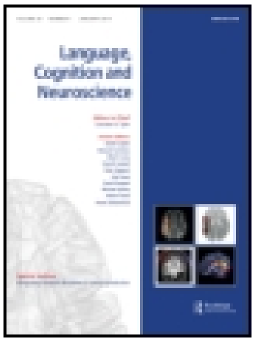

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Putting language back into ecological communication contexts

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ABSTRACT
Language is a multi-faceted form of communication. It is not until recently though that language research moved on from simple stimuli and protocols toward a more ecologically valid approach, namely "shifting" from words and simple sentences to stories with varying degrees of contextual complexity. While much needed, the use of ecologically valid stimuli such as stories should also be explored in interactive rather than individualistic experimental settings leading the way to an interactive neuroscience of language. Indeed, mounting evidence suggests that cognitive processes and their underlying neural activity significantly differ between social and individual experiences. We aim at reviewing evidence, which indicates that the characteristics of linguistic and extra-linguistic contexts may significantly influence communication – including spoken language comprehension. In doing so, we provide evidence on the use of new paradigms and methodological advancements that may enable the study of complex language features in a truly interactive, ecological way.

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Language; social interaction; contextual information; ecologically valid stimuli; communication

1. Introduction

Language is one of the most studied human cognitive functions. The rationale behind this abundance of research is that to a large extent language constitutes what makes us humans: Many other animal species developed communicative systems of different complexity (Fröhlich, 2017; Hari & Kujala, 2009; Scott-Phillips, 2015) yet none of them reaches the highly complex and recursive level of knowledge that constitutes human language (e.g. Berwick, Friederici, Chomsky, & Bolhuis, 2013; Friederici & Singer, 2015).

Despite being one of the most prominent neuroscience fields of investigation, our current knowledge of the mechanisms supporting language is still limited, as most studies employ controlled stimuli created ad-hoc in the laboratory to investigate specific linguistic functions. While this approach greatly advanced our knowledge of the neurobiological basis of language (Friederici & Singer, 2015; Friederici, Chomsky, Berwick, Moro, & Bolhuis, 2017), it lacks continuity with what language stands for: A method of communication *between people* that not only conveys linguistic content but also emotions, intentions, and meta-messages. Recently, researchers have noted this gap and started to utilise a more ecologically valid approach to the study of language. This "shift" started and developed along two main axes: One relating to the necessity of shifting from laboratory-created simple sentences to real stories; the other reflecting the necessity to place language into contexts capturing what really happens in communication. In the following, we review studies from both lines of research with the intent to highlight new paradigms that may facilitate a rigorous investigation of language while also assuring its ecological validity.

2. "Shifting": from sentences to narratives

Human language is an incredibly complex form of communication: In its oral form – speech – it is governed by specific rules concerning how sounds are pronounced (phonology), how they combine together into words (phonotactics) which are then combined into sentences (syntax), how meaning is conveyed (semantics), and how they are influenced by context (pragmatics). To make sense of this complexity, a theory-driven approach has been deemed necessary. Pioneering studies on speech segmentation (i.e. how adults and children identify words in speech) have employed continuous chains of nonsense syllables with different transition probabilities (François, Chobert, Besson, & Schön, 2013; Saffran, Newport, & Aslin, 1996; Thiessen & Saffran, 2003) and word or part-word lists with different phonotactic and

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prosodic characteristics (stress patterns – Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993; allophonic positions – Christophe, Dupoux, Bertoncini, & Mehler, 1994). Moving from words to sentences, classical approaches to syntactic comprehension employed a range from simple to more complex sentence structures (see Meyer & Friederici, 2016 for a comprehensive overview on the neural processing of complex sentences) consisting of either real words or pseudo-words (Friederici, Meyer, & von Cramon, 2000) to contrast syntactically correct structures with incorrect ones (e.g. Friederici, Pfeifer, & Hahne, 1993). An example from one such studies (Friederici et al., 2000) is depicted in Figure 1, Box 1. These experiments are informed by linguistic theories of how speech may be organised and processed at the brain level; accordingly, they utilise stimuli that are typically created ad-hoc to avoid contaminations from linguistic elements other than those of interest; for example, pseudo-words eliminate semantic content and the same speaker records all sentences to exclude any influence of prosodic inflections. This theoretically-driven approach has dominated language research for many decades, and it is still fruitfully employed (Schell, Zaccarella, & Friederici, 2017; Yang, Marslen-Wilson, & Bozic, 2017) with the unmistakable advantage of being elegant and rigorous in unveiling how language is organised at the brain level. However, its downside is being far from "real" language use: We rarely use single words or short sentences, and we more often than not listen to different speakers that use variations of prosodic inflections. Hence, it is unclear if and how these results can extend to everyday language use.

