Sabine Frenzel: How actors become attractors: A neurocognitive investigation of linguistic actorhood. Leipzig: Max Planck Institute for Human Cognitive and Brain Sciences, 2016 (MPI Series in Human Cognitive and Brain Sciences; 181)

How actors become attractors

A neurocognitive investigation of linguistic actorhood

Impressum

Max Planck Institute for Human Cognitive and Brain Sciences, 2016

Druck: Sächsisches Druck- und Verlagshaus Direct World, Dresden

Titelbild: © GlebStock/shutterstock.com

ISBN 978-3-941504-67-7

How actors become attractors

A neurocognitive investigation of linguistic actorhood

Inaugural-Dissertation

zur Erlangung der Doktorwürde
des Fachbereichs 09
Germanistik und Kunstwissenschaften
der Philipps-Universität Marburg

vorgelegt von
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aus Worms

München, 28. November 2015

Fachbereich Germanistik und Kunstwissenschaften der Philipps-Universität Marburg (Hochschulkennziffer 1180).

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Für meine Familie

Acknowledgment

While writing these lines, I have been thinking how it all began. I guess, it all started with my appreciation for enjoying a good glass of wine at the DGfS & GLOW summer school in Stuttgart in 2006, where I met Ina and Matthias. I would like to thank them for their boundless support and confidence in me throughout this entire endeavor.

Throughout my time at the Max Planck Institute for Human Cognitive and Brain Sciences and also at the Philipps-Universität, I would like to especially thank my office mate R. Muralikrishnan, who helped me through seemingly endless scripts and taught me about the beauty of graphics outputs in R. He is one of the most patient and understanding people I have ever worked with and that despite my complete ignorance with respect to any type of program without a user interface when I first started out. My time in Leipzig was both inspiring and very intense in terms of learning everything about scripting, experimental procedures, statistics and the neuro-business altogether – in short: everything in relation to this dissertation. The people I would like to thank helping me through all this are Dietmar Roehm, Kamal Kumar Choudhary, Luming Wang, Susann Wolff, Ina Koch and Kerstin Flake. A special thanks goes to Sylvia Krauspenhaar for her invaluable support in the lab but also as a dear friend, who gave me shelter whenever I needed a place to stay in Leipzig.

Once arrived in Marburg, I could always count on the support of Markus Philipp (who helped me in the very beginning long before I started with my Ph.D. in Leipzig), Franziska Kretschmar, Sarah Tune, Jona Sassenhagen, Andreas Jansen, Jens Sommer, Henriette Schneider-Haßloff, Mechthild Wallnig und Rita Werner. My time in Marburg is inseparably connected to Alexander Dröge, Laura Maffongelli and Phillip Alday. Rödelchen, you are the most diligent and eager lab assistant I have ever worked with. When there was no relying on the Deutsche Bahn, you or Laura lend me a place to stay and helped me in the lab whenever possible. Phillip, you were my brain, when I was lost in the world of numbers and formulas. Your feedback on the last chapters of this dissertation was invaluable and I am glad, you took the time to skype with me despite nine hours time lag. Thank you my

three Marburg musketeers! Last but not least of the people I connect with Marburg, I would like to express my thankfulness to Arne Nagel, a mentor in all academic matters, and dear friend. Thank you for being there for me, when I needed advice in academics and beyond.

Finally, I want to thank my entire family and all my friends, especially my parents Leonie and Otto Keller, who supported me all along although they never really knew what exactly it was that I did. Together with my, mother-in-law, Marion Frenzel, they always jumped in, whenever their grandson could not go to the daycare center because of the cold season, holidays, the teachers decided to go on strike, they had staff training, etc. To my grandparents Irmgard and Philipp, I would like to say: “Ja, ich bin jetzt endlich fertig mit der Schule”. Thank you for being so patient with me. Another special thanks goes to Carolyn Seybel. Caro, you suggested to go to the summer school in Stuttgart in 2006 and, therewith, set the ball rolling. You were always there for me and gave me that gentle but determined pushed in the right direction when I needed it. Now, I will be there for you. If I could do it, you can do it all the more!

Last but not least I would like to thank the two most important men in my life, my husband Oliver and my son Moritz. My love, if it wasn’t for you, I would have never thought of even considering graduate studies. Especially during this very intense last year, you kept my back free and supported me in every possible way – you are my soziales Unterstützungssystem. Moritz mein Herz, if it wasn’t for you being such an open and kind little boy, who always enjoyed being around other people be it at day care, with neighbors, nanny, friends or grand-parents, I would still be writing. I love you both endlessly and cannot put in words how thankful I am to have you.

1 Introduction

The present dissertation investigates neural correlates of actor identification during online language comprehension. A linguistic actor is associated with the participant that is the most responsible for the state of affairs described. The ease at which linguistic actor identification is accomplished during online language comprehension depends mainly on an event participant's prominence status, just like Hollywood actors, who are more easily recognized in public the more prominent they are. For instance, high prominence of linguistic actors correlates with animacy, such that humans are more prototypical actors than inanimate objects, but also with further language specific notions such as nominative case marking in contrast to accusative case marking. Accordingly, a deviation from a prototypical actor with respect to its prominence features hinders online language comprehension, which will be outlined in more detail in chapter 1.1. The cross-linguistic generalizability, as well as the recruitment of general cognitive processes (e.g. the detection of animate versus inanimate objects during actor identification) suggests that language processing is not special to our brain. Rather, it is proposed to follow more basic mechanisms of information processing (e.g. Alday, Schlesewsky, & Bornkessel-Schlesewsky, 2014; Bornkessel-Schlesewsky & Schlesewsky, 2013a; Bornkessel-Schlesewsky, Schlesewsky, Small, & Rauschecker, 2015). The present dissertation thus aimed to investigate, which basic psychological mechanisms are recruited during online language processing in general, with a focus on the identification of a linguistic actor as one of the core processes in order to comprehend language.

In chapter 2, the first publication reviews an online questionnaire and an electrophysiological experiment, using event-related potentials (ERPs). It examines word-level semantics during actor identification, by investigating the impact of an event participant's inherent 'actorhood' potential. This potential was determined according to first, an adaptation of the three dimensions of affective meaning (evaluation, potency and activity), originally put forward by Osgood, Suci, and Tannenbaum (1957), second, findings about non-linguistic agency detection (e.g. Frith & Frith, 1999), as well as third, proto-agent entailments proposed by Dowty (1991). The

second neuroimaging experiment is described in chapter 3 and used functional magnetic resonance imaging (fMRI). In this publication, we investigated how two essential components of our sense of self as human beings, volition and sentience, affect online language comprehension. In this respect, volition denotes our intuition as seeing ourselves or others as deliberately acting agents (Haggard, 2008; Nichols, 2004). Sentience refers to our capability to experience our own mental states, but also those of others. The third experiment is described in chapter 4. It also used fMRI technique and aimed to bridge neurolinguistics and social neuroscience, by examining neural substrates for the effect of the social speaker-hearer relation on the attribution of causality in a linguistic context. The theoretical framework for all three experiments is the (extended) Argument Dependency Model (eADM), which was originally put forward by Bornkessel (2002), and has been refined continuously until today (e.g. Bornkessel & Schlesewsky, 2006; Bornkessel-Schlesewsky & Schlesewsk, 2015; Bornkessel-Schlesewsky & Schlesewsky, 2013a; Bornkessel-Schlesewsky et al., 2015; Schlesewsky & Bornkessel, 2004).

Section 1.1 gives an overview of the notion of actorhood from a linguistic perspective by providing evidence for the relevant prominence scales affecting neural actor identification, as well as the cross-linguistic generalizability of these findings. Section 1.2 briefly outlines the basic architecture of the most recent version of the eADM, including a comparison with other neurobiological models of language. Furthermore, this section describes the underlying principles for actor identification, as well as a motivation for the postulation of a cognitive and neural attractor category for the actor role. An attractor category refers to a neural state, which is associated with a constant and high firing rate of neurons (Rolls & Deco, 2015; Rolls & Webb, 2012). Section 1.3 presents evidence for effects beyond the classic prominence features on online language comprehension, which are envisaged as evidence supporting the idea of an attractor network for the actor role. In the last section of this chapter (1.4), the aim of this dissertation is given. As outlined before, chapters 2 through 4 are dedicated to the publications, which form the core of the present dissertation. Chapter 5 postulates a conclusion and an outlook for prospective research.

1.1 The emergence of linguistic actors and the central role they play in online language processing

The linguistic term actor was introduced by Role and Reference Grammar (RRG) (e.g. Foley & van Valin Jr., 1980; van Valin Jr., 1999; van Valin Jr., 2004) in order to describe the generalized semantic relations between the participants involved in a linguistically expressed event (also termed arguments in the following). In contrast to the undergoer, the actor (also called proto-agent according to e.g. Dowty, 1991; or Primus, 1999) denotes the entity that is primarily responsible for a given event. Such generalized semantic roles were introduced in order to explain the cumbersome and sometimes virtually impossible task of linking between form (syntax) and meaning (semantics). For instance, sentences (1) through (7) in Table 1 (examples are taken from van Valin Jr., 2004, p. 65) illustrate that subjects and direct objects can bear a range of different semantic relations. For instance, the roles of experiencer as in examples (4) and (7) or that of recipient as in examples (3) and (5) can be assigned to the grammatical subject and direct object respectively, rendering a one-to-one mapping between syntax and semantics impossible.

Table 1: Simple transitive sentences illustrating form-to-meaning mapping by indicating semantic roles for subject (left column) and the direct object (right column) according to van Valin Jr. (2004).

		Subject	**Direct object**
(1)	The farmer killed the duckling.	Agent	Patient
(2)	The rock broke the window.	Instrument	Patient
(3)	The lawyer received the summons.	Recipient	Theme
(4)	Many tourists saw the accident.	Experiencer	Stimulus
(5)	Sally presented Bill with the award	Agent	Recipient
(6)	The mugger robbed Sam of $50.	Agent	Source
(7)	The clown amused the child.	Agent	Experiencer

Thus, the missing link between syntax and semantics is decoded by the argument structure, i.e. the semantic relationship between the arguments involved in the event described. Traditionally, grammatical theories dealing with the form-to-meaning mapping are verb-centered, such as RRG but also quite different approaches such as Minimalism (e.g. Chomsky, 1995) or Lexical Functional Grammar (LFG, e.g. Bresnan, 2001). They assume in some way or the other that the verb determines the argument structure (for a detailed discussion of predicate-centered versus argument-centered approaches please refer to Kasper, 2011). The perspective adopted by the eADM is quite different in that it proposes an argument-centered approach. The idea behind this approach is twofold. First, arguments are conceptually more basic than predicates (events) with respect to their semantic dependency. For instance, an event such as writing is not possible without a writer or reading without a reader. Second, a verbocentric perspective to argument structure seems inefficient in light of the incremental nature of the mental processing mechanisms underlying language (e.g. Stabler, 1994). This is due to the fact that such a perspective entails that the processing system does not interpret the arguments with respect to their semantic role until a verb is encountered. However in this respect, 'incrementality' presupposes that "[…] the processing system attempts to maximize interpretation at each point within a sentence […]" (Bornkessel-Schlesewsky & Schlesewsky, 2009a, p. 1542). In view of the fact that a pattern in which at least one of the event participants of a transitive sentence precedes the verb is quite common amongst the languages of the world (Dryer, 2005), a verbocentric processing mechanism would render these languages much more inefficient than verb-initial structures, which are cross-linguistically more infrequent.

But what if not the event (verb) determines the semantic relations between the arguments? Over the past fifteen years, research groups around Bornkessel-Schlesewsky and Schlesewsky have provided a compelling amount of evidence that, cross-linguistically, argument interpretation is determined via a variety of different prominence features, which are more or less language specific as outlined in example (8).

(8) Prominence features related to actor-prototypicality (Bornkessel-Schlesewsky & Schlesewsky, 2009b, 2013a; adapted from Primus, 1999):

(a) +self (represented linguistically as the first person singular pronoun, *I*)

(b) +animate/+human	e.g *man* in contrast to an inanimate entity such as *stone*
(c) +definite/+specific	e.g. a definite individual *the man* rather than undefined *a man*
(d) +1st position	the first sentential argument is cross-linguistically biased towards an actor interpretation (e.g. Tomlin, 1986)
(e) +nominative/+ergative	morphological case marking is a language-specific clue that is less relevant in language such as English with impoverished case-marking features (e.g. Bates, Devescovi, & Wulfeck, 2001; MacWhinney & Bates, 1989)

In order to identify the actor in a sentence, the language processing system is assumed to establish a prominence hierarchy between the arguments, such that the actor semantically outranks the other argument with respect to its prominence features. Hence, the more distinct the arguments with respect to their prominence features, the easier the identification of an actor (e.g. Alday et al., 2014). The easiest case of distinction is given in an intransitive sentence with only one event participant. Actor identification is potentially hindered as soon as a second argument comes into play. In this case, both arguments might compete for the actor role depending on their prominence features as outlined in (8). Importantly, effects related to increased competition between two arguments for the actor role are observable even in the absence of verb information, suggesting that prominence features are essential cues during online argument interpretation. To this end, findings about the effect of prominence features on actor identification during online language comprehension had been corroborated for in a range of different languages such as German (e.g. Frisch & Schlesewsky, 2001; Roehm, Schlesewsky, Bornkessel, Frisch, & Haider, 2004) and English (Frenzel, Schlesewsky, & Bornkessel-Schlesewsky, 2011), but also very different languages from a typological perspective such as Turkish (Demiral, Schlesewsk, & Bornkessel-Schlesewsky, 2008), Japanese (Wolff, Schlesewsky, Hirotani, & Bornkessel-Schlesewsky, 2008), Mandarin Chinese (Philipp, Bornkessel-Schlesewsky, Bisang, & Schlesewsky, 2008; Wang, Schlesewsky, Bickel, &

Bornkessel-Schlesewsky, 2009), Hindi (Choudhary, Schlesewsky, Roehm, & Bornkessel-Schlesewsky, 2009) or Tamil (Muralikrishnan, Schlesewsky, & Bornkessel-Schlesewsky, 2015). All in all, these studies provide a compelling amount of evidence for the cross-linguistic generalizability of an actor-centered processing strategy during online language comprehension even in the absence of verb information. The different prominence features and their specific affect on actor identification processes during online language comprehension will be outlined in more detail below.

1.1.1 About the egocentricity of good actors

Although prominent Hollywood actors are often accused of being pathologically self-centered, a healthy awareness of a self (i.e. having a mental state of me) is a prerequisite for true social cognition according to Lewis & Brooks-Gunn (1979). A self-concept is thus also an important prominence feature for linguistic actors. For instance, knowledge about the self can be envisaged as a prerequisite for self-consciousness, which was defined according to Vogeley and Fink (2003, p. 38) “as the ability to become aware of one’s own mental and bodily states (e.g. perception, attitude, opinions and intentions to act) as one’s own mental and bodily states.” Based on findings by Berlucchi and Aglioti (1997), Vogeley and Fink (2003, p. 40) further suggested a feed-forward model of action, which assumes “that 1PP [first-person perspective] creates a literally spatial model of one’s own body, upon which the experiential space is centered.” In other words, before we are able to engage in social interaction, a key component of human self-consciousness is our ability to not only refer to our body schema representation in the brain when we act ourselves, but also when we observe action of another person. Such a feed-forward model of action goes hand in hand with the assumption that first, humans typically feel that they have control over their own actions (e.g. Haggard, 2008), and second, can use this self-as-actor perspective to understand other actors and their actions (Frith & Frith, 2010). The significance of a self-as-actor perspective in linguistics is also recognized by Dahl (2008).

To my knowledge, the literature on effects of a *self-as-actor principle* during online language processing is rather sparse. However, a self-paced reading study in English conducted by Reali and Christiansen (2007) found that object-relative clauses are processed more easily (i.e. reading times at the positions directly adjacent to the relative clause pronoun *that* in sentences

(9) through (12) in Table 2 were significantly faster) when the relative clause subject (indicated in bold) was a first (9) or second person pronoun (10) in comparison to a personal (11) third person pronoun. Interestingly, a comparison with an impersonal third person pronoun (12) did not evoke a processing advantage for object relative clauses.

Table 2: Example stimuli from (Reali & Christiansen, 2007).

	Object relative clause	**Subject relative clause**
(9)	The lady that **I** visited...	The lady that visited **me**...
(10)	The consultant that **you** called…	The consultant that called **you**…
(11)	... the landlord that **they** telephoned…	... the landlord that telephoned **them**...
(12)	…The studies that **it** motivated...	…The studies that motivated **it**...

According to the results of a preceding corpus study, the authors suggest that findings for comparisons (9) through (11) can be accounted for by the relative frequency of occurrence of object relative clauses with a pronominal relative clause subject, which are more frequent in comparison to subject relative clauses (cf. Fig. 2 Reali & Christiansen, 2007, p. 7). Reali and Christiansen (2007, p. 18) thus assume "that exposure to language might provide an additional factor involved in the facilitation of sentences containing pronominal object relative clauses." However, this assumption is not satisfactory in two ways. First, it cannot account for the contradicting findings of sentences with an impersonal third person pronoun (12). Second, it is not clear what is the reason behind the frequency differences. With respect to the first shortcoming, they assume that a direct comparison between the different sentences is problematic because the referent for the relative clause subject in example (12) was introduced in a separate sentence, thus leading to a more complex discourse context, which in turn might have caused an increased working memory load. While this account can explain the overall longer reading times for both subject and object relative clauses in (12), it cannot explain the absence of a processing advantage for subject relative clauses in this condition.

