does that correlate with a reduced amount of information exchanged and/or less efficient information exchange? Or are there adaptations that make coupling less important for older than younger adults? If coupling remains important but is more difficult for older adults, are there factors that can mitigate against those difficulties?

Beyond possible differences between young and older intragenerational dyads, what are the specific challenges and possibilities for dyads that cross generations? Is the extent of coupling predictive of the same communicative and social outcomes in intra- and intergenerational dyads? And does a "failure to couple" within intra- and intergenerational dyads arise from the same underlying neural cause (e.g., temporal delay in both cases), or is coupling qualitatively different across generations? On the one hand, it is possible that older adults are better able to successfully couple within intragenerational dyads if, for example, alignment is easier when baseline properties of physiology (e.g., frequency of a core oscillation like alpha) or cognitive factors (like speech rate) are more similar in those dyads. On the other hand, it is also possible that older adults may experience more successful inter-brain coupling in intergenerational dyads if, for example, accommodation is easier for younger than for older conversation partners (but see Szabo, 2019).

The ability to accommodate may depend on the level of representation. As we have shown, in addition to "lower-level" factors critical for successful alignment, our review suggests that an important—and thus far largely overlooked—factor that can affect inter-brain coupling, especially in intergenerational dyads, is processing strategy. In particular, age-related changes in the tendency to engage "active" comprehension mechanisms, including predictive preactivation, may yield substantial differences in when information is activated and which processing mechanisms are engaged over the time course of a sentence, discourse, and/or conversation. Failure to couple, therefore, may arise for different reasons—in some cases because brains are performing the same computations but with a temporal delay or jitter, but in other cases because they are performing different computations altogether. These differences, moreover, will themselves be variable as a function of the predictability of the information—such that coupling is likely to fluctuate as a function of elapsed time in the conversation and may do so differently for intergenerational compared to intragenerational dyads, and even for intragenerational dyads of different ages.

Because people seem to have some ability to control their processing strategies, including the deployment of predictive preactivation, adaptation offers an additional mechanism that may be critical for the success of alignment and coupling and an additional dimension along which inter-brain coupling should be studied. Successfully adopting an appropriate strategy may be facilitated by and/or underlie some of the beneficial effects of factors like familiarity and personality that have already been shown to affect inter-brain coupling. To the extent that participants within a dyad can learn to select complementary processing strategies—i.e., if older adults can strategically engage in predictive preactivation when interacting with younger adults or if younger adults are willing and able to adopt more or less predictive strategies—then this may facilitate successful inter-brain coupling in intergenerational dyads, with concomitant benefits for comprehension and social cohesion.

5. Conclusion

While successful communication may lead to better overall health outcomes for older adults, very few studies to date investigate the neural basis of (intergenerational) communicative exchanges involving older adults. As such, the current state of the literature does not permit clear conclusions to be drawn about exactly how successful intergenerational communication is achieved. It does, however, afford some predictions to be tested and some promising questions for future research, along with emerging methods to address those questions.

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