To fill this gap, recent language research has relied more on an ecological approach in which complex, naturalistic, real-life stimuli are employed to unveil the neural processes underlying speech comprehension. For example, stories have been frequently employed (Beeman et al., 2000; Ferstl, Rinck, & Cramon, 2005; Hartung, Hagoort, & Willems, 2017; Haupt, Schlesewsky, Roehm, Friederici, & Bornkessel-Schlesewsky, 2008; Kandylaki et al., 2016, 2017) in both first and second language studies (Hsu, Jacobs, & Conrad, 2015). The degree of naturalness and complexity varies; for example, Haupt et al. (2008) used very short stories and engaged participants in a comprehension task, while Kandylaki and colleagues employed longer texts in the absence of a specific task (Kandylaki et al., 2017). In both cases the stories were artificially constructed to embed experimental linguistic stimuli, with the dual purpose of maximising the ecological validity of the experimental set-up while still enabling a rigorous scientific investigation; a very simple example is provided in Figure 1, box 2. However, other authors adopted an even more naturalistic approach by opting for real tales (Brennan et al., 2012; Whitney et al., 2009) and book excerpts (Hsu et al., 2015). Besides being closer to real-life story telling, stories also allow tackling mechanisms – such as the processing of information spanning over longer time scales – that short phrases would not allow identifying: As stories usually follow a coherent evolution, predictions on what is going to happen next in the narrative can be done based on the evolving context. This process has been explored in an fMRI study by Kandylaki and colleagues, who showed that this type of prediction engages the dorsal auditory stream, comparable with a hierarchical predictive coding architecture (Kandylaki et al., 2016; see also Willems, Frank, Nijhof, Hagoort, & Van Den Bosch, 2016). Such long-range effects could not be detected in classical experimental set-ups that would also not allow marking sustained effects that arise in an evolving story line which generates expectations (e.g. suspense – Lehne et al., 2015).

3. From the individual to the dyad: an interactive approach to language

Another attempt to increasing the ecological validity of language studies is to move from the individual to social interaction (Schilbach, 2014; Schilbach et al., 2013; Verga & Kotz, 2013; Figure 1, Box 3): Indeed, language use facilitates the exchange of information *between* people and therefore should be explored this way. In addition, there are specific situations in which social interaction not only is unavoidable but necessary: From birth to schooling the presence of a social partner – the primary caregiver in infancy (Kuhl, 2007; Mundy, 2017; Mundy & Jarrold, 2010; Tomasello, 2000), teachers and peers in school – is quintessential for the development of linguistic competence. What would happen if we could not rely on such interaction in language development? Reports of so-called "feral" children (i.e. infants deprived of any social and linguistic input from birth or early infancy onward) show that the lack of social and sensory input correlates with severe linguistic deficits. Depending on the severity of the deprivation, improvement of this condition may partially occur only with the re-integration into a caring and socially appropriate environment (Curtiss, 1977; Fromkin, Krashen, Curtiss, Rigler, & Rigler, 1974; Krashen, 1973). Evidence from normal development from childhood to adulthood also support the claim that social interaction improves language abilities: Proficiency in a non-native language not only relates to the age of language acquisition (Arnon, McCauley, & Christiansen, 2017; Johnson & Newport, 1989; Klein, Mok, Chen, & Watkins, 2014; Newport, 1990), but also to the time a person has been exposed to the second language at home or outside in