If it is assumed that prominence affects actor prototypicality during online language comprehension and, therewith, actor identification processes as postulated by the eADM, the findings by Reali and Christiansen (2007) can

smoothly be justified (cf. Table 3). Accordingly, relative clause subjects as in (9) with a first person pronoun converge with the self-as-actor-principle and are thus ranked high with respect to their definiteness / specificity in contrast to the matrix clause subject (pronoun > common noun) rendering the argument as a highly prototypical actor (cf. section 1.1.3 for theoretical considerations and experimental findings on definiteness / specificity). The effects for sentences (10) and (11) nicely converge with this assumption, still rendering the relative clause subject as higher in definiteness / specificity but lower with respect to the *self-as-actor principle* in comparison to (9). Sentence (12) still shows an advantage in definiteness / specificity for the relative clause pronoun, but a disadvantage with respect to its animacy status. This suggests that animacy might be weighted heavier than definiteness / specificity in English (e.g. MacWhinney, Bates, & Kliegl, 1984).

Converging evidence for an interpretation along these lines is provided by similar findings on the facilitation of object-relative clauses via animacy of the arguments (e.g. Chen, West, Waters, & Caplan, 2006; Mak, Vonk, & Schriefers, 2002, 2006; Traxler, Morris, & Seely, 2002; Traxler, Williams, Blozis, & Morris, 2005). These studies show that inanimate matrix clause subjects and animate relative clause subjects facilitate object relative clause processing, which is normally more difficult in comparison to subject relative clause processing. While Traxler et al. interpret these finding to reflect effects of animacy on role prototypicality, which are assumed to abandon the processing system's original preference for an argument's role (Traxler et al., 2002; Traxler et al., 2005), Mak et al. (2002, 2006) propose that animacy cues might even guide the processing system's preference for an argument's role assignment .

Furthermore, a prominence based account of actor-prototypicality can also provide an answer to the second shortcoming of the interpretation given by Reali and Christiansen (2007), namely a missing source for the opposite frequencies reported for the usage of pronouns in object versus subject relative clauses as depicted in Table 3. Accordingly, the number of prominence entailments would correctly render the 1st person pronoun as the most proto-typical candidate to fulfill the actor role in a sentence, and leave the impersonal 3rd person pronoun to be the least proto-typical one. Accordingly, prominence could be considered as the missing link in explaining the frequency differences with respect to pronoun occurrence in object-relative clauses.

Table 3: Comparison of frequency of pronoun (PRN) occurrence for arguments in subject position of object-relative clauses (cf. Fig. 2, Reali & Christiansen, 2007, p. 7) and their corresponding prominence features as exemplified in (8). The + in this respect represent the relative rank of the individual prominence cues entailed in the pronouns with respect to the corresponding prominence scale such that +++ > ++ > + > -. Note that the implicated weighting of the prominence cues is just an approximation (cf. Alday et al., 2014).

Frequency rank (high-low)	Prominence features
1st person PRN	+self
	+animate
	+++definite/specific
2nd person PRN	-self
	+animate
	++definite/specific
3rd person personal PRN	-self
	+animate
	+definite/specific
3rd person impersonal PRN	-self
	-animate
	+definite/specific

1.1.2 Actors as animated characters

Just like the quality of an animated character mainly depends on how close he is to a real living being, animate linguistic actors are better than inanimate ones. Accordingly, a number of ERP and fMRI studies investigate the relevance of the animacy status of sentential arguments for language comprehension and production, such as the facilitation of object relative clause comprehension for inanimate matrix clause subjects as outlined above (e.g. Chen et al., 2006; Mak et al., 2002, 2006; Traxler et al., 2002; Traxler et al., 2005; Weckerly & Kutas, 1999), the preference for animate entities as subjects in early word order positions during language production (e.g. Branigan, Pickering, & Tanaka, 2008; Ferreira, 1994), or increased processing cost for arguments that do not differ in animacy during online argument interpretation (e.g. Bornkessel-Schlesewsky & Schlesewsky, 2009b; Frenzel et al., 2011; Frisch & Schlesewsky, 2001; Grewe et al., 2006; Grewe et al., 2007; Muralikrishnan et al., 2015; Philipp et al., 2008; Roehm et al., 2004).

In an fMRI study by Grewe et al. (2007), sentences with either two animate event participants (13) or an animate and an inanimate event participant (14) were compared.

(13) Wahrscheinlich hat der Mann den Direktor gepflegt.

Probably has [the man]$_{NOM}$ [the director]$_{ACC}$ taken care of

'The man probably took care of the director.'

(14) Wahrscheinlich hat der Mann den Garten gepflegt.

Probably has [the man]$_{NOM}$ [the garden]$_{ACC}$ taken care of

'The man probably took care of the garden.'

In sentence (13) both event participants (*the man*, *the director*) are animate and thereby likely candidates for the actor role. In sentence (14) the event participants differ with respect to animacy. The second argument (*the garden*) is inanimate and hence an atypical actor counteracting competition between the arguments for the actor role. Grewe et al. (2007) found increased activation in the left posterior temporal sulcus (pSTS) when contrasting sentences with two animate arguments (13) with sentences with an animate and an inanimate argument (14). They propose that activation in the pSTS correlates with the difficulty of online actor identification processes due to increased competition between the arguments for the actor role. Since the pSTS is also linked with the processing of non-linguistic agency such as the detection of biological motion (e.g. Beauchamp, Lee, Haxby, & Martin, 2003; Grèzes et al., 2001; Grossman et al., 2000; Saygin, Wilson, Hagler, Bates, & Sereno, 2004; Vaina, Solomon, Chowdhury, Sinha, & Belliveau, 2001) or Theory of Mind (ToM) processing (e.g. Frith & Frith, 1999; Ochsner et al., 2004; Saxe, 2006; Saxe & Kanwisher, 2003), it was proposed that the pSTS might be an interface for linguistic actor detection and action understanding (Bornkessel-Schlesewsky & Schlesewsky, 2013b).

1.1.3 Only specific, definite actors stand out from the masses

One characteristic all good Hollywood actors share, is their ability to stand out from the masses in order to be considered for the lead in the next

blockbuster film. Just like their Hollywood pendants, linguistic actors outperform competitors by being more definite and/or specific, a feature that has already been touched upon briefly in section 1.1.1. Evidence for the impact of definiteness / specificity is motivated theoretically by differential object marking (DOM). DOM is a cross-linguistically frequent phenomenon, which describes increased markedness of objects that are high in prominence. The reasoning behind this increase in markedness of the object is that the grammatical subject is typically more actor-like and, accordingly, higher ranked with respect to its prominence features than the object. Examples for differential object marking due to a deviation from a typical prominence hierarchy with respect to definiteness / specificity of the arguments (subject > object) are attested for with respect to definiteness in Hebrew and with respect to specificity in Turkish (e.g. Aissen, 2003)[1].

The impact of definiteness / specificity on online processing of German was investigated with fMRI by Bornkessel-Schlesewsky, Schlesewsky, and von Cramon (2009). They manipulated noun referentiality as a special case of definiteness / specificity, which is based on the referentiality scale put forward by Croft (2003, p. 130) as outlined in example (15).

(15) pronoun < proper name < common noun

According to the scale in (15), they varied referentiality of the sentential arguments (high = proper name, low = bare plural common noun) with respect to their linear order as exemplified in sentences (16) and (17).

(16) Subject-initial high referentiality in subject and low referentiality in object:

…dass | Reinhold | Autorinnen | auslacht/applaudiert.

…that Reinhold$_{SG}$ authors$_{PL}$ laughs-at$_{ACC.SG}$/applauds$_{DAT.SG}$

'…that Reinhold laughs at/applauds authors.'

[1] The difference between definiteness and specificity in this respect can be exemplified with indefinites in English (nouns marked with an indefinite article, *a* or *an*), which are ambiguous with respect to specificity (specific: *I am looking for **a book**, but cannot find **it**.* Non-specific: *I am looking for **a book**, but cannot find **any**.*).

(17) Subject-initial low referentiality in subject and high referentiality in object

. . . dass | Autorinnen | Reinhold | auslachen/applaudieren.

. . . that authors$_{PL}$ Reinhold$_{SG}$ laugh-at$_{ACC.PL}$/applaud$_{DAT.PL}$

'. . . that authors laugh at/applaud Reinhold.'

They found increased activation in the left inferior frontal gyrus (IFG) when the subject was lower in specificity (referentiality) than the object. These findings suggest that the left IFG is recruited when the processing system detects a mismatch between mapping prominence information onto linear order such that the less prominent argument with regard to specificity precedes the more prominent one. In a similar vein are the results reported in an ERP study by Schlesewsky, Bornkessel, and Frisch (2003). They showed that a highly prominent sentence initial pronoun although unambiguously marked for dative or accusative case suppressed a scrambling negativity. Scrambling negativities had hitherto been associated with a non-canonical object-before-subject word order, an effect, which will be outlined in more detail in the next section.

1.1.4 Leading actors are always named first in the credits

A Hollywood actor knows he is the lead if he is named first in the credits. The same applies for linguistic actors across different languages. Generally, the actor-initial preference is a corroboration of the well-established subject-first preference for European languages (German: e.g. Bader & Meng, 1999; Spanish: e.g. Casado, Martín-Loeches, Muñoz, & Fernández- Frías, 2005; Italian: e.g. de Vincenzi, 1991; Dutch: e.g. Frazier & d'Arcais, 1989; French: e.g. Holmes & O'Regan, 1981; English: e.g. King & Just, 1991). However, as will be outlined in the following, an actor-first preference appears more suitable for several reasons. First, object-before-subject structures in German are electrophysiologically associated with a so-called scrambling negativity as mentioned in section 1.1.3. Accordingly, sentences such as (19) with an initial accusative object (underlined) elicit a scrambling negativity in comparison to sentence such as (18) with an initial nominative subject (Bornkessel, Schlesewsky, & Friederici, 2002, 2003a; Rösler, Pechmann, Streb, Röder, & Hennighausen, 1998; Schlesewsky,

Bornkessel, et al., 2003), accounting for the well-established subject-first preference. Note that example sentences (18) through (22) stem from Schlesewsky, Fanselow, and Frisch (2003, p. 120).

(18) Sentence initial nominative subject (baseline):

Gestern hat der Vater dem Sohn den Schnuller gegeben.

yesterday has the_{NOM} father the_{DAT} son the_{ACC} pacifier given

'Yesterday the father gave the pacifier to the son.'

(19) Sentence initial accusative object (negativity in comparison to baseline):

Gestern hat den Schnuller der Vater dem Sohn gegeben. (no effect in comparison to baseline)

yesterday has the_{ACC} pacifier the_{NOM} father the_{DAT} son given

However, an explanation related to word order permutations per se does not suffice, as it cannot account for the absence of a scrambling negativity in dative initial structures such as sentence (20), which theoretically also allow for a passive reading with only one (dative) argument involved (…dass dem Sohn applaudiert wurde. " /...that [the author]DAT applauded was / '...that the author was applauded.') (Bornkessel, Schlesewsky, & Friederici, 2003b). This null-effect can be accounted for by the assumption of the minimality as distinctness (MaD) hypothesis put forward by Bornkessel-Schlesewsky and Schlesewsky (2009a). Accordingly, maximal distinctness is achieved by the fact that there is only one element under consideration. Converging support for this finding is provided by electrophysiological studies on very different languages from German typologically, such as Turkish (Demiral et al., 2008) or Japanese (Wolff et al., 2008). The absence of a scrambling negativity at the position of a sentence initial object in these languages is associated with the possibility of subject drop, which also renders the object the sole overt argument.

(20) Sentence initial dative objects (no effect in comparison to baseline)

Gestern hat dem Sohn der Vater den Schnuller gegeben.

yesterday has theDAT son theNOM father theACC pacifier given

Second, no scrambling negativity is elicited in sentences with pronominal objects as in sentence (22) when compared to the canonical subject initial order (21). The absence of a scrambling negativity for this comparison can

be accounted for by an increase in actor-prototypicality of the sentence initial pronoun due to its high prominence status with respect to definiteness / specificity in comparison to a full-fledged noun phrase as in (19) (cf. chapter 1.1.3), such that the more prominent event participant should linearly precede the less prominent one (e.g. Bornkessel-Schlesewsky et al., 2009; Schlesewsky, Bornkessel, et al., 2003).

(21) Sentence initial subject pronoun (baseline)

Gestern hat er dem Sohn den Schnuller gegeben.

yesterday has he$_{NOM}$ the$_{DAT}$ son the$_{ACC}$ pacifier given

Yesterday he gave the pacifier to the son.

(22) Sentence initial accusative pronoun (no effect in comparison to baseline)

Gestern hat ihn der Vater dem Sohn gegeben.

yesterday has it$_{ACC}$ the$_{NOM}$ father the$_{DAT}$ son given

All in all, these finding further support the significance of different prominence scales for actor identification during online language comprehension.

1.1.5 Its all about the looks

A rather obvious way for a person to become a famous actor is related to their physical appearance such that the most good-looking and well-built actors tend to end up in Hollywood's first squad. Analogously, linguistic arguments can increase their prominence status, if their looks – via overt case-marking – meet their typological standard. Nominative-accusative languages, mark the subject in transitive and intransitive constructions with nominative case. While the subject in intransitive constructions can bear a variety of semantic roles due to its status as the most distinct (sole) argument of a sentence, it is typically associated with the actor role in transitive constructions. In an ergative language, only the actor in transitive constructions is marked with ergative case. Sole arguments in intransitive constructions are pooled with undergoers in transitive constructions. This nicely accounts for the assumption of maximal distinctness within the eADM (e.g. Bornkessel-Schlesewsky & Schlesewsky, 2009a), such that

transitivity is a prerequisite for an argument to engage in competition for the actor role. If there is only one argument involved as in intransitives, there is no need for a special look.

In an ERP study by Frisch and Schlesewsky (2001), they showed that ill-formed sentences with two nominative arguments as in sentence (24) elicit a negativity peaking around 400ms (N400) followed by a late positivity around 600ms (P600) in comparison to their well-formed counterparts as in sentence (23).

(23) Well-formed accusative-nominative:

Paul fragte sich, welchen Angler der Jäger/der Zweig gelobt/gestrieft hat.

Paul asks himself [which angler]$_{ACC}$ [the hunter/the twig]$_{NOM}$ praised/touched has

(24) Ill-formed double nominative:

Paul fragte sich, welcher Angler der Jäger/der Zweig gelobt/gestreift hat.

Paul asks himself [which angler]$_{NOM}$ [the hunter/the twig]$_{NOM}$ praised/touched has

Interestingly, when the second argument was inanimate in comparison to a sentence initial animate argument (which angler – the twig), only a P600 was evoked. This suggests that only the N400 is sensitive to problems during actor identification as it disappears, if animacy is an additional cue besides case to rank the arguments with respect to their prominence. These results nicely show that despite the importance of case-marking for argument interpretation in German (also MacWhinney et al., 1984), it is not the only determining factor. Rather, the findings account for a close interplay between different prominence features, attesting for their importance in order to identify the actor role during online language comprehension.

1.2 The eADM as a neurobiological "screenplay" for online language comprehension

A good movie is dependent on a strong screenplay, which lays out the storyline, but also functions as a manual for the production by giving detailed instructions about the setting, camera angles, etc. The same holds true for an adequate model of language comprehension, which should at least provide a basis for descriptive adequacy for the comprehension of simple transitive constructions (i.e. *who is doing what to whom*). At the core, this presupposes the identification of the main character, the linguistic actor, and the underlying neurobiological mechanisms, which will be outlined in more detail in section 1.2.2. As already outlined in the preceding sections, prominence based argument interpretation can go a long way in explaining a variety of peculiar findings in studies on online language comprehension. All these explanations can be couched within the cross-linguistically motivated extended Argument Dependency Model (eADM). Recently, the model's architecture has been grounded neurobiologically in accordance with the basic design principles of the dual-stream model of speech processing proposed by Rauschecker and colleagues (e.g. DeWitt & Rauschecker, 2012; Rauschecker, 1998, 2011; Rauschecker & Scott, 2009; Rauschecker & Tian, 2000). Spezifically, the eADM's architecture follows five basic neurobiological design principles which include: (1) dorsal and ventral streams of information processing, (2) all processing streams are organized in a hierarchical manner, (3) a meaningful division of labor between dorsal and ventral processing streams, (4) a computational grounding of the processing streams in primate audition, and (5) domain general control functions of the frontal cortex (Bornkessel-Schlesewsky & Schlesewsk, 2015).

In a nutshell (for a comprehensive overview please refer to Bornkessel-Schlesewsky & Schlesewsk, 2015; Bornkessel-Schlesewsky & Schlesewsky, 2013a; Bornkessel-Schlesewsky et al., 2015), the ventral stream functions as an instance of identification and unification of conceptual schemata such as the activation of word-level semantics. It is assumed to be commutative, as the activation of the schemata is not bound to the sequential order of the incoming input. The dorsal stream on the other hand is non-commutative as it serves to combine the sequence of incoming elements into syntactic structure including the computation of

linguistic actorhood. The prefrontal cortex subserves control functions for instance in order to link linguistic processing to behavior rather than language specific computations, such as syntactic structuring (e.g. Friederici, 2012). Furthermore, it is assumed that the integration of information from ventral and dorsal streams is accomplished via the integration of top-down and bottom-up information to each stream. It is further suggested that all functions although entirely based on findings from language processing should apply to domain-general aspects of information processing, providing a ground for an overarching neural network that integrates domain general and domain specific information. Most importantly, the mechanisms of the eADM do not follow a particular linguistic theory. Rather, its processing principles are based on the notion of cross-linguistic applicability and, currently – at least to my knowledge, it is the only model that aims to incorporate cross-linguistic diversity with only one underlying cognitive system, the human brain.

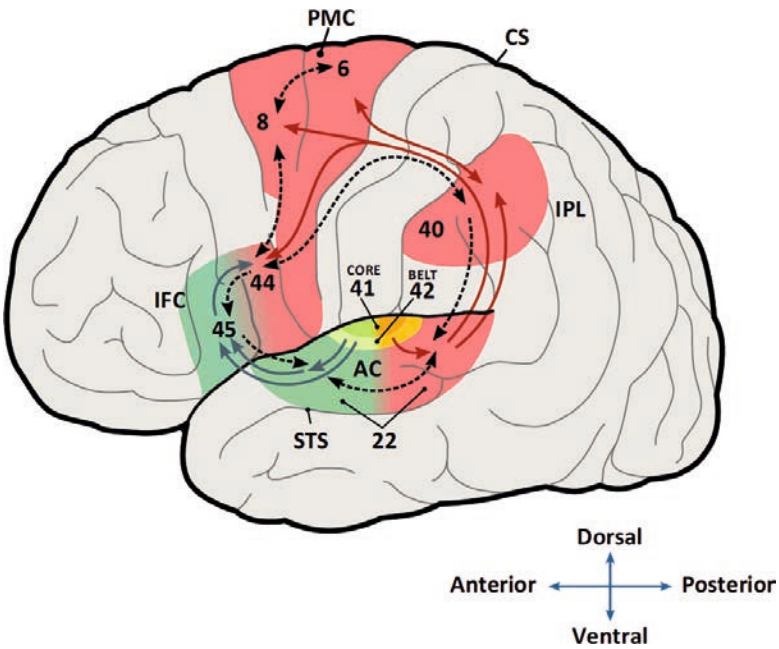

Fig. 1: Schematic description of the dual streams supporting language processing in the human brain according to the eADM (reproduced with permission from Bornkessel-Schlesewsky et al., 2015). Both the (postero-)dorsal (red) and the (antero-)ventral (green) emanate from auditory cortex. Cross-stream integration in the inferior frontal gyrus is depicted by the transition from red to green. Abbreviations: AC, auditory cortex; CS, central sulcus; IFC, inferior frontal cortex; IPL, inferior parietal lobule; PMC, premotor cortex; STS, superior temporal sulcus. Numbers denote Brodmann areas.

1.2.1 Evaluating the eADM in the light of other neurobiological "screenplays" of language

Often times, there are several versions of screenplays for the same film, and the producer has to choose between them. The winning screenplay is usually the most coherent and sensible with respect to the stage directions. One of the advantages of the eADM in comparison to other neurobiological models of language, proposing a dual-stream architecture (e.g. Friederici, 2009; Hickok & Poeppel, 2004, 2007; Saur et al., 2008; Ueno, Saito, Rogers, & Ralph, 2011), is its division of labor between a sequence-

independent ventral stream (anterior temporal lobe) and a sequence-dependent dorsal stream (posterior temporal - parietal lobe), which provides a unifying functional interpretation of the different streams. For instance, Friederici (2009, 2011) assumes that the ventral pathway is subdivided into a stream engaged in semantic processing; whereas a second ventral pathway supports local syntactic structure. Furthermore, she proposes two dorsal pathways, one of which is associated with the processing of complex syntactic structures, dorsal pathway II (if sentences entail embedded clauses or if the word order derivates from the canonical order of a given language) and another one (dorsal pathway II) with sensory-motor integration. At least two fundamental problems arise within this approach: First, the division between simple and complex syntax is highly controversial. The underlying syntactic principles are qualitatively similar (i.e. the underlying computational operations are analogous only differing quantitatively for instance in the number of iterations of the processes). Second, this division of labor contradicts activation of the posterior portion of the superior temporal sulcus (pSTS) within the dorsal pathway, which is evoked when contrasting simple transitive sentences that varied the demands for processes of role identification, i.e. *who is acting on whom* (e.g. Bornkessel, Zysset, Friederici, von Cramon, & Schlesewsky, 2005; Grewe et al., 2007).

Another dual-stream model of language although limited to word-level processes was proposed by Hickok and Poeppel (2007). It assumes that the ventral pathway indexes a lexical interface as well as a combinatorial network. In their approach, the dorsal pathway is exclusively associated with the linking of the auditory input to the motor system. Due to topographical deviations from other dual stream models, this model could possibly account for activation in posterior regions of the temporal cortex in response to sentence level combinatorics (e.g. by Grewe et al., 2007). However, their model only explains phenomena at the word level, and was not meant to account for sentence-level processes. Nevertheless, the role of the dorsal pathway in language, according to their approach, seems unclear, as the major processing load with respect to the activation of lexical semantic information as well as combinatorial processes are both associated with the ventral pathway. Other approaches put forward by Saur, Kreher, Schnell, Kümmerer, et al. (2008) or Ueno et al. (2011) assume a division of labor between language comprehension (ventral stream) and language production (dorsal stream). These accounts also fail to account for the previously mentioned findings by Grewe et al. (2007) and Bornkessel et al. (2005), who both examined language comprehension of

visually presented stimulus sentences in postero-dorsal regions. Accordingly, the eADM's strict division of labor between sequence-independent feature combination into increasingly more complex auditory objects antero-ventrally, and time-dependent predictive sequence processing postero-dorsally can explain a range of different neurophysiological findings on online sentence processing.

1.2.2 How to get discovered as an actor according to the eADM

The following section sketches out the mechanism, which determines how actors are identified during online language comprehension according to the eADM. Unsurprisingly, an argument's prominence status plays a key role in the recognition of an actor in linguistics just like in the film industry. The underlying mechanisms at least with respect to linguistic actor identification are described in the following. As already outlined in 1.2, the neural computation of linguistic actorhood, according to the eADM, is accomplished by the interplay of lexical-activation in ventral processing streams and the sequential structuring in dorsal processing streams (e.g. Fig. 1). Sequence-dependent combinatorial processes within dorsal-processing streams are suggested to initially segment the input into prosodic words, which are then combined in a syntactic structure. Syntactic structuring (sequencing) in this respect is accomplished via simple binary branching without any type of movement or empty categories (Bornkessel-Schlesewsky & Schlesewsky, 2013b). The resulting structure determines an argument's position within a sentence, which in turn serves as an important cue for actor prototypicality (i.e. an argument's prominence status). The interpretation of an argument as the actor is accomplished via AE schema unification in the ventral stream. Sentence-level interpretation is thus based on the activation of AE schemata, which are complete word-level semantic representations (cf. Fig. 2).

Fig. 2: Sample actor-event (AE) schemata (reproduced with permission from Bornkessel-Schlesewsky & Schlesewsky, 2013b)

The schemata are assumed to be combined via schema unification such that the slots *what*, *with whom*, *where*, *when* etc. are filled (for a detailed description refer to Bornkessel-Schlesewsky & Schlesewsky, 2013b). The qualitatively distinct processing streams attest for the independence of sequencing in the dorsal stream from sentence level interpretation through AE schemata unification in the ventral stream both of which are influenced by prominence features that can either be semantic (cf. (8)-(c)) or syntactic in nature ((8)(d) and (e)). The assumption that all prominence features are equally considered for the form-to-meaning-mapping in either of the processing streams thus, refraining from a traditionally strict division between syntax and semantics, is postulated as the "Interface Hypothesis" (Bornkessel-Schlesewsky & Schlesewsky, 2009b, p. 28):

> *"Incremental argument interpretation (i.e. role identification and assessment of role prototypicality) is accomplished by the syntax-semantics interface, that is, with reference to a cross-linguistically defined set of prominence scales and their language-specific weighting."*

As already outlined in chapters 1.1.1 through 1.1.5, there is considerable evidence how the different prominence features affect online language comprehension. However, in order to account for human language processing in general and keeping in mind that all languages rely on the same biological system (the human brain), an overlap between the prominence-based establishment of an argument hierarchy with more general cognitive processes, involved for instance in decision-making, seems worth further examination, thus, forming a point of departure for the present dissertation.

1.2.3 Why actors should be considered attractors

It is indisputable that Hollywood's superstar actors are attractors, mobilizing the masses wherever they appear. Why should linguistic actors be an exception? Bornkessel-Schlesewsky and Schlesewsky (2009b) provide initial evidence for a cross-linguistically valid actor-strategy, according to which the language comprehension system attempts to identify the actor as quickly and unambiguously as possible. In more recent work (Bornkessel-Schlesewsky & Schlesewsky, 2013a, p. 250), they extend this approach by proposing that "the actor role might be a candidate for a cognitive and neural attractor category." Accordingly, actor computation in the brain would follow psychological functions similar to the processes involved in perceptual decision-making (Deco, Rolls, Albantakis, & Romo, 2013; Deco, Rolls, & Romo, 2009), with the actor role constituting a stable attractor category. Within neurobiological attractor network models, attractor states are associated with stable high firing rates.

> *"Which state 'wins' during decision making is determined by the current input and the initial stochastic firing behavior of the network […] We could assume, then, that an attractor network for actor categorization exists independently of language and that, as a result of the general human ability to recognize goal-directed action and to differentiate between self and other, it is universal" (Bornkessel-Schlesewsky & Schlesewsky, 2013a, p. 241f).*

To my knowledge, a first attempt to model language computationally along the lines of attractor networks was put forward by Rolls and Deco (2015). For this attempt they used word-order cues in order to compute a one-to-one linking between syntax and semantics such that the first argument (subject) is interpreted as the more actor-like argument in contrast to the second argument (object) as the undergoer-like argument. For this purpose, they assume a word module consisting of 3 different attractor networks each of which corresponds to a specific syntactic function (subject, verb and object). These attractor networks are interconnected via weak non-selective forward coupling, which is initialized by a small extra input. Once an attractor state is reached, the firing rate decreases but still remains moderately high and stable (spike-frequency adaptation) thereby providing a forward bias to the next word. Such an adaptation allows for a

word to be stored in short-term memory in order to be corrected or repeated later on. Furthermore, they propose a deep module, which is associated with word-level semantics based on the syntactic function, such that the subject is equal to an actor and the object to an undergoer. This deep module is implemented through place coding, which means that different neural regions are associated with the different attractor-pools and, hence, assuming different cortical modules with about 2-3 mm in diameter for subjects, verbs and objects. These modules are assumed to fire continuously, thereby biasing a word attractor in the correct state. Thus, the particular word in a sentence is derived from the selective bias of the deep network, while temporal order is determined by the weak forward non-selective connections between the word modules (cf. Fig. 3).

To this end, the computational implementation provided by Rolls and Deco (2015) cannot easily deal with the reversed word-order for instance in passive constructions in English, where the undergoer precedes the actor argument, let alone languages with a more variable word order such as German. In order to overcome this, they propose two future adjustments. One is associated with an adaptation of a strict feed-forward connection between the attractor modules, such that a set of different couplings between the modules is available (learned by early experience with varying word order patterns), which is triggered by a top-down bias possibly in a similar manner to so-called integrate-and-fire networks implemented in order to map flexible, context- or rule-dependent neural activity observed for instance by task-specific neural firing activity during working memory delay periods in the primate prefrontal cortex (e.g. Deco & Rolls, 2003). Another adjustment, suggests to extend the current model by using a more sophisticated system of coupled interacting attractor networks, so-called Potts attractors (Rolls & Deco, 2015). This extension would allow for each syntactic category (subject, verb and object) to consist of several attractor network modules in order to each code additional properties such as shapes, color, texture but possible also the prominence features as proposed in (8).

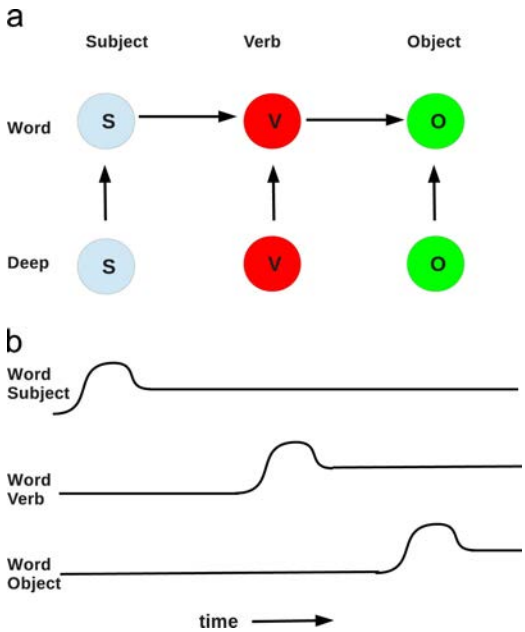

Fig. 3: Schematic diagram of the interplay between word module (top of figure a) and deep layer modules (bottom of figure a). Each circle represents a local cortical attractor network capable of storing 10,000 items. Horizontal arrows between word attractor networks represent the non-selective forward coupling. Vertical arrows correspond to the weak selective bias provided by the deep layer attractor networks to the word attractors. Figure b on bottom depicts the operation in time of the system indicating the initialization by a small extra input to the subject word network. This together with the selective bias from the deep subject network lead to a peak firing and subsequent adaptation during which the firing rate decreases but remains in a moderate firing rate in order to initiate the feed-forward bias to the verb word network, which in turn reaches an attractor state through the selective bias of the deep verb network. A similar process leads subsequently to an attractor state of the object word network (reproduced with permission from Rolls & Deco, 2015).

A first step in order to use a more diverse set of prominence features in order to compute actor-prototypicality was put forward by Alday et al. (2014). They modeled actor identification in simple transitive German sentences based on the different prominence cues as outlined in (8). For this purpose they used the Manhattan metric to calculate the distance between two competing arguments for the actor role based either on language-specific weighted or unweighted prominence features. This weighted distance measure could more robustly replicate N400 amplitude elicited in response to competition between the arguments for the actor role

during online language comprehension in comparison to an unweighted one. The unweighted measure represents similarity-based inferences as assumed for instance by memory based accounts of language processing (e.g. R. L. Lewis, 2000; R. L. Lewis, Vasishth, & Van Dyke, 2006; McElree, Foraker, & Dyer, 2003), which can go a long way in explaining experimental findings on language comprehension and production. The crucial difference between similarity-based inferencing and the proposal put forward by Alday et al. (2014) lies in the language-specific weighting. While the former accounts assume an all or nothing approach to prominence features, such that there either is or is no feature overlap, Alday et al. (2014) propose that certain cues are more important in one language over the other such as case-marking in German versus English in line with findings by e.g. MacWhinney and Bates (1989). Thus, the model implementation put forward by Alday et al. (2014) provides a promising first indication for quantifying effects of attractor basins (cf. Fig. 4) such that the 'depth' of the attractor basins, i.e. the strength of the attractor, corresponds to prominence (Alday et al., 2014).

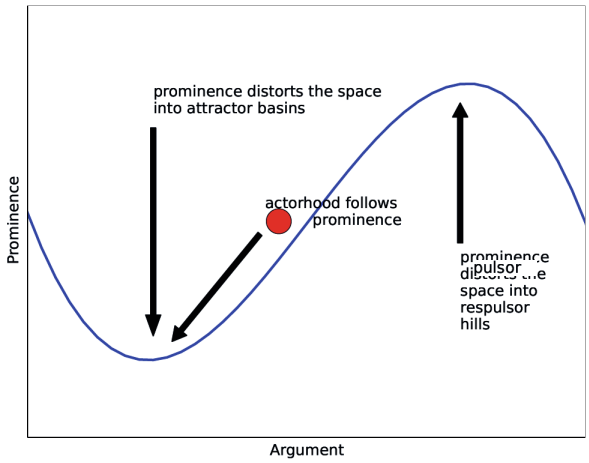

Fig. 4: Attractor basins in actor space. Prominence can be viewed as a distortion of actor space. The curvature of actor space then pulls or pushes actorhood towards a particular argument (reproduced with permission from Alday et al., 2014).

All in all, a computational implementation of language using attractor models (Rolls & Deco, 2015) provides an interesting basis for the processes outlined within the eADM. Accordingly, the sequence-dependent place coding of the deep layer modules might be a plausible solution in order to model the commutative processes associated within dorsal

processing streams within the eADM framework. Additionally, a major drawback of the computational implementation proposed by Rolls and Deco (2015), namely, the assumption that meaning can be read-off the syntactic function of a word, can easily be overcome by assuming category-neutral notions such as actor and undergoer, which are used to build word-level semantic representations, so-called event schemata (cf. Fig. 2) as proposed along the lines of the eADM (Bornkessel-Schlesewsky & Schlesewsky, 2013b). Furthermore, a Potts system could tentatively be a possible candidate for representing cross talk between the dorsal and ventral processing streams representing a selective bias of either stream on the other.