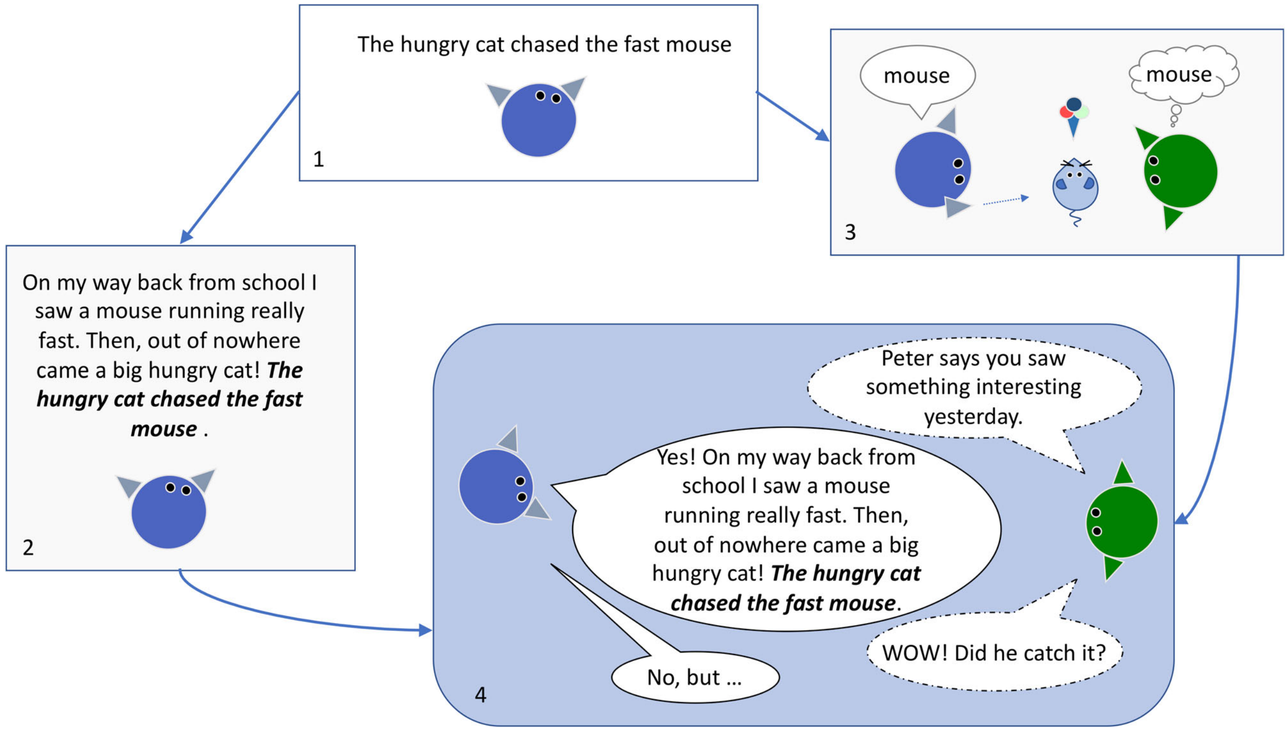

Figure 1. Schematic representation of a classical language stimulus presented to a single participant (1: "the hungry cat chased the fast mouse", extracted from Friederici et al., 2000), and of two possible directions to increase its ecological validity: On the one hand, by shifting to a more complex stimulus embedding the target phrase (as in 2 – Haupt et al., 2008; Kandylaki et al., 2016); on the other, by shifting from the individual to the dyad (as in Kuhlen et al., 2017; Verga & Kotz, 2017). These two approaches may ultimately be combined into a complex setting reflecting an ecological interactive conversation (4).

social situations (Consonni et al., 2013; Perani et al., 2003): The larger the exposure, the more native-like a language will become.