One essential idea behind the application of attractor networks in order to model how language is implemented in the brain is that the underlying mechanisms are in consensus with other functions such as memory, perception, attention or decision-making (Rolls & Deco, 2015). Thus, an investigation towards basic cognitive mechanisms such as the detection of biological motion (e.g. Grewe et al., 2007), which are recruited in order to identify a linguistic actor during online language comprehension, is an important ingredient in order to make realistic modeling of language via attractor networks possible. Accordingly, the present dissertation aims to provide initial evidence for a systematic investigation of neural correlates of basic psychological mechanisms, which are recruited for the identification of a linguistic actor during online language comprehension.

1.3 Good actors outside mainstream prominence

The following section describes how not only certain personal traits, but also societal context encourage an ordinary person's potential to become an actor with mass appeal. If the postulation of an attractor network for the actor role as outlined in section 1.2.3 holds true, it is a logical consequence that prominence features as exemplified in (8) are insufficient in order to account for actor prototypicality and actor identification. On the one hand, some of the prominence features such as humanness might be decomposed further in order to account for the neural correlates associated with biological motion as outlined in section 1.1.2. On the other hand, the

classical prominence features neglect influences from social context. However, the importance of social influences is already indirectly entailed in the self-as-actor perspective such that as a self-perspective is only possible in relation to a social context as outlined in section 1.1.4. Thus, in the following, I will present previous considerations towards a decomposition of the actor role into more fine-grained psychological entailments (section 1.3.1), as well as socio-cultural effects on language comprehension (section 1.3.2).

1.3.1 Actors are not superhuman

Although one might have the impression that all famous actors are superhuman, they are just human like you and me. Thus, their prominence status can sometimes outshine their underlying personal traits. Accordingly, linguistic actorhood is investigated beyond the mainstream prominence features in this dissertation. As outlined earlier, actor identification processes are associated with activation of the pSTS. This region is a robust substrate for the detection of biological motion in the literature, which in turn is associated with the detection of non-linguistic (human) agents (e.g. Frith & Frith, 1999; Opfer, 2002). As shown in a paper-pencil test by Opfer (2002), biological motion is composed of goal-directedness and autonomy of the movement. His results further suggest that biological motion per se is not sufficient in order to unambiguously identify a human agent as adults judge goal-directedness or autonomy with biological rather than psychological attributes. Accordingly, the capability of experiencing a mental state, (i.e. being sentient) is another independent feature for the detection of a human agent (Opfer, 2002). Similar independent actor entailments become evident from a linguistic viewpoint when considering sentences (25) through (28) (adapted from Dowty, 1991, p. 572f; Primus, 2011, p. 94).

(25)	John refrains from smoking	→	volition
(26)	John knows/sees/fears Mary	→	sentience
(27)	Unemployment causes delinquency	→	potency
(28)	Water filled the boat	→	telicity

Sentences (25) through (28) provide evidence that volition, sentience, potency (i.e. to have the power to cause an event or change of state in another participant) as well as telicity (i.e. goal-directedness, as an important dimension of biological motion) can be expressed independently in English. In order to further investigate the actor-as-attractor hypothesis, it seems worthwhile to investigate how these fine-grained actor entailments affect neural correlates of actor-identification an endeavor which was pursued at the core of the first two publications described in chapters 2 and 3.

1.3.2 What determines an actor's mass appeal

Another important aspect, which determines a good actor – in linguistics as well as in Hollywood, is his mass appeal. Therefore, it is critical to investigate the impact of socio-cultural effects on actorhood. Although not addressing this issue directly, an ERP study by van Berkum and colleagues (2008) provides initial evidence for the interaction between the social status of a speaker and the content of his utterance. They found that a discrepancy between a speaker's status with respect to his / her gender (30)(a), social status (30)(b) or age (30)(c) and the content of his / her utterance yields an increased N400 with the classical centro-parietal distribution between 200 and 700 milliseconds in comparison to the congruent baseline conditions outlined in sentences (29)(a) through (c). The latency peak around 400 milliseconds suggested that integration of domain general aspects are integrated during language processing early on. These findings are particularly interesting because N400 modulations are robustly associated with actor identification processes some of which have been reported in previous sections (e.g. Bornkessel & Schlesewsky, 2006; Bornkessel-Schlesewsky & Schlesewsky, 2009b; Frenzel et al., 2011; Frisch & Schlesewsky, 2001; Schlesewsky & Bornkessel, 2004).

The same stimulus material was used by Tesink et al. (2009) in order to investigate neurophysiological correlates of speaker-content-incongruences. Their results show increased activation for incongruent sentences (30) in comparison to congruent sentences (29) in the left inferior frontal gyrus (IFG), the right cerebellum, the left middle temporal gyrus (MTG), the bilateral superior temporal sulcus (STS), the left middle frontal gyrus (MFG), as well as the left frontal operculum. Activation in the left MTG was claimed to index the storage of semantic information, which correlates with

increased unification load (indexed by activation of the IFG). This in turn functions as a top-down control within the unification network (Hagoort, Hald, Bastiaansen, & Petersson, 2004). Thereafter, top-down feedback from IFG to MTG would determine, which information was stored in order to make sure the relevant information is activated for unification to take place (Tesink et al., 2009). The incongruence between the speaker and the semantic content of the utterance was proposed to impede associations between the speaker's voice and the retrieval of word-level semantics, which was associated with increased activation of the MTG where (semantic) representations are suggested to be stored (Tesink et al., 2011).

(29) Congruent:

(a) female: If only I looked like **Britney** Spears in her talent video.

(b) lower-(social)class: I have a large **tattoo** on my back.

(c) adult: Every evening I drink some **wine** before I go to sleep.

(30) Incongruent:

(a) male: If only I looked like **Britney** Spears in her talent video.

(b) upper-(social)class: I have a large **tattoo** on my back.

(c) young child: Every evening I drink some **wine** before I go to sleep.

A recent ERP study by Bornkessel-Schlesewsky, Krauspenhaar, and Schlesewsky (2013) supports the impact of a speaker's social status on early mental processes involved in language comprehension. In their experiment, they contrasted true and false political and general utterances by three speakers with different social statuses (Peer Steinbrück, at the time of data collection, Federal Minister of Finance, Ulrich Wickert, well-known news anchorman, as well as a university professor, who was not known to the participants). Only false political utterances by the politician elicited an increased negativity between 150-450ms (N400 modulation) post stimulus onset while false general utterances elicited an increased N400 by all speakers. Assuming that N400 effects are robust correlates of actor-identification cross-linguistically, the results show decisively that not just the degree of familiarity but the precise social status (linked with the actual potency to act out the utterance) influenced rapid and early language processing mechanisms. Thus, the present dissertation provides evidence how common mechanisms of social interaction, which are considered key-drivers for intergroup dynamics, affect online language comprehension. For this purpose, the last publication investigated the impact of the social

speaker-hearer-relation on actor identification processes during online language comprehension.

1.4 Trailer of the following publications

The following publications systematically manipulate general cognitive notions of linguistic actorhood in order to provide neurophysiological evidence in support of a cognitive and neutral attractor category for the actor role as initially proposed by Bornkessel-Schlesewsky and Schlesewsky (2013b). In a first step, actorhood was thus decomposed into more fine-grained semantic features in order to examine how they contribute to the notion of actorhood with the help of structural equation modeling. Subsequently, it was investigated how the resulting actor potential affected online language comprehension (chapter 2). Event-related potentials (ERPs) were chosen as an experimental method due to their high temporal resolution and, in order to ensure comparability, previous cross-linguistic investigations of actor-identification as outlined in chapter 1.1.

The second study investigated whether underlying neural networks related to volition (willed in contrast to accidental actions) and sentience (actions versus sentient states) directly influenced actor identification during visual sentence comprehension (chapter 3). The third study is concerned with socio-cultural effects on language processing as a first attempt to systematically investigate the impact of the social speaker-hearer-relation on online actor identification processes during auditory language comprehension (chapter 4). This last experiment includes a parametric modulation of actorhood in order to investigate the neural network sensitive to successively increasing actor-prototypicality. For experiments two and three, functional magnetic resonance imaging (fMRI) was used in order to compare our findings with the very rich literature on neural substrates of volition, sentience and social cognition, on the one hand as well as provide additional information for the neurobiological grounding of the eADM on the other.

2 What it takes to be a good actor

Prominence is a common denominator in order to determine the goodness of an actor in Hollywood and linguistics respectively. As already outlined above, the eADM postulates that prominence features determine both actor identification and actor prototypicality in a linguistic context. However, to date, most of the research beyond linguistic factors (e.g. word order of morphological case marking) has been limited to animacy and definiteness/ specificity (cf. section 1.1). In the following experiment, we decomposed the notion of actorhood into more fine-grained dimensions in order to investigate the interplay between bottom-up lexical pre-activation and top-down integration of prominence information in the current sentence context. The idea that even fine-grained semantic features affect linguistic actor identification in a bottom-up manner provides further support for the attractor-principle of actorhood.

2.1 Publication

Peer-Reviewed Article: Frenzel, S., Schlesewsky, M., & Bornkessel-Schlesewsky, I. (2015). Two routes to actorhood: Lexicalized potency to act and identification of the actor role. *Frontiers in Psychology, 6*.

Conference: Poster presented at 23rd Annual CUNY Conference on Sentence Processing 2010, New York, NY, USA; Invited speaker at Donder's Discussions 2011, Nijmegen, Netherlands

My Contribution: For this paper I developed the stimulus material as well as the derivation of the structural equation model. I programmed and analyzed the online questionnaire and the follow-up ERP study, using structural equation modeling as well as mixed effects models. I prepared the manuscript for publication (introduction and discussion partially and methods and results completely).

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ORIGINAL RESEARCH ARTICLE
published: 30 January 2015
doi: 10.3389/fpsyg.2015.00001

Two routes to actorhood: lexicalized potency to act and identification of the actor role

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The inference of causality is a crucial cognitive ability and language processing is no exception: recent research suggests that, across different languages, the human language comprehension system attempts to identify the primary causer of the state of affairs described (the "actor") quickly and unambiguously (Bornkessel-Schlesewsky and Schlesewsky, 2009). This identification can take place verb-independently based on certain prominence cues (e.g., case, word order, animacy). Here, we present two experiments demonstrating that actor potential is also encoded at the level of individual nouns (a *king* is a better actor than a *beggar*). Experiment 1 collected ratings for 180 German nouns on 12 scales defined by adjective oppositions and deemed relevant for actorhood potential. By means of structural equation modeling, an actor potential (ACT) value was calculated for each noun. Experiment 2, an event-related potential study, embedded nouns from Experiment 1 in verb-final sentences, in which they were either actors or non-actors. N400 amplitude increased with decreasing ACT values and this modulation was larger for highly frequent nouns and for actor versus non-actor nouns. We argue that potency to act is lexically encoded for individual nouns and, since it modulates the N400 even for non-actor participants, it should be viewed as a property that modulates ease of lexical access (akin, for example, to lexical frequency). We conclude that two separate dimensions of actorhood computation are crucial to language comprehension: an experience-based, lexically encoded (bottom–up) representation of actorhood potential, and a prominence-based, computational mechanism for calculating goodness-of-fit to the actor role in a particular (top–down) sentence context.

Keywords: language comprehension, actor, causality, agency, event-related potentials, N400, extended argument dependency model

INTRODUCTION

The identification of causal relations is a fundamental property of human cognition. When there is an effect, we feel the need to identify a cause and when two events take place in rapid succession, we tend to understand them as causally connected. Identifying causes is typically synonymous with identifying a causer, i.e., a person or thing responsible for the state of affairs in question. Language processing is no exception: it has long been assumed that the language processing system employs certain strategies for the identification of the "actor." Note that we use the term actor to refer to the participant primarily responsible for a linguistically expressed event or state of affairs. Thus, while actors are prototypically causers, they need not be, e.g., in the case of Experiencers (cf. Van Valin, 2005). (For a more detailed explanation in a psycholinguistic context, see Bornkessel-Schlesewsky and Schlesewsky, 2009.) For example, Bever (1970) posited that (English) sentences are preferentially analyzed as adhering to the structure "actor action object modifier" and many similar strategies have been proposed in subsequent research (e.g., Ferreira, 1994, 2003; Townsend and Bever, 2001).

Recent research on sentence comprehension has revealed that, beyond these sentence-level heuristics relating actors with actions and patients, the identification of the actor itself seems to be of particular importance. Thus, typologically diverse languages (including English, German, Mandarin Chinese, Tamil), (a) show a tendency for initial arguments to be analyzed as actors whenever possible; and (b) penalize the processing of non-prototypical actors. Both of these observations are independent of verb information as they occur even before the verb is encountered in verb-final sentences (for a detailed discussion of these properties and the findings from different languages, see Bornkessel-Schlesewsky and Schlesewsky, 2009). From findings such as these, we have proposed that linguistic actorhood is based on a "language-independent [actor] category, possibly rooted in the human ability to understand goal-directed action" (Bornkessel-Schlesewsky and Schlesewsky, 2013b) and that this accounts for the cross-linguistic importance of actor identification during language comprehension.

Several previous results indicate that online actor identification may be influenced by fine-grained lexical information in combination with real-world knowledge (e.g., McRae et al., 1997, 1998). For example, McRae et al. (1998) contrasted sentences such as (1) in a self-paced reading study.

(1) Role-filler biases which modulate reading time patterns (McRae et al., 1998, segmentation for self-paced reading indicated by slashes)

(a) The cop/arrested by/the detective/was guilty/of taking/bribes.

(b) The crook/arrested by/the detective/was guilty/of taking/bribes.

(+unambiguous control conditions)

In the sentences in (1), the sentence initial noun phrase (NP) is either a good actor (*cop*, 1a) or a good undergoer (*crook*, 1b) for the following verb (*arrested*) and this goodness of fit (determined via a norming study) was independent of animacy (only animate nouns were used; most were human, some were animals). Reading times showed a strong influence of verb-specific role-filler congruence. At the verb + preposition region, there was a general penalty for reduced relative clauses, but this was larger for the sentences in which the first argument was a good undergoer, i.e., when NP1 and the verb combined to yield an unlikely actor-verb sequence. At the actor NP region, reading times were slowed for reduced relative clauses and for sentences in which the initial NP was a good undergoer rather than a good actor.

The findings by McRae et al. (1998) indicate that the goodness of fit between a noun and the roles specified by the verb is, at least in part, determined by lexical features and that this information appears to be used quite rapidly during the comprehension process (though how immediate its application is cannot be determined by means of self-paced reading). These results thus suggest that actor identification can be understood within the context of a larger body of psycholinguistic work which demonstrates that lexical information plays an important role in incremental language comprehension (e.g., MacDonald et al., 1994; Trueswell and Tanenhaus, 1994; Jurafsky, 1996; Vosse and Kempen, 2000; for a recent overview, see McRae and Matsuki, 2013). From this perspective, actor identification could be viewed as a special case of constraint satisfaction: competition between possible alternative interpretations (role assignments) leads to a particular participant being interpreted as actor (McRae et al., 1998; see also the notion of "competition for the actor role" in Bornkessel-Schlesewsky and Schlesewsky, 2009, 2013a,b). The proposal that the main burden of sentence processing lies on lexical representations and their interaction has recently gained additional support from the domain of event-related potentials (ERPs) brain, with many researchers arguing that the well-known N400 component is best understood as reflecting lexical preactivation (or the lack thereof) rather than aspects of higher-level linguistic computation (e.g., Kutas and Federmeier, 2000; Lau et al., 2008; Brouwer et al., 2012; Stroud and Phillips, 2012). As the cross-linguistic conclusions relating to the actor role that were mentioned above are primarily based on modulations of the N400, these observations could be viewed as further evidence for a lexicalist perspective on actor identification.

However, a notable restriction on lexicalist accounts of semantic role assignments is that, to date, findings such as those by McRae et al. (1997, 1998) have been confined to noun–verb combinations. It is therefore not clear whether and, if so, how they might generalize to a verb-independent, lexicalized actor concept. This is particularly relevant to the processing of verb-final structures, which are widespread throughout the languages of the world (Dryer, 2005), in combination with the well-established notion of incremental interpretation (e.g., Crocker, 1994; Stabler, 1994). Indeed, previous findings suggest that actor participants are identified incrementally even in verb-final structures and thus independently of verb information (e.g., Bornkessel et al., 2003; for evidence regarding other semantic roles, see Kamide et al., 2003). Accordingly, inanimate (i.e., non-prototypical) actors have been shown to elicit processing difficulties prior to the verb (e.g., increased N400 effects in ERP studies: Weckerly and Kutas, 1999; Roehm et al., 2004, 2007; Philipp et al., 2008) and actor prototypicality has also been shown to modulate the processing of verb-final relative clauses (e.g., Mak et al., 2002, 2006; Traxler et al., 2002, 2005; Chen et al., 2006). This indicates that knowledge regarding prototypical actor properties (e.g., animacy) is used to inform verb-independent actor identification. By contrast, it has hitherto not been examined whether this observation extends beyond broad semantic categories such as animacy to more fine-grained lexical-semantic properties. The aim of the present study was to shed light on this possibility. In the following, we discuss how one might extract the relevant meaning dimensions of nouns before going on to describe a model of an individual noun's "potency to act" (cf. Bornkessel-Schlesewsky et al., 2013) based on a questionnaire study (Experiment 1) and an ERP study designed to test the electrophysiological correlates of this value (Experiment 2).

A systematic attempt to determine dimensions of word (concept) meaning was undertaken by Osgood and colleagues as early as the 1950s (Osgood, 1952; Osgood et al., 1957, 1975). This method, termed the "semantic differential" measures meaning by examining how a concept is mapped "to an experiential continuum, definable by a pair of polar terms" (Osgood, 1952, p. 227) under the assumption that "[a] limited number of such continua can be used to define a semantic space within which the meaning of any concept can be specified" (Osgood, 1952, p. 227). Specifically, Osgood et al. (1957) showed that, cross-culturally, the affective meaning of words can be represented as a three dimensional semantic space consisting of the dimensions Evaluation (positive–negative), Potency (strong–weak), and Activity (active–inactive). The semantic differential appears suited to our purposes of defining the "actor potential" of individual nouns because (a) it has been tested extensively with noun stimuli in a range of languages, leading to the extraction of a small number of stable meaning dimensions, and (b) one of these meaning dimensions is described as the "potency" of a concept and thereby appears related to the notion of actorhood. The assumption that affective meaning is relevant to the concept of agency and, hence, potentially important for actorhood is not new. Especially in motivational and social psychology, a key driver of agency (i.e., initiative, action) is affect (Rolls, 2000; Reeve, 2009). From this perspective, emotional reactions are key to ensuring a certain degree of flexibility in behavior- ("flexibility of behavioral responses to reinforcing stimuli," Rolls, 2000, p. 179) and allow for the rapid monitoring of salient stimuli (i.e., typically stimuli of high emotional valence; e.g., Blackwood

et al., 2000, p. 878). Additionally, there is neurophysiological evidence that emotional valence and arousal not only influence behavior but also the perception of language as reflected in a manipulation of the N400 effect (e.g., Schirmer et al., 2005; Kanske and Kotz, 2007; Bayer et al., 2010; Chwilla et al., 2011).

The connection between Osgood's affective dimensions and language interpretation is also supported by more recent behavioral results which indicate that the semantic differential dimensions may indeed be suited to shedding light on causal attributions and, by extension, actorhood. Thus, Corrigan (2001, 2002) showed that the causal attributions in a linguistically expressed event are highly dependent on the Evaluation and Potency ratings of the event participants in relation to the verb. Activity, by contrast, did not have an effect. In a questionnaire study, participants were asked to judge causality in simple transitive sentences (see 2 for examples).

(2) Sample stimulus from Corrigan (2001) to test whether causality would most likely be attributed to the event participant congruent with evaluation and potency of the verb:

The teenager/elder harassed/praised the elder/teenager. Did the teenager/elder cause the event because he is the kind of person that harasses/praises people? (*very unlikely* 1 2 3 4 5 6 7 *very likely*) Did the elder/teenager cause the event because he is the kind of person that people harass/praise? (*very unlikely* 1 2 3 4 5 6 7 *very likely*) Did something else cause the event? (*very unlikely* 1 2 3 4 5 6 7 *very likely*)

In her study, Corrigan (2001) showed that causal attributions were made to the event participant that most closely matched the evaluation and potency of the verb. In order to account for order effects and attribution biases inherent to the verb, each noun was presented in subject and object position and with a different verb from the opposite verb bias class (e.g., subject bias: *harass, pull, change*; object bias: *praise, encourage, protect*). Corrigan showed that the implicit causality bias of an object-biasing verb such as praise can be overridden by the identity of the event participant. According to an initial rating, *praise* is a positively evaluated verb and the likelihood for *the elder* to do something positive (evaluation value: 5.2) is higher than the likelihood for *the teen* to do something positive (evaluation value: 3.91). The results reveal that causality was more often attributed to *the elder* than to *the teenager* even if it occurred in subject position and the verb-inherent bias would predict attributions to the object (Corrigan, 2001, pp. 300–301). These findings were replicated and extended by Corrigan (2002), thus attesting to the stability of the findings: "When the subject and the verb match, perceivers attribute causality to the subject, but when they do not match, they attribute causality to the object" (Corrigan, 2002, p. 379).

Corrigan's studies examined how Evaluation and Potency ratings can override implicit causality biases of verbs rather than studying their effect on actorhood as encoded via linguistic features such as case marking. Nevertheless, her findings yielded two important results for present purposes: (a) the semantic features of the participants in a linguistically described event influence readers'/listeners' expectations about the actions that these participants are likely to perform; and (b) the semantic differential dimensions Evaluation and Potency appear to provide an appropriate and robust characterization of the relevant participant-inherent features. Nevertheless, like the findings by McRae et al. (1997, 1998), Corrigan's observations pertain mainly to noun–verb combinations and thus do not demonstrate verb-independent lexical influences on incremental actor identification.

The present study therefore aimed to examine the effects of individual nouns' inherent actor potential independently of the verb. To this end, we performed a questionnaire study (Experiment 1) in which nouns were rated on the scales defined by Osgood et al. (1957, 1975) as well as on scales derived from Primus's (1999) linguistic actor features (see below). From these, we derived an actor potential value for each individual noun using structural equation modeling (SEM). This value was then used to predict the amplitude of ERP effects correlating with actor processing during online sentence comprehension (Experiment 2).

EXPERIMENT 1: QUESTIONNAIRE STUDY AND STRUCTURAL EQUATION MODEL

Based on the centrality of the actor construct for sentence processing (Bornkessel-Schlesewsky and Schlesewsky, 2009, 2013a,b), we hypothesized that experience about the suitability of individual nouns to fill the actor role may lead to a lexicalization of actorhood potential. If true, we should be able to quantify actorhood potential for individual nouns. To this end, we conducted an online survey, which was analyzed using confirmatory factor analysis (CFA), a special case of a structural equation model. SEM is a type of probabilistic network modeling, which allows us to study causal relationships by means of path relations (see e.g., Grace et al., 2012). Importantly for present purposes, SEM allows for the inclusion of latent variables (such as actorhood potential or Osgood's affective dimensions). While these variables are hythesized, they cannot be measured directly, but only inferred from relations between measured variables. Thus, based on theory and previous experimental findings a model is set up which defines causal relations between observed and latent variables. The CFA then tests via an estimation algorithm whether or not the causal relations in the model can be upheld with the gathered data.

IDENTIFICATION OF SUITABLE RATING SCALES

In a first step, we identified relevant scales as the observed variables, indicating the actorhood potential of a noun, the latent variable (cf. **Table 1**). As the most prototypical actor is a human, we included a scale representing consciousness (CON) as a uniquely human trait that reflects our ability to reason as well as a scale representing animacy (ANI). However, recent corpus studies suggest that properties related to humanness or animacy do not suffice in order to derive the full range of actor-based effects in natural language. Examining impersonal passives in several Germanic languages using data from natural discourse, Primus (2011) observed that the classic generalization that impersonal passives are restricted to human/animate agents is too strong. At least in Dutch and German, the presence of a self-organized (goal-

Table 1 | Scales used in Experiment 1, abbreviated in terms of indicators (observed variables).

Indicator	Scale (German)	English translation	Dimension
GOA	ziellos – zielgerichtet	aimless – goal-directed	Actorhood
VAL	schlecht – gut	bad – good	Evaluation/ Arousal
PLE	unangenehm – angenehm	unpleasant – pleasant	
APP	hässlich – schön	ugly – pretty	
POW	machtlos – mächtig	powerless – powerful	Potency
SIZ	klein – groß	small – big	
STR	schwach – stark	weak – strong	
CON	ohne Bewusstsein – mit Bewusstsein	without consciousness – with consciousness	Humanness
ANI	leblos – lebendig	inanimate – animate	
VOL	leise – laut	quiet – loud	Activity
SPE	langsam – schnell	slow – fast	
AGE	alt – jung	old – young	

directed) activity appears to suffice for an impersonal passive to be possible [see examples 3 and 4, from Primus's (2011) corpus].

(3) Dutch:

het systeem is gevuld met lucht en wordt als er een sprinkler is gesprongen als gevolg van brand met water gevuld waarna er wordt geblust.

'The system is filled with air and when a sprinkler has switched on due to fire it is filled with water whereafter there is spritzing.'

(4) German:

Mit einem Schalter am Amaturenbrett kann der Fahrer jederzeit auf Benzinbetrieb umschalten. Wenn der Gasdruck auf einen zu niedrigen Wert sinkt, wird automatisch umgeschaltet.

'The driver can always switch to petrol by pressing a button on the dashboard. When the gas pressure sinks to a level that is too low, [the system] switches automatically.'

From examples such as these and additional judgment studies, Primus concludes that goal-directedness should be treated as a dimension of actorhood that is independent of humanness:

> "[S]elf-organized activity or motion presupposes an own source of energy and an own motor program specialized for the type of event denoted by the predicate. This kind of motion can be performed by inanimates which have their own specialized motor program." (Primus, 2011, p. 97)

Crucially, goal-directedness in this sense does not imply that the argument performing the action has a specific goal in mind. Rather, its activity is directed toward a particular (physical) goal, which may well have been programmed into the system to fulfill a certain function (e.g., the sprinklers in example 3 or the system for switching the gas pump in example 4). The importance of goal-directedness in inferring agency independently of humanness is also well-established in psychology (Piaget, 1929; Heider and Simmel, 1944; Premack, 1990; Opfer, 2002) and neuroscience (e.g., Schultz et al., 2005). For instance, Opfer (2002) showed adults and children (4–10 years of age) videos of unfamiliar blobs moving either aimlessly or in a goal-directed fashion. His study demonstrated that goal-directedness is a prominent feature of biological motion and a decisive factor for both adults and children in order to identify novel entities as alive. Thus, even though goal-directedness is often correlated with humanness, the two dimensions are in principle independent of one another and contribute independently to linguistic actorhood. In view of these considerations and following Primus (2011), we hypothesize goal-directedness (GOA) to be a direct indicator of actorhood potential rather than an indicator of humanness.

As demonstrated by Corrigan (2001, 2002), the semantic differential dimensions Evaluation and Potency are relevant for the attribution of causality and hence, the identification of an actor. Accordingly, in the context of a verb, Evaluation has a strong effect on causal attributions that can override the verb-inherent bias. Thus, nouns with either a positive or a negative implied valence serve as good actors. As indicators for this dimension, we used three prominent semantic differential scales measuring emotional valence (VAL), pleasance (PLE), and appearance (APP) according to Osgood et al. (1975). Since the polarity of these ratings only became relevant in relation to the verb, we used absolute values of the resulting ratings in order to assess the strength of the emotional valence (arousal) rather than ipolarity. The semantic differential dimension Potency measures how strong, powerful or large a person or activity is. We thus included three prominent Potency scales relating to power (POW), strength (STR), and size (SIZ) in the model (1975). According to Corrigan (2001) there is no evidence that a noun's Activity affects causal attributions. However, Corrigan (2001, 2002) only used Activity scales to rate how dynamic or energetic the verbs she used in her study were perceived. For the sake of completeness, we therefore also included three scales for the semantic differential dimension Activity measuring sound volume (VOL), speed (SPE) and age (AGE), respectively, in order to examine whether activity serves as an indicator of a noun's actorhood potential. A summary of the scales used here is given in **Table 1**.

MATERIALS AND METHODS

Participants

A total of 227 participants completed the online questionnaire. Participants were recruited in Mannheim, Munich, and Marburg and received an invitation via e-mail with a link to the questionnaire. This link could only be accessed once in order to control for multiple participation. After completing the questionnaire, participants could sign up for a lottery to win 1 of 22 book vouchers worth 10€ each. 29 participants were excluded from the analysis as they were non-native speakers of German or bilinguals (14), or their rating pattern resembled outliers (15). 198 participants (98 male and 100 female) were included in the analysis. 89% of the participants were between 18 and 29 years of age (18–20: 22%; 21–23: 34%; 24–26: 26%; 27–29: 7%). Only a minority of the participants (11%) were over 30 years old (30–32: 6%; 33–35: 3%; 36–38: 1%; 39–41: 1%). Most of the participants (82%) were undergraduate students at a German university or a university of

applied sciences; 16% of the participants held a university degree (Ph.D. or higher: 2%; 3–6 year degrees: 14%).

Materials

The stimulus material consisted of 180 German nouns (see Supplementary Materials for a full list): 60 referring to humans (A: e.g., *butcher, father, nun*), 60 to animals (B: e.g., *cat, bird, wasp*) and 60 to inanimates, respectively. Inanimate nouns were subdivided into 30 concrete things (C: e.g., *chair, hammer, pen*) and 30 abstract concepts (D: e.g., *hope, danger, respect*). The nouns were distributed across six online questionnaires so that each participant rated a subset of 30 nouns on 12 semantic differential scales. The order of the scales was randomized for each word.

Procedure

After agreeing to participate in the study, participants received a link to the online survey conducted with the open source application LimeSurvey[1]. They were instructed to complete the questionnaire in one run and were not able to save their responses in order to continue the questionnaire at a later time. Each word was presented on the screen with 12 scales in a randomized order. Participants were required to rate the word on each scale before they could proceed to the next word. After they had rated the 30 words, participants answered a few demographic questions about their language skills, age and education.

[1] http://www.limesurvey.org

Data analysis

Structural equation modeling was conducted using the sem package (version 0.9-21 in R version 2.11.1) by Fox et al. (2012). The SEM tested here is shown in **Figure 1**, which shows the assumed relations between the manifest (i.e., measurable) and the assumed latent variables. A fundamental assumption of this type of analysis is that correlations between latent and manifest variables and among latent variables are non-zero. Indicators which are not related to a latent variable (factor) are thus considered fixed parameters in the model specified by zero loadings. The goal of a SEM is to find the values of free model parameters, which minimize the discrepancy between the sampled covariance matrix and the

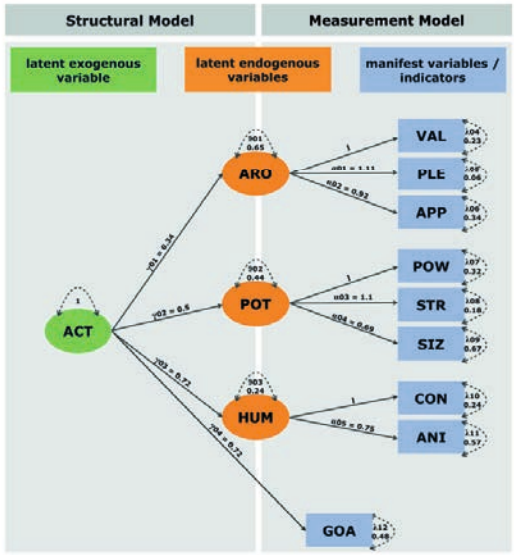

FIGURE 1 | Structural equation model. The model consists of a latent exogenous variable (ACT), three latent endogenous variables (EVA, POT, and HUM) and nine manifest variables (VAL, PLE, APP, POW, STR, SIZ, CON, ANI, and GOA). The causal paths gamma 01–04 state that all endogenous latent variables as well as the manifest variable (GOA) are causally dependent upon the exogenous variable (ACT). Alpha 01–05 represent the causal dependency of manifest variables VAL, PLE, and APP on EVA; POW, STR, and SIZ on POT as well as CON and ANI on HUM. Error variance is represented by delta 1–12 (dashed double-headed arrows).

model's reproduced covariance matrix by an iterative algorithm [here: restricted maximum likelihood (REML) estimation].

The three activity-related scales were excluded from the final model because, as in Corrigan's (2001, 2002) findings, they did not contribute to improving the fit of the model (see below).

RESULTS

According to the goodness-of-fit-indices in **Table 2**, the comparative fit index (CFI > 0.95), the standardized root mean square residual (SRMR < 0.8) and the root mean square of approximation index (RMSEA < 0.08) suggest a close fit between the sampled data and the estimated model although chi-square is significant on a 0.01 level (Fan et al., 1999; Bühner, 2004). As expected, a model including Activity ratings (**Table 2**, alternative model) did not yield a close fit between sampled data and the estimated model as shown by a highly significant chi-square ($p < 0.001$) and CFI < 0.96.

Positive loadings on causal paths (one-headed arrows in **Figure 1**) indicate a positive relation between latent and manifest variables as well as among latent variables. All factor loadings differed significantly from zero ($p < 0.05$). The model depicted in **Figure 1** suggests that an increasing potential to act is positively correlated with arousal (ARO: $\gamma 01 = 0.34$), potency (POT: $\gamma 02 = 0.5$), humanness (HUM: $\gamma 03 = 0.72$), and goal-directedness (GOA: $\gamma 04 = 0.72$). The same is true for the effect of latent factors on the indicator variables ARO (PLE: $\alpha 01 = 1.1$; APP: $\alpha 02 = 0.92$), POT (STR: $\alpha 03 = 1.1$; SIZ: $\alpha 04 = 0.69$), and HUM (ANI: $\alpha 05 = 0.75$).