Although in both previous examples the relevance of social interaction has been "hinted at", only a few studies directly explored its impact on complex linguistic interactions such as language learning (Jeong et al., 2010; Verga & Kotz, 2017; under review), interviews (Jeong et al., 2011), and conversations (Kuhlen, Bogler, Brennan, & Haynes, 2017). These studies consistently demonstrated that a social partner (as opposed to a computer or a non-social setting) influences communication either by enhancing temporal coordination between partners with the purpose of boosting their attention (Verga & Kotz, 2017) or by enhancing the activity of brain regions recruited for the task at hand (Jeong et al., 2010, 2011; Kuhlen et al., 2017). For example, regions involved in language learning such as the Supramarginal and Middle Frontal Gyrus are more active when healthy adults learn words in a social as compared to a non-social context (Jeong et al., 2010); activity of the mentalizing brain network is boosted when participants undergo an interactive interview as compared to a semi-interactive one (Jeong et al., 2011), and areas in the Prefrontal Cortex, involved in the processing of socio-affective information, are recruited when responding to a human partner but not when participants speak in a non-conversational setting (Kuhlen et al., 2017). This last study in particular testifies a growing interest in a more ecological approach to language based on its most common contextual use – dialogues. In addition, it proposes a new set-up showing that communication can be explored in interactive conditions without the need to reduce it to mere observation (Jeong et al., 2010) of social scenes (Schilbach, 2014; Schilbach et al., 2013).

The shift from an individual to a dyadic approach naturally comes with new challenges, both on a methodological as well as on a technical level: Concerning the former, interactive settings include several additional variables that need to be accounted for, such as audiovisual feedback from the partner (e.g. eye gaze, gestures, body movements, etc.) and other aspects related to the quality of the interaction (e.g. affective and emotional components); in addition, social set-ups are technically challenging as imaging techniques have been traditionally tailored for individual settings. Luckily however, the raising interest in interactive paradigms led researchers to find progressively more refined solutions to these issues and – dependent on the purpose of the study – these aspects may be controlled in different ways: Pre- or post-experimental questionnaires are often employed to target emotional, affective, and personality components (Newman-Norlund et al., 2009; Verga & Kotz, under review), and eye-tracking devices are employed to have quantitative measures of the direction and speed of participants' gaze (Koike et al., 2016; Schilbach et al., 2013). These methods can also be combined with sophisticated neuroimaging techniques tailored toward social paradigms. Such interactive approaches are collectively defined as "hyper-scanning" (Montague et al., 2002) as they allow brain activity to be recorded simultaneously from two or more participants; hyper-scanning is currently available for most neuroimaging techniques, including functional Magnetic Resonance Imaging (fMRI; Koike et al., 2016), functional Near-Infrared-Spectroscopy (fNIRS; Liu et al., 2016; Reindl, Gerloff, Scharke, & Konrad, 2018), electroencephalography (EEG; Babiloni et al., 2012), and transcranial Alternating Current Stimulation (tACS; Novembre, Knoblich, Dunne, & Keller, 2017).

In terms of paradigms, a possible way to keep social settings as natural as possible while still controlled is represented by simple interactive games: New set-ups – especially used in combination with hyper-scanning techniques – are often inspired by the long and rich tradition of game-like experiments (King-Casas, 2005; Liu et al., 2016; Montague et al., 2002; Redcay, Dodell-Feder, & Pearrow, 2010; Rolison, Naples, Rutherford, & McPartland, 2018). Indeed, games are probably the most ecological way to study human interaction as they represent a first step in face-to-face interactions as early as in infancy (Bates, Thal, Whitesell, Fenson, & Oakes, 1989; Bornstein, Vibbert, Tal, & O'Donnell, 1992; Laakso, Poikkeus, Eklund, & Lyytinen, 1999) and are, consequently, not perceived as artificial tasks; at the same time, they allow minimising the participants' movements – because they are required to perform a simple and specific task – and eye contact – as participants have to focus on a target (e.g. an object on a screen, a board, etc.) instead of their partner. As they represent a simplified form of communication, game settings are particularly useful in combination with neuroimaging techniques, which usually impose strict requirements on the experimental setting (e.g. avoid movements as much as possible). This allows tackling research questions that cannot be otherwise investigated, such as: Which brain regions are involved in interactive communication? Are the same neural circuits involved in individual and interactive language processing?