In order to compute a value representing the actorhood potential of a given noun (ACT), the ratings per scale were multiplied with their regression coefficients and the products were added (see 5). Error variances were multiplied and subtracted (see the Supplementary Materials for factor values per noun).

$$
\begin{aligned}
(5)\quad \mathrm{ACT} &= (\gamma 01(\mathrm{ARO} - \delta 01) + \gamma 02(\mathrm{POT} - \delta 02) \\
&\quad + \gamma 03(\mathrm{HUM} - \delta 03)) + \gamma 02 * \mathrm{GOA} \\
\mathrm{ARO} &= -1(\mathrm{VAL} * \delta 04) + \mathrm{PLE}(\alpha 01 - \delta 05) \\
&\quad + \mathrm{APP}(\alpha 02 - \delta 06) \\
\mathrm{POT} &= -1(\mathrm{POW} * \delta 07) + \mathrm{STR}(\alpha 03 - \delta 08) \\
&\quad + \mathrm{SIZ}(\alpha 04 - \delta 09) \\
\mathrm{HUM} &= -1(\mathrm{CON} * \delta 10) + \mathrm{ANI}(\alpha 05 - \delta 11)
\end{aligned}
$$

CROSS-VALIDATION OF RESULTS

In order to examine the validity of the actorhood construct as derived by our structural equation model, we conducted an additional questionnaire study with a total of 67 participants (16 male, 51 female, mean age = 28.5 years). Two participants were excluded because their native language was not German. All participants rated the noun material on a 4-point scale (1 = sehr schlechter Handlungsverursacher 'very bad actor,' 2 = eher schlechter Handlungsverursacher 'rather bad actor,' 3 = eher guter Handlungsverursacher 'rather good actor,' 4 = sehr guter Handlungsverursacher 'very good actor'). Note that the noun "Handlungsverursacher," which was used to instruct participants, is more specific than "actor" in English and translates approximately as "event instigator." Thus, this rating study essentially tested participants' intuitions regarding relatively prototypical actors.

Mean ratings for each noun were compared to the actorhood potential computed according to the structural equation model. A simple correlation of the values revealed a correlation coefficient of 0.67 (*95% confidence interval = 0.58–0.74*), thus demonstrating that our model measures the concept or construct that it is intended to measure (see **Figure 2**). All in all, this result attests to the psychological validity of the "actorhood" concept. Nevertheless, it is subject to the limitation that, since it is very difficult – if not impossible – to instruct naïve participants to rate nouns in accordance with the precise linguistic meaning of actor as a generalized semantic role, the ratings given here were based on the notion of "event instigator" as a relatively prototypical instance of an actor.

DISCUSSION

The structural equation model constructed on the basis of the data from Experiment 1 suggests that a noun's actor potential depends on its humanness, its arousal level, its potency and its ability to behave in a goal-directed manner. Thereby, a good actor is conscious and animate, emotionally arousing (positive or negative), perceived as potent (strong, powerful, and big) and moves in a goal-directed manner. This demonstrates that fine-grained semantic characteristics that go beyond the mere animate-inanimate

Table 2 | Fit indices for structural equation model.

	$p > \chi^2$	DF	RMSEA	SRMR	CFI
	0.004	24	0.068	0.075	0.97
Alternative model	2.6e-06	50	0.078	0.077	0.94

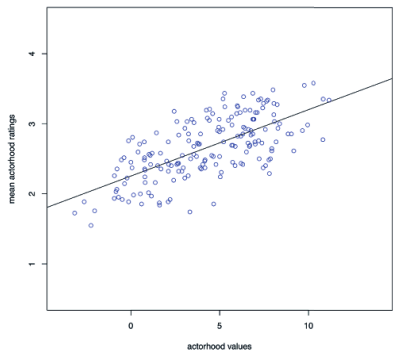

FIGURE 2 | Visualization of the cross-validation analysis. Correlation between the actorhood values for individual nouns derived from the structural equation model in **Figure 1** and participants' ratings of actor goodness in the validation study.

dichotomy influence the goodness of an actor, thus providing a measure to differentiate "good" human actors (e.g., mother, murderer, fighter or doctor) from "poor" human actors (e.g., widow, beggar, pensioner, or servant). Moreover, our findings attest to the psychological validity of our multidimensional actor construct (ACT): ACT shows a high correlation with people's overt judgments about the goodness-of-actorhood of individual nouns. A parsimonious explanation for this correlation is that people's judgments about actorhood potential are indeed based on the dimensions contributing to the ACT value. The effects of this actor potential on real time language processing were investigated in Experiment 2.

EXPERIMENT 2: ERP STUDY

In a second step, we investigated whether the goodness of an actor has an impact on online language processing. We chose ERPs as they provide a fine-grained, multidimensional measure of language processing with a very high temporal resolution (e.g., Kutas et al., 2006). To this end, we used the noun material from Experiment 1 and treated the actor value (ACT) as a parametric variable. In order to analyze the electroencephalography (EEG) data, we used mixed-effects modeling (Baayen, 2008), which, unlike the common ANOVA approach, allows for the inclusion of parametric variables. It also takes variance per participant and stimulus item into account and is thus a very promising approach for the analysis of linguistic ERP data in which by-item variability is an important factor.

In order to measure the effects of individual-noun ACT values during sentence comprehension, we capitalized on previous ERP results on pre-verbal actor identification. A number of studies in several typologically diverse languages have demonstrated that a non-prototypical (inanimate) actor following an undergoer engenders an increased N400 effect in comparison to a prototypical actor. For example, Weckerly and Kutas (1999) observed an N400 effect at the relative clause subject noun for "The editor that the poetry..." in comparison to "The poetry that the editor..." in English and comparable results have been demonstrated for German (Roehm et al., 2004), Mandarin Chinese (Philipp et al., 2008), and Tamil (Muralikrishnan et al., in press). We have argued that this effect can be attributed to the non-fulfillment of a prediction for a prototypical actor which is set up when an undergoer is processed (see Bornkessel and Schlesewsky, 2006; Bornkessel-Schlesewsky and Schlesewsky, 2009, for reviews and discussion). By contrast, undergoer arguments do not engender comparable atypicality effects (see Bornkessel-Schlesewsky and Schlesewsky, 2009; Paczynski and Kuperberg, 2011). If the basic assumptions of lexically based models of sentence comprehension indeed extend to incremental interpretation independently of the verb, lexical actor potential, as defined via a noun's ACT value, should engender a similar N400 modulation to that elicited by inanimate actors in previous studies. In order to test this hypothesis, we constructed sentences such as those in (6).

(6) Anja fragte sich, ...
Anja asked herself...
(a) Subject-initial target sentence (critical NP = undergoer)
... wer den Anwalt eingeschaltet hat.
... who$_{NOM}$ [the attorney]$_{ACC}$ employed has
'... who employed the attorney.'
(b) Object-initial target sentence (critical NP = actor)
... wen der Anwalt verteidigt hat.
. . . who$_{ACC}$ [the attorney]$_{NOM}$ defended has
'... who the attorney defended.'

As is apparent from the sentence conditions in (6), we used embedded wh-questions in order to construct German sentences with a verb-final order, thus allowing us to examine the effects of actor potential independently of verb-based information. (Note that sentences were completed in order to be maximally plausible, as shown by the two different completions following the critical NP, the attorney, in (6), since no ERPs were analyzed at the verb and auxiliary positions.) A second advantage of using wh-questions of the type in (6) (i.e., questions with wh-pronouns) was that they minimized the semantic content of the first NP and kept it constant across all sentences. Thus, wh-pronouns only differed with regard to their case marking, thereby rendering the following critical NP either an undergoer (6a) or an actor (6b). Nouns within the critical NP were taken from the questionnaire study in Experiment 1 and varied with respect to their actor potential (ACT value as derived from the structural equation model).

If the hypothesis advanced above is correct, i.e., if actor potential modulates N400 amplitude for predicted actor participants (i.e., actors following undergoers), we should observe a modulation of the N400 via ACT values for object-initial orders as in (6b). Subject-initial sentences such as (6a) served as controls and as a means of examining the degree of lexicalization of the ACT value. Thus, if the ACT values influence processing in exactly the same way as animacy, we would predict an interaction between ACT and word order (WO), with only object-initial sentences showing an ACT modulation. If, by contrast, ACT affects processing in the same way as an inherent lexical property (e.g., concreteness, frequency), we should observe ACT-based effects for all nouns, i.e., even in subject-initial orders, though perhaps to a lesser degree than in the object-initial sentences.

MATERIALS AND METHODS

Participants

A total of 41 native speakers of German participated in the ERP experiment after giving informed consent (22 women and 19 men; mean age: 25 years, range: 19–32). All participants were right handed and reported normal or corrected to normal vision. One female participant was excluded from the analysis due to software problems.

Materials

A total of 168 nouns were used in sentences with subject -initial (SO) and object-initial (OS) WOs (see example 10), thus yielding a total of 336 critical sentences. Each noun's potential to be a good actor was obtained from the online questionnaire (Experiment 1) in conjunction with the structural equation model as outlined in Section "Experiment 1: Questionnaire Study and Structural Equation Model." All nouns were two syllables in length (mean length in characters: 6.54; standard deviation: 1.55). The material was divided into two lists of 168 sentences each, which were presented in pseudo-randomized order. Each participant saw only

Table 3 | Set of experimental stimuli consisting of a matrix clause ([proper name] asked himself/herself...) and an embedded subordinate clause.

	Matrix clause: Anja fragte sich, (Anja asked herself, ...)	Comprehension questions:			
	Subordinate clause:	**S-question:**	**N-question:**	**V-question:**	**O-question:**
SO:	... wer den Anwalt eingeschaltet hat.	Hat jemand den Anwalt eingeschaltet?	Hat jemand den Richter eingeschaltet?	Hat jemand den Anwalt verteidigt?	Hat der Anwalt jemanden eingeschaltet?
	... who the attorney employed has	Did someone	Did someone	Did someone	Did the attorney
	... 'who employed the attorney.'	employ the attorney?	employ the judge?	defend the attorney?	employ someone?
OS:	... wen der Anwalt verteidigt hat.	Hat der Anwalt jemanden verteidigt?	Hat der Richter jemanden verteidigt?	Hat der Anwalt jemanden eingeschaltet?	Hat jemand den Anwalt verteidigt?
	... whom the attorney defended has	Did the attorney	Did the judge	Did the attorney	Did someone
	... 'whom the attorney defended.'	defend someone?	defend someone?	employ someone?	defend the attorney?
	Total number of questions	168	56	56	56
	Expected response?	yes (correct)	no (incorrect)		

Each critical noun phrase (underlined) was presented in subject initial (SO) and object-initial (OS) word order. Only one comprehension question per sentence occurred (in black). Questions in gray represent possible questions and are depicted in order to exemplify stimulus generation only.

one list of materials. After each sentence, participants responded to a yes/no comprehension question (see **Table 3**). Trials for which the comprehension question was not answered correctly were excluded from further analyses. As is apparent from **Table 3**, several different types of questions were constructed in order to limit participants' ability to strategically prepare for a particular question type during sentence processing. S-questions asked whether the NP that served as the grammatical subject of the preceding sentence was responsible for the event. These questions always had to be answered with yes in order to be correct. Questions which had to be answered with no varied in order to exclude answering strategies. N-questions asked for an incorrect noun and V-questions for an incorrect verb. O-questions asked whether the NP that served as the grammatical object of the critical sentence was responsible for the event (i.e., reversed thematic role assignments).

Procedure

Participants were seated in front of a computer screen in a soundproofed booth. Each trial began with the presentation of a fixation cross [400 ms followed by an inter-stimulus-interval (ISI) of 100 ms]. Subsequently, sentences were presented visually in a word-by-word manner, with the exception of critical NPs, which were presented together as a single phrase (e.g., der Anwalt 'the attorney'). This phrase-by-phrase presentation mode is very common in psycholinguistic and neurolinguistic research on German (e.g., Mecklinger et al., 1995; Friederici et al., 1998; Hopf et al., 1998; Frisch and Schlesewsky, 2001; Bornkessel et al., 2002, 2004b), as it serves to rule out ambiguities that are present when the case-bearing determiner is presented without the following noun (e.g., on its own, the determiner "der" is compatible with either a nominative-masculine-singular, a dative-feminine-singular or a genitive-feminine-plural). In the case of present experiment, however, the unambiguously case-marked initial wh-pronoun already disambiguates whether the second NP should be interpreted as a subject or an object, thus substantially reducing the degree of ambiguity.

Words were presented for 400 ms and phrases for 500 ms followed by an ISI of 100 ms. At the end of a sentence, there were 500 ms of blank screen before the presentation of the comprehension question. Following a participant's response or after the maximal response time of 2000 ms had run out, a further 1000 ms of blank screen preceded the beginning of the next trial. Participants responded to the comprehension question by pushing one of two push-buttons on a response box. Assignments of "yes" and "no" responses to the left and right button were counterbalanced across participants.

Electrophysiological recordings

The EEG was recorded from 64 AgAgCl-electrodes fixed at the scalp with an elastic cap (Electrocap International, Eaton, OH, USA). Electrodes were arranged according to the international 10-10 system and average impedances were kept below 4 kΩ. The electrooculogram (EOG) was monitored by means of electrodes at the outer canthi of each eye as well as above and below the right eye. EEG and EOG signals were recorded using two Twente Medical Systems DC amplifiers at a sampling rate of 500 Hz. The signal was referenced to the left mastoid and re-referenced to linked mastoids offline. A bandpass filter from 0.3 to 20 Hz was applied offline to the raw data in order to exclude slow signal drifts. ERPs were not baseline-corrected (for a detailed motivation, see Wolff et al., 2008; for a direct comparison between baseline-corrected and non-corrected, filtered data, see Choudhary et al., 2009; see also recent guidelines for electroencephalographic research, Keil

et al., 2014, as well as recent methodological recommendations for the use of filters in EEG research, Widmann et al., 2014). ERP plots were smoothed with an 8 Hz lowpass filter for display purposes only.

Data analysis

For statistical analysis of the ERP data, mixed-effects models were used with subjects and items as crossed random effects (e.g., Baayen, 2008; Baayen et al., 2008). The analysis was performed with the lme4 package (Bates et al., 2011) for R (R Development Core Team, 2012). ERPs were timelocked to the onset of the critical NP (underlined) and analyses were performed on mean amplitudes for a typical N400 time-window (300–500 ms). Parametric variables, which served as fixed effects, were: a noun's actorhood potential (ACT) and its logarithmic frequency of occurrence (FRQ) according to the online corpus "Wortschatz Lexikon" provided by the University of Leipzig, Germany[2]. In order to ensure that the fixed effects of ACT were not driven by individual differences in the subjects, we included a random-slope for subjects in the analysis. Note that a random-slope of item is not included since the item-specific values of ACT and FRQ consistently yield a high correlation of the slope and the intercept of item random effects for each predictor, respectively (–1.00) indicating that such a model would be overparameterized (see, for example, Baayen, 2008). Additional fixed factors included in the analysis were WO (object-before-subject, OS versus subject-before-object, SO) and case ambiguity (CASE; UNAM = unambiguously case marked masculine nouns; AMB = feminine and neuter nouns ambiguously marked for case). Lateral electrodes were grouped into left-anterior (F7, F5, F3, FT7, FC5, FC3), right-anterior (F8, F6, F4, FT8, FC6, FC4), left-posterior (P7, P5, P3, TP7, CP5, CP3) and right-posterior (P8, P6, P4, TP8, CP6, CP4) regions of interest (ROI). ROI was included into the analysis as a four-level factor. We began by fitting a model with all predictor variables and allowed for maximal interactions. This maximal model was reduced in a stepwise fashion by excluding those fixed effects that did not reach significance at $t \geq 2$. According to Baayen et al. (2008), for large data sets, an absolute value of the t-statistic exceeding two indicates significance at the 5%-level. In order to compute p-values for the best-fitting model, we performed Markov chain Monte Carlo simulations with 10,000 samples from the posterior distribution (Baayen et al., 2008) without random correlation parameters. For present purposes, we only report effects and interactions involving the factors ACT and WO in accordance with our hypotheses. A detailed summary of the complete model can be found in the Supplementary Materials. Results are reported including coefficient estimates (CEs) and 95% confidence intervals (CIs).

RESULTS

Comprehension task

Across participants and items, the mean accuracy for the behavioral task was 94.55% (7.06% incorrect and 0.18% timeouts). Thus, participants processed the sentences attentively and understood them. In order to analyze the reaction times and the accuracy of the comprehension task, we used a mixed effects model with the factors WO, actorhood potential (ACT), and frequency (FRQ). In order to account for the variance that is caused by the different question types (QTYPE), we also included this variable as a random factor into the model. This additional random factor is justified as the likelihood ratio test comparing the model with (model 2) or without (model 1) a random factor of question type (see **Table 4**) shows a significantly smaller probability for model 2 both comparing the models for reaction time ratings and the accuracy of the responses (for a detailed description of the procedure cf. Baayen, 2008, p. 253). We refrained from including either by-question type, by-subject, or by-item random slopes for ACT as these analyses yielded a high correlation of slope and intercept (1.00) thus indicating that the model is overparameterized. The analysis only revealed a main effect of WO (CE = –50.56, CI = –67.33 to –34.02, $p < 0.000$). In order to account for the binomial distribution of the comprehension ratings (yes/no), we fit a generalized linear mixed model (Baayen, 2008). Unlike in the linear mixed-effects models fit for reaction times and ERP data, the standard error (SE) rather than a CI is reported. We found an interaction of WO and FRQ (CE = 0.22, SE = 0.01, $p < 0.002$) and a three-way interaction of WO, ACT, and FRQ (CE = –0.03, SE = 0.2, $p < 0.000$).