Several games have been developed even for adults to investigate how information flows in silent non-linguistic contexts (De Ruiter et al., 2010; Newman-Norlund et al., 2009; Noordzij et al., 2009), linguistic contexts (Verga & Kotz, 2017; Verga, Bigand, & Kotz, 2015), and dialogues (Branigan, Pickering, & Cleland, 2000). In alignment with the aforementioned studies (Jeong et al., 2010, 2011; Kuhlen et al., 2017), these experiments consistently show that participants change their behaviour when interacting with a social partner; for example, they tend to spend more time on the task if they consider interacting with a child as compared to an adult (Newman-Norlund et al., 2009), and both partners' neural activity becomes synchronised in brain areas involved in social cognition (Liu et al., 2016). In addition, when interacting with a human partner as compared to a computer they become faster and more consistent in their behaviour (Verga et al., 2015; Verga & Kotz, 2017), and they show enhanced neural sensitivity to a rewarding outcome (Rolison et al., 2018).

Taken together these results strongly suggest that "social" language competence is largely different from the "individual" language competence investigated so far. However, most of the studies summarised here still simplify language competence by reducing it to tacit communication (Liu et al., 2016; Newman-Norlund et al., 2009; Rolison et al., 2018), single words (Verga & Kotz, 2017), or observed social contexts instead of interactive ones (Jeong et al., 2010). For this reason, while they are a meaningful step in the right direction, new studies are called for that may employ language in a way that is closer to its situational use while still preserving methodological rigour. An example would be to employ stories embedding experimental stimuli (such as in Kandylaki et al., 2016, 2017) as part of a scripted conversation between interlocutors. In the following paragraph, we explore in more detail how these experimental set-ups could be developed and which questions they may answer.

4. A challenge for the future: neural correlates of shared narratives

To further improve the ecological validity of neurolinguistic studies, the shifts in stimulus complexity and from the individual to the dyad need to be merged into a miniaturised in-lab model of natural shared narratives (see Figure 1, Box 4). Indeed, while individual speech studies and communicative (interactive) approaches have been traditionally intended as separated lines of research, both empirical evidence and theoretical accounts (for example see Schilbach et al., 2014; Verga & Kotz, 2013) propose that the behaviour and neural processes of people are significantly different during social interaction. Based on this evidence, we suggest that an important new line of research should investigate whether and to what extent speech processing is influenced by interaction with others. A step in this direction has been done in psychology and psycholinguistics by studying conversations. These investigations have shown that dialogues are governed by several unspoken rules implemented by interlocutors to improve their communicative efficiency. For example, Stivers et al. (2009) found that both overlaps and gaps are minimised when turn-taking occurs in conversations, possibly because interlocutors are able to predict the other speaker's behaviour and prepare their responses accordingly (Corps, Gambi, & Pickering, 2018; Garrod & Pickering, 2009; Levinson, 2016). These rules do not make sense in individual language settings; in addition, they are also likely to influence speech itself. Supporting this claim, a recent study showed that when people are engaged in a conversation their individual speech rates tends to converge (Schultz et al., 2016). This tendency to "fall in synch" is not limited to speech, but also extends to body posture (Shockley, Baker, Richardson, & Fowler, 2007; Shockley, Santana, & Fowler, 2003), gaze (Richardson & Dale, 2005; Richardson, Dale, & Kirkham, 2007; Richardson, Marsh, & Schmidt, 2005), and even neural activity (Stephens, Silbert, & Hasson, 2010) of the conversational partners.

Hence, the timing of utterances and speech rates, behavioural indices (e.g. body postures, gaze), and preliminary neural data all seem to point toward the existence of "alignment" between conversing partners (Koban, Ramamoorthy, & Konvalinka, 2017; Shockley, Richardson, & Dale, 2009; Wilson & Wilson, 2005). The next question to ask is then: Why is this happening? A recent account suggests that the answer – at least for synchronisation at the motor level – lies in our brain's computational limits: Synchronising with other people is more efficient than not (Koban et al., 2017). This account leaves at least two questions open: How does this translate to the cognitive level, and is this invariably happening regardless of who we are interacting with, or do we synchronise better with some people as compared to others?

Concerning the first question, indirect evidence from learning studies suggest that human interaction dynamics may go hand-in-hand with the ability to comprehend and learn both a first language (Louwerse, Dale, Bard, & Jeuniaux, 2012; Pereira, Smith, & Yu, 2008) and a second language (Verga & Kotz, 2017). However, these results refer to learning of isolated words; what is currently lacking is a unifying account trying to catch what happens when rich, complex, naturalistic stimuli are embedded in an equally naturalistic context, such as a dyadic interaction.

The second question requires not only looking at the interlocutors' individual characteristics, but also at how they interplay in dyadic interactions: Every person has different qualities and predispositions toward others that may influence the relation with an interlocutor. For example, extraverted people may feel more comfortable performing a social task as compared to introverts, and yet this may still depend upon who they are interacting with: A particularly hostile partner may frustrate even the more sociable person, while someone who is shy by nature may feel inhibited interacting with an excessively open interlocutor. In other words, it is possible that the way people behave in interactive tasks may depend to some extent on who they are but also who they are interacting with. A study by Pecenka and Keller (2011) investigated this topic in a joint tapping task. The authors observed that people differed in their ability to predict another person's behaviour and that this individual skill influenced the combined performance in a dyad: Dyads in which both members were good "predictors" led to better synchronisation than dyads in which only one participant was a good predictor, and both outperformed dyads in which both partners were not good at predicting the other' behaviour. However, why are some people good predictors while others are not? Pecenka and Keller suggest that this may depend on the ability to mentally generate precise temporal predictions of upcoming events (Pecenka & Keller, 2011). Yet, the form that these mental representations may take is unclear: In a sensorimotor task, such as tapping, they likely relate to motor commands; in other words, good predictors are better at predicting what the partner is going *to do*. In other instances, it may be more efficient to predict what the other person is going to *think*. A recent fMRI study on story comprehension suggests that people may differ in how they make sense of other individuals: While some focus primarily on thoughts and beliefs of others, others prefer to pay attention to more concrete events such as actions (Nijhof & Willems, 2015). An intriguing possibility would be to add an interactive dimension to this task, to evaluate if this preference impacts the ability to synchronise with a partner. For example, using scripted or partially scripted dialogues including both action and mentalizing related content (Nijhof & Willems, 2015), would allow examining if participants who tend to simulate actions differ from those who prefer to focus on other's thoughts in their ability to get "in synch" with their interlocutor (e.g. smoother turn-taking – Stivers et al., 2009, converging speech rates – Schultz et al., 2016, etc.). However, whether these individual preferences also influence how listeners understand a story is one of the questions that still remain open for further investigation.

Due to progressively more complex methods of analysis (e.g. the Cross Recurrent Quantification Analysis – Coco & Dale, 2014; Richardson, Lopresti-Goodman, Mancini, Kay, & Schmidt, 2008; Shockley, Butwill, Zbilut, & Webber, 2002) and techniques (e.g. hyperscanning – Dumas, Lachat, Martinerie, Nadel, & George, 2011; Montague et al., 2002) answers to these questions may finally be within our reach.

5. Conclusions

The use of controlled, ad-hoc created laboratory stimuli has immensely advanced our understanding of how specific language properties are organised in the human brain. However, it is unclear whether the conclusions drawn using these stimuli can extend to real life situations, where humans typically use language as a rich, complex, multi-faceted form of communication between people. Also, due to the advancement of methodological techniques, recent studies have been focusing on trying to fill-in this gap by employing progressively more naturalistic stimuli. The studies introduced in this overview testify not only that bridging the gap between laboratory and real life is possible, but also that it can significantly enhance our knowledge of how language is used in everyday life. Nowadays both attempts to shift from simple to complex stimuli and from an individual to an interactive perspective have passed the "laboratory test". The next necessary step is to combine them to get a real grasp of how complex linguistic communication takes place in natural conversations: a step closer to define what makes us humans.

Disclosure statement

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