Table 4 | Results of likelihood ratio test comparing models without a random factor QTYPE (model 1) and with a random factor QTYPE (model 2).

Reaction times (RTs)

Model 1: RT ~ ACT * WO * FREQ + (1| subj) + (1| item)
Model 2: RT ~ ACT * WO * FREQ + (1| subj) + (1| item) + (1| qtype)

	Df	AIC	BIC	logLik	Chisq	Chi Df	Pr(> Chisq)
Model 1	11	96613	96688	–48295			
Model 2	12	95986	96068	–47981	628.56	1	<0.0001

Accuracy of responses (ANS)

Model 1: ANS ~ ACT * WO * FREQ + (1| subj) + (1| item)
Model 2: ANS ~ ACT * WO * FREQ + (1| subj) + (1| item) + (1| qtype)

	Df	AIC	BIC	logLik	Chisq	Chi Df	Pr(> Chisq)
Model 1	10	2777.3	2845.2	–1378.7			
Model 2	11	2587.2	2662.0	–1282.6	192.06	1	<0.0001

The test was performed for reaction times and accuracy of the responses to the comprehension task.

ERP data

The main aim of this study was to test the hypothesis that individual nouns' ACT values would correlate with modulations of the N400 at the position of NP2. Firstly, however, in order to ensure that our experiment replicated well-established ERP findings with respect to the N400, we performed a median split for lexical frequency at the position of NP2. As shown in **Figure 3**,

[2]http://wortschatz.uni-leipzig.de

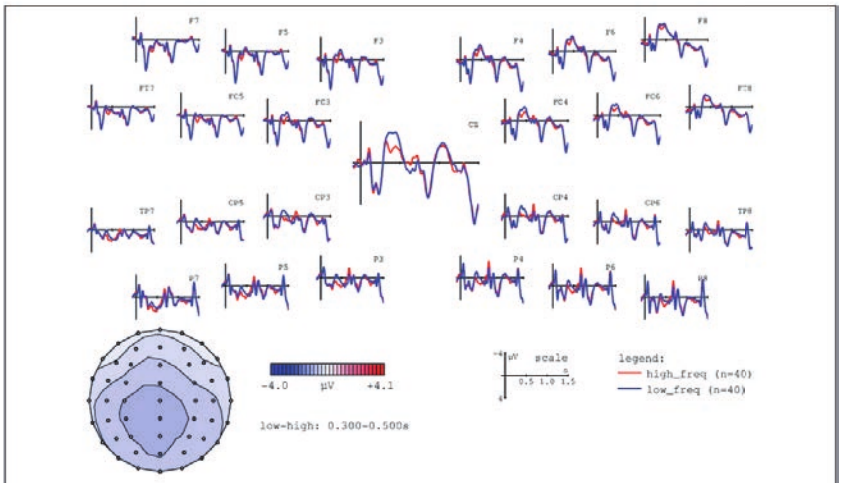

FIGURE 3 | Grand average ERPs time-locked to the second NP (onset at the vertical bar) for high (red line) and low frequency (blue line) nouns. Negativity is plotted upward. The voltage map shows the topography of the effect (amplitudes for low – high frequency nouns in the 300–500 ms time window).

this comparison indeed replicated the observation of higher N400 amplitudes for low versus high frequency words (e.g., Kutas and Federmeier, 2000).

In a second step, we examined the effects of noun-specific ACT values on ERPs at NP2. Recall that we predicted higher N400 amplitudes for nouns with low ACT values. Depending on the concrete hypothesis, this effect should be observable: (a) only in object-initial sentences, i.e., when the noun in question is the actor and, furthermore, predicted by the presence of an undergoer within the preceding sentence context (ACT as comparable to prominence scales); or (b) in both object- and subject-initial sentences (ACT as comparable to lexical properties such as concreteness). In order to visualize the effect of ACT, we thus performed a median split and contrasted high versus low ACT nouns in object-initial and subject-initial sentences. These comparisons are shown in **Figures 4** and **5,** respectively.

As is apparent from **Figures 4** and **5,** low ACT nouns engendered a more pronounced negativity between ~300 and 500 ms post NP onset in comparison to their high ACT counterparts. This effect appears to be stronger in the object-initial sentences, i.e., when the critical NP was an actor rather than an undergoer.

In order to examine the effect of ACT statistically, we fitted mixed-effects models including ACT as a fixed effect and ERP amplitude in the N400 time window (300–500 ms) as the dependent variable (see Materials and Methods). The best-fitting model (see the Supplementary Materials for a full specification), which provided a significantly better fit to the data than a comparable model without the factor ACT [likelihood ratio test: $X^2(6) = 781.9$, $p < 0.0001$], showed an interaction of WO * FRQ * ACT (see **Figure 6**). This interaction was driven by more negative-going voltage changes in the OS condition (CE = –0.004, CI = –0.006 to –0.002, $p < 0.000$) with increasing ACT and FRQ values. Note that positive slopes in the figures indicate larger (i.e., more negative) N400 amplitudes for nouns with a low ACT value. **Figure 7** illustrates the source of the interaction by showing the effect of ACT in subject- and object-initial orders for high and low frequency nouns, respectively.

The results reported above provide compelling evidence for an ACT-based modulation of N400 amplitudes during sentence comprehension. In a final analysis step, we sought to examine how these effects relate to the animacy effects reported for actor arguments (following undergoers) in previous studies (e.g., Weckerly and Kutas, 1999; Roehm et al., 2004; Philipp et al., 2008). In particular, we wanted to ensure that the ACT-based effects reported above cannot be reduced to underlying animacy differences (i.e., to a correlation between ACT values and animacy/humanness). **Figure 8** shows ERPs for actor nouns in each of the animacy categories used in the present study.

As is apparent from **Figure 8**, the present study replicates several previously reported N400 modulations: an N400 effect for non-human versus human actors (e.g., Weckerly and Kutas, 1999;

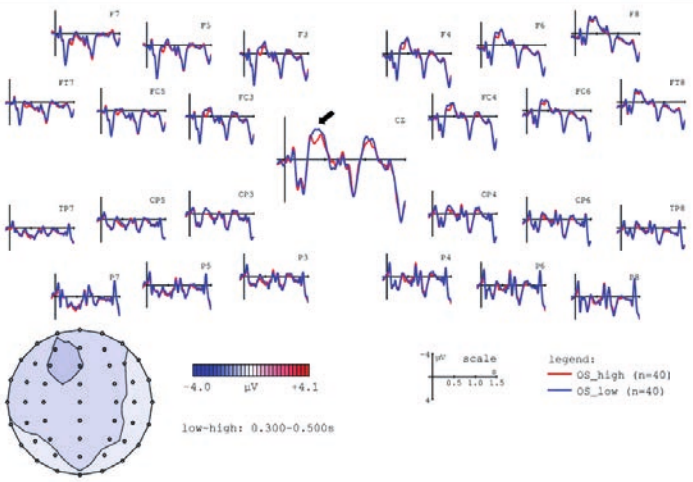

FIGURE 4 | Grand average ERPs time-locked to the second NP (onset at the vertical bar) for high (red line) and low ACT (blue line) nouns in object-initial sentences. Negativity is plotted upward. The voltage map shows the topography of the effect (amplitudes for low – high ACT nouns in the 300–500 ms time window).

Roehm et al., 2004; Philipp et al., 2008) and for concrete versus abstract inanimate nouns (e.g., Kounios and Holcomb, 1994; West and Holcomb, 2000).

However, the animacy-based effects cannot account for the ACT effects reported above. As is apparent from **Figure 9**, an ACT-based N400 modulation was observable for both human and inanimate nouns. Furthermore, an additional mixed effects model analysis involving only human nouns replicated the effects reported for all nouns above. **Figure 10** shows the effects the ACT × FRQ interaction on ERP amplitude in this analysis (for further information regarding the best-fitting linear mixed effects model, see the Supplementary Materials).

DISCUSSION

The ERP results from Experiment 2 provide strong converging support for the assumption that an individual noun's inherent potential for actorhood (ACT value) influences online language processing. ACT values modulated N400 amplitude at the position of the critical noun and this modulation was stronger for object- than for subject-initial sentences, i.e., for critical nouns that were actors following an unambiguously marked undergoer. Interestingly, the effect was not confined to object-initial orders, but was also present in subject-initial orders, albeit in a weaker form. This pattern of results speaks in favor of a strong degree of lexicalization of the ACT value. The assumption of lexicalization is further supported by the observation that effects of ACT on the N400 were modulated by word frequency, with high frequency words showing stronger ACT effects than low frequency words.

GENERAL DISCUSSION

We have presented two experiments on the inherent potential for actorhood of individual nouns and how it impacts upon sentence comprehension. In Experiment 1, a questionnaire study, we obtained values for a number of actorhood-related dimensions for German nouns. By means of a structural equation model, these were used to calculate an index of each noun's potency to act (ACT). Experiment 2, an ERP study, demonstrated that a noun's ACT value modulates the N400 component during sentence comprehension, a component which has been shown to be sensitive to the processing of actorhood in previous research. Nouns with a low ACT value engendered more negative-going N400 amplitudes and this correlation was more pronounced when the critical noun was designated as an actor by morphosyntactic cues and preceded by an unambiguously marked undergoer, and for high frequency as opposed to low frequency nouns. In the following, we begin by discussing the interaction between WO and ACT, before moving on to discuss the difference between actorhood potential and actor identification and the effects of lexical frequency. Here, we will argue that our results provide evidence for a lexicalized encoding of potency to act that is (at least partially) independent of prominence scales such as animacy. Finally, we turn to consequences for models of language processing.

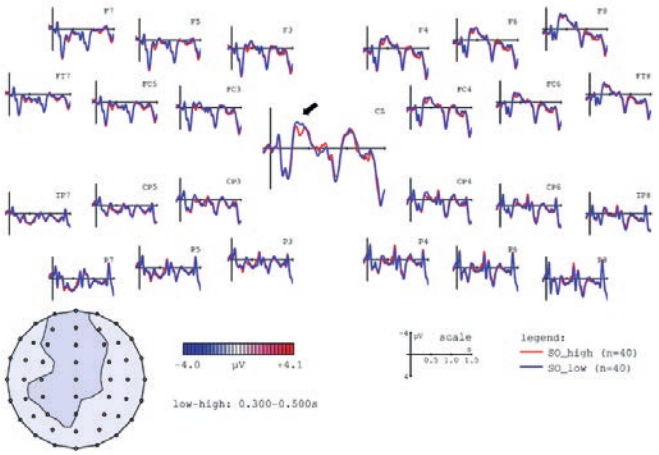

FIGURE 5 | Grand average ERPs time-locked to the second NP (onset at the vertical bar) for high (red line) and low ACT (blue line) nouns in subject-initial sentences. Negativity is plotted upward. The voltage map shows the topography of the effect (amplitudes for low – high ACT nouns in the 300–500 ms time window).

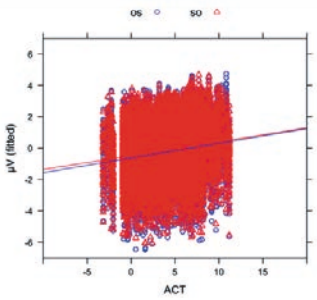

FIGURE 6 | Mean voltages in the N400 time window at the position of the critical noun phrase plotted against actorhood potential (ACT). Sentences in object initial order (OS) are shown in blue circles and sentences in subject initial order (SO) in red triangles.

POTENCY TO ACT AND WORD ORDER

The results of Experiment 2 demonstrated a stronger ACT-based modulation of the N400 for object-initial sentences. In these structures, the critical noun was the actor of the sentence and, since it was preceded by a clearly case-marked undergoer (the accusative wh-pronoun *wen*), it was predicted by the processing system: an initial accusative undergoer requires a following nominative actor, but not vice versa, hence resulting the asymmetrical prediction (see e.g., Gibson, 1998, 2000; Bornkessel et al., 2004a; Schlesewsky and Bornkessel, 2004; Wolff et al., 2008). Thus, the ACT value had a similar effect to manipulations of animacy in previous studies, in which an inanimate actor following an undergoer also engendered a more pronounced N400 (e.g., Weckerly and Kutas, 1999; Roehm et al., 2004; Philipp et al., 2008). This finding therefore suggests that a noun's potency to act is not only determined by prominence scales such as animacy, but also by fine-grained lexical-semantic features inherent to the individual noun itself. This conclusion is further supported by the observation of an ACT-based N400 modulation when only human nouns were considered (see **Figures 9** and **10** and the Supplementary Materials), thereby demonstrating that the effects observed here were not driven by the different animacy classes included in the stimulus materials.

These findings provide the first demonstration that an individual noun's potency to act can be assessed fully independently of verb information. They thereby go beyond previous studies showing that verb-noun combinations can induce role typicality effects (e.g., McRae et al., 1997, 1998; Corrigan, 2001, 2002), thus further strengthening the notion of incremental thematic interpretation in verb-final sentences (Bornkessel et al., 2003; Kamide et al., 2003; Schlesewsky and Bornkessel, 2004; Bornkessel and Schlesewsky, 2006). As we have previously argued, verb-independent thematic

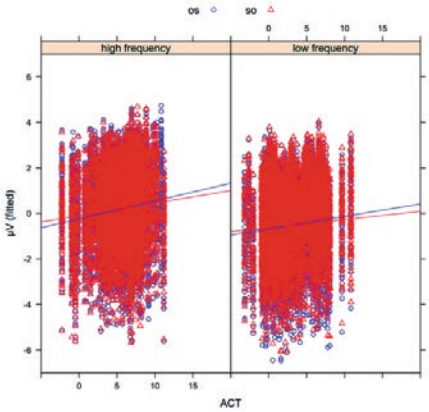

FIGURE 7 | Mean voltages in the N400 time window at the position of the critical noun phrase plotted against actorhood potential (ACT) for high frequency (FRQ; left panel) and low FRQ (right panel) nouns. Sentences in object initial order (OS) are shown in blue circles and sentences in subject initial (SO) order in red triangles. Positive slopes indicate larger (i.e., more negative) N400 amplitudes for nouns with a low ACT value. Note that this figure also demonstrates the correspondence between the mixed model fits and the observed ERP pattern: the N400 amplitude difference for low versus high FRQ nouns (see **Figure 4**) is reflected here in the generally more negative amplitudes for low FRQ nouns **(right panel)** than their high FRQ counterparts **(left panel)**.

interpretation presupposes the assumption of generalized semantic roles (Bornkessel et al., 2003). However, the assignment of nouns to these roles appears to go beyond the previously demonstrated influence of prominence scales such as animacy (Weckerly and Kutas, 1999; Roehm et al., 2004; Philipp et al., 2008) and case marking (Frisch and Schlesewsky, 2001, 2005) and to also rely on the experience-based ascription of properties which attest to an individual entity's potency to act. Note that "act" here includes here the full range of roles associated with the generalized semantic role actor, i.e., not only the capacity for voluntary, goal-directed action, but also the ability to "bring about change" evident in inanimate causers (see **Figure 9** for an ACT-based modulation of N400 effects for human and inanimate nouns) and the capacity to experience mental states. To re-emphasize the independence of these results from animacy distinctions, recall that entities that can cause goal-directed action [see the discussion of Primus's (2011) findings in Section "Identification of Suitable Rating Scales"] or that are associated with a high level of emotional arousal appear to be powerful sources of change and are treated as such by the language processing system. As shown by our second questionnaire study, the combination of these individual components in a noun's overall ACT value not only predicts ERP responses but also correlates with native speakers' intuitions about a noun's capacity for actorhood.

However, the additional finding of a (smaller) ACT effect in subject-initial sentences suggests that goodness-of-fit to the actor role in the current sentence does not account for the complete set of results. Rather, the data suggest that, in addition to modulating actor fit, ACT behaves like a purely lexical feature (e.g., concreteness, frequency) in that it influences N400 amplitude for every noun independently of its thematic and syntactic role. This observation attests to the importance of the actor concept beyond the level of sentence processing: assuming that "any factor that facilitates lexical access should reduce N400 amplitude" (Lau et al., 2008, p. 921), our findings support the claim that high actorhood potential facilitates lexical access. We envisage this observation as resulting from the higher conceptual accessibility for nouns with a high actorhood potential -analogous to the higher conceptual accessibility that is often assumed for animate as opposed to inanimate entities (see Branigan et al., 2008, for discussion). Following Keil (1979), Bock and Warren (1985), and Branigan et al. (2008) describe conceptual accessibility in terms of the number of pathways to a concept, with more pathways correlating with easier lexical retrieval. Pathways, in turn, are defined in terms of "predictability" or the number of conceptual relations into which an entity can enter: "[A] human being is highly predicable because he or she can enter into many relations (e.g., growing, eating, sleeping, talking, ironing, and arguing). Spiders can enter into fewer relations (e.g., growing, eating and sleeping, but not talking, ironing, or arguing), and clouds still fewer." (Branigan et al., 2008, p.174). This notion of predictability is, in fact, quite close to our notion of "potency to act," as entities with a higher ACT value can be assumed to enter into a higher number of relations as the actor of an event. We shall return to the broader

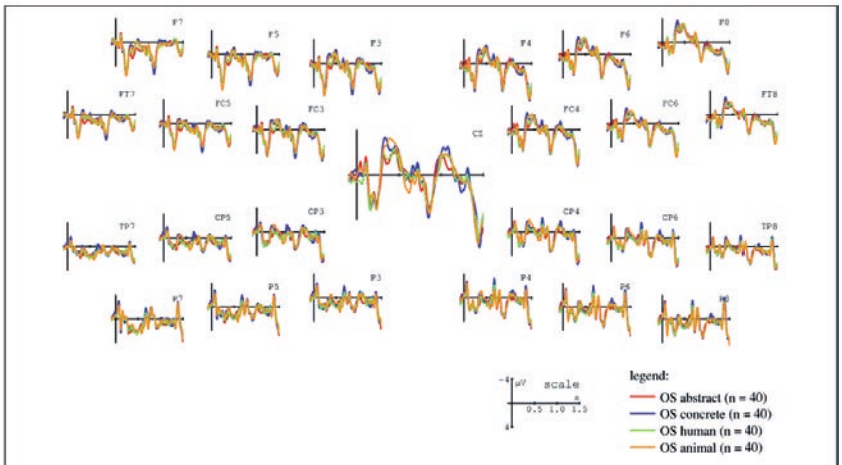

FIGURE 8 | Grand average ERPs time-locked to NP2 (onset at the vertical bar) in object-initial sentences. The figure contrasts human (hum; green line), non-human animate (yellow line), concrete inanimate (con; blue line), and abstract inanimate (abs; red line) actor arguments. Negativity is plotted upward.

consequences of positing higher lexical accessibility for high ACT nouns below.

To summarize, the ERP results from Experiment 2 suggest that the ACT value of individual nouns impacts upon online sentence processing in two ways: (a) by reflecting the goodness-of-fit to a predicted actor role in the current sentence even before the verb is reached (as shown by the stronger ACT effect for actors as opposed to undergoers); and (b) by modulating lexical access (as shown by the presence of an ACT-based N400 modulation for undergoers as well as actors).

ACTORHOOD VERSUS ACTOR POTENTIAL

In the preceding discussion, we have suggested that a noun's ACT value influences online sentence comprehension in two different ways, namely by influencing actor identification within the current sentence and by modulating lexical access. As this is clearly a claim with potentially far-reaching implications, this subsection examines additional evidence in its favor.

Firstly, why should these two dimensions be distinct? Clearly, it is important to separate an entity's inherent "potency to act," which is independent of the current sentence context, from the status of a sentence participant as an actor or non-actor within a particular sentence context, which is independent of that referent's inherent potency to act. Consider, for example, the two nouns *Ärztin* ("female doctor," ACT value = 8.0) and *Greisin* ("very old woman," ACT value = −0.14), which differ clearly with regard to their inherent potency to act. Nevertheless, a sentence in which the low ACT noun acts upon the high ACT noun is perfectly possible, e.g., *Die Greisin schubste die Ärztin die Treppe hinunter* ("The old woman pushed the doctor down the stairs."). Thus, in addition to being able to determine inherent (lexical) actor potential, the language processing system must have the ability to infer which argument is the actor within the current sentence context (actor identification).

We have argued extensively in previous publications that actor identification is accomplished with reference to linguistic prominence scales such as those in (7) (for detailed discussion, see Bornkessel-Schlesewsky and Schlesewsky, 2009):

(7) Linguistic prominence features related to actor identification–

(a) +animate/+human (follows from control/volition and sentience)
(b) +definite/+specific (follows from independent existence; see Primus, 1999)
(c) +1st position (correlates with actorhood cross-linguistically; see Tomlin, 1986)
(d) +nominative (correlates with actorhood in nominative-accusative languages)

While the prominence feature animacy/humanness (a) in part also defines the ACT value (see Experiment 1), properties (b) through (d) are lexically independent. They thus ensure that nouns which do not have a high degree of inherent actorhood potential can nevertheless be realized as actors. The degree to which the prominence features in (7) determine actor identification

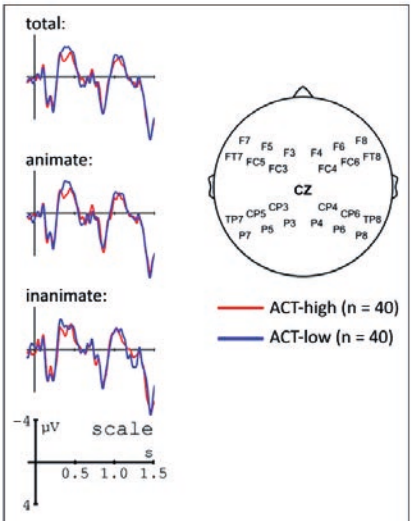

FIGURE 9 | Grand-average ERPs at the position of NP2 in object-initial sentences (onset at the vertical bar) at electrode FC3. The figure contrasts high ACT (red trace) and low ACT (blue trace) nouns for animate and inanimate nouns, respectively. Negativity is plotted upward.

within a particular language depends on their relative weighting within the language in question (cf. Bates and MacWhinney's Competition Model, e.g., MacWhinney and Bates, 1989). Thus, while position (or WO; property c) is particularly important in English, case marking (property d) is particularly central in German (MacWhinney et al., 1984). In other languages, by contrast, animacy plays a comparable role: in the languages Fore and Awtuw (spoken in Papua New Guinea), for example, sentences are interpreted according the animacy hierarchy (human > non-human animate > inanimate) such that, in the absence of additional marking, a sentence with a non-human and a human argument will always be interpreted with the human as actor (Scott, 1978; Feldman, 1986; for discussion within a psycholinguistic context, see Bornkessel-Schlesewsky and Schlesewsky, 2009). Animacy thus has a very different status to ACT here, since it determines interpretation independently of a noun's inherent actorhood potential. Importantly, even though prominence scales can clearly override ACT in actor identification within a particular sentence context, we nevertheless assume that ACT influences a noun's goodness-of-fit to the actor role in a given sentence (i.e., a low-ACT noun is a "worse" actor candidate than a high-ACT noun; see Consequences for Models of Language Processing below for an interpretation in terms of constraint-based sentence processing).

We thus propose that there are two dimensions to actor processing during online sentence comprehension: a noun's lexicalized potency to act (ACT), which influences lexical access (in the sense of conceptual accessibility/ease of retrieval as discussed in Section "Potency to Act and Word Order"), and actor identification as determined via prominence scales and modulated via ACT values. Indeed, a dissociation along these lines even appears to be neurobiologically plausible: we have recently proposed that the two major functional-neuroanatomical processing streams for speech and language in the human brain (the antero-ventral and postero-dorsal streams; cf. Rauschecker and Scott, 2009) are responsible for the recognition and sequence-independent (commutative) combination of auditory objects (e.g., phonemes, morphemes, words, phrases; see also DeWitt and Rauschecker, 2012) and the processing of linguistic sequences, respectively (Bornkessel-Schlesewsky and Schlesewsky, 2013a; Bornkessel-Schlesewsky et al., in press). Lexicalised potency to act, as a property of individual referents, clearly falls into the former domain and thereby accords with the overall function of the antero-ventral stream in sentence processing. Actor identification, by contrast, is dependent at least in part on the sequence in which the words in a sentence are encountered and thereby falls into the domain of the postero-dorsal stream (see Consequences for Models of Language Processing). Animacy, as one of the dominant features related to actorhood across languages, thereby plays a twofold role in that it is both a determinant of ACT and a lexically independent prominence scale.

But why should the ACT effect be larger for object-initial than for subject-initial sentences in the present study (i.e., for actor as opposed to undergoer arguments)? We assume that this reflects both actor identification and lexical access. On the one hand, a low-ACT noun leads to a mismatch with a predicted, prototypical actor (reflected in the N400 effect), thus modulating actor identification. On the other hand, we posit that the increased N400 for low-ACT actor nouns is due to a top–down modulation of lexical access: since the processing system has already encountered an unambiguously marked undergoer, it expects to process an actor, thus leading to a stronger preactivation of good actor candidates. When a noun with a low ACT value is subsequently encountered, an N400 effect results and this effect is more pronounced than in the absence of actor preactivation (as in a subject-initial sentence when no prediction for an upcoming actor is required).

EFFECTS OF LEXICAL FREQUENCY

In view of the proposal that ACT is a lexically encoded feature, the additional observation of an interaction between ACT and frequency is not surprising. Recall that the correlation between a noun's ACT value and N400 amplitude was modulated by frequency such that it was stronger for high frequency as opposed to low frequency nouns. While this interaction was not predicted prior to the experiment, it fits very well with the perspective on an entity's lexicalized potency to act that was advocated in the previous sections. High frequency nouns are those with which people have a lot of experience. Hence, they will have more detailed and precise knowledge about the properties of these nouns (as well as

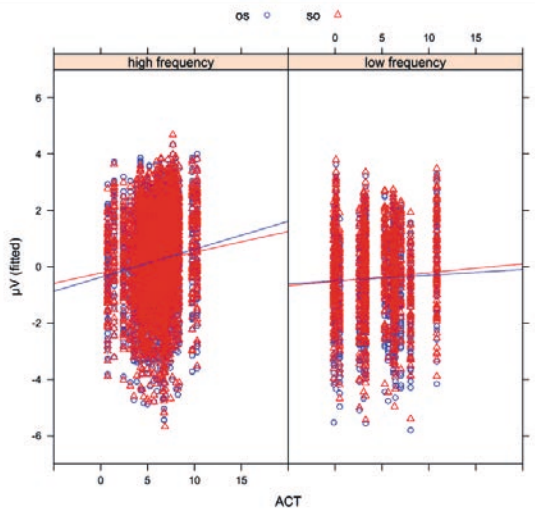

FIGURE 10 | Mean voltages plotted against actorhood potential (ACT) for high (left panel) and low frequency (right panel) human nouns only. Sentences in object initial order (OS) are shown in blue circles and sentences in subject initial order (SO) in red triangles.

the entities that they denote) and the actions that they are likely to perform. This does not mean that actor potential cannot be calculated for low frequency nouns – Experiment 1 demonstrates that it can. However, the semantic properties relevant to determining actor potential may not be as readily, and as rapidly, available for low frequency nouns as for their high frequency counterparts. In other words, something akin to an ACT value may be "precompiled" and lexically encoded for high but not for low frequency nouns. This claim is reminiscent of the proposal that highly frequent words may be stored as full forms in the lexicon even if they are regular (e.g., Laine et al., 1995; Baayen et al., 1997; Alegre and Gordon, 1999). Here, we suggest that high frequency of occurrence may lead to the lexical storage of additional properties such as actor potential.

CONSEQUENCES FOR MODELS OF LANGUAGE PROCESSING

The discussion in the previous section revealed that the present findings call for two separate dimensions of actorhood computation: an experience-based, lexically encoded representation of actorhood potential, and a prominence-based, computational mechanism for calculating goodness-of-fit to the actor role in a particular sentence context. In the following, we discuss the consequences of this observation for theories of sentence processing in general and, more specifically, for neurocognitive theories of language comprehension.

Firstly, our overall result can be couched within constraint-satisfaction architectures of language comprehension (cf. McRae and Matsuki, 2013, for an overview), assuming that (a) constraint-satisfaction applies incrementally and, if necessary, independently of verb-based representations; (b) actor identification is governed by constraints determining goodness-of-fit to the actor role in a given sentence; and (c) the impact of lexical potency to act (ACT) is determined by constraints at least partially separable from those involved in actor identification. As discussed in detail above, actor identification constraints must be able to override ACT-based constraints, since low-ACT nouns could not otherwise be interpreted as actors. This suggests that the two types of constraints are at least quantitatively distinct. On the basis of our results (i.e., the differential N400 modulations observed for ACT-values as opposed to animacy as an actor-identifying prominence feature), we would assume that they are, in addition, qualitatively distinct. This proposal leads to the testable prediction that ACT-values should be independent of (or at least not determined by) the relative weighting of the animacy prominence feature in a given language (i.e., we would still expect animacy to play a role in determining ACT-values in a language such as English, even though it is a relatively weak cue to overall sentence interpretation in this language; MacWhinney et al., 1984).

Turning now to neurocognitive models of language processing, a central consequence of our results for such models is

that they need to be able to incorporate the two independent dimensions of actor processing identified here. Indeed, all established neurocognitive models of sentence processing provide a principled means of dissociating lexicalized information from computational factors. In Hagoort's (2003, 2005, 2013) Memory, Unification and Control (MUC) model, this is achieved via the distinction between unification (offering the potential to derive prominence computation) and memory (offering the potential to derive retrieval of lexicalized actorhood potential). Like the MUC approach, Ullman's (2001, 2004) declarative/procedural model of language processing also distinguishes combinatory mechanisms, which form part of procedural memory, from lexical information, which forms part of declarative memory. Friederici's (2002, 2012) neurocognitive model likewise assumes a principled separation between the processing of morphosyntactic and lexical-semantic information, which are processed independently but in parallel in the model's second phase. Finally, Tyler and Marslen-Wilson (2008) put forward a neurocognitive model of language processing focused on "three aspects of language function" and posit that "two of these, involving inflectional morphological and syntactic processes, clearly group together in distinction from the third, semantic function" (Tyler and Marslen-Wilson, 2008, p. 1051). They thereby once again echo the purported distinction between combinatory and lexical/conceptual aspects of language. Thus, all of these approaches could, in principle, easily account for lexically based effects of actorhood by simply introducing a word-specific actor potential value into each lexical entry of a potentially "nouny" word.

By contrast, combinatory effects based on prominence information such as animacy are not naturally accounted for by any of these models. Both Friederici's and Ullman's models subscribe to a traditional (categorical) notion of linguistic rules. It is therefore not clear how weighted, combinatorial interactions – as required in prominence-based actor identification – might be derived. In addition, these approaches – like Tyler and Marslen-Wilson's account – assume a principled separation between syntax and semantics, thus rendering a direct interaction of semantic and morphosyntactic cues for actor identification problematic (see Bornkessel-Schlesewsky and Schlesewsky, 2009, for a general discussion of this issue). The MUC model is lexicalist in nature and thereby does not offer a natural way of dealing with pre-verbal argument interpretation in verb-final sentences (see Vosse and Kempen, 2000, for discussion of this topic in reference to the computational model of sentence processing on which the MUC model is based; and Bornkessel and Schlesewsky, 2006). In addition, the syntactic representations currently assumed (lexical frames) do not incorporate prominence features; thus prominence-based unification would appear to have to rely on an interaction with the lexicon (e.g., in the sense of features such as animacy modulating competition for positions within a syntactic frame).

In contrast to the models discussed so far, our own neurocognitive model of language processing, the (extended) Argument Dependency Model [(e)ADM; Bornkessel, 2002; Schlesewsky and Bornkessel, 2004; Bornkessel and Schlesewsky, 2006; Bornkessel-Schlesewsky and Schlesewsky, 2008, 2009, 2013a] was developed precisely to account for computational (prominence-based) mechanisms of actor identification, since these appear to constitute a cross-linguistically stable aspect of the language processing architecture. Thus, one of the model's strengths has traditionally lain in its ability to derive the relational – rather than the lexical – aspects of actor processing. The most recent version of the eADM (Bornkessel-Schlesewsky and Schlesewsky, 2013a; Bornkessel-Schlesewsky et al., in press), however, provides a principled, neurobiologically grounded motivation for the distinction between lexical and computational facets of actorhood.

In its latest version, the eADM posits a fundamental, functional-neuroanatomical computational division of labor between the antero-ventral and postero-dorsal processing streams. As already noted in Section "Actorhood Versus Actor Potential," the model assumes that the dorsal stream engages in sequence processing (non-commutative combinatorics), while the ventral stream engages in commutative combinatorics (i.e., the order-independent combination of features to form successively more complex feature or dependency structures). Processing in both streams is organized in a hierarchical manner in accordance with the neurobiological principle of hierarchical processing (e.g., Felleman and Van Essen, 1991; Rauschecker, 1998; Rauschecker and Scott, 2009; DeWitt and Rauschecker, 2012) and classic assumptions regarding the structure of complex cognitive models (Simon, 1962; Newell, 1990). This means that, as information flows along the streams, the representations that are processed are assumed to become increasingly complex.

Crucially, the representations identified and processed by the antero-ventral stream are assumed to correspond to "auditory objects" of successively increasing size – a proposal which was originally put forward on the basis of single unit recordings in non-human primates (Rauschecker, 1998; Rauschecker and Scott, 2009). In the language domain, the smallest of these auditory objects might correspond to the phoneme and the largest to complex phrases or perhaps even sentences (DeWitt and Rauschecker, 2012), and the eADM posits that word-level representations can be modeled via "actor-event schemata" (AE-schemata). These schemata are lexical objects which are unified with one another to form larger interpretive units (for details, see Bornkessel-Schlesewsky and Schlesewsky, 2013a). They are associated with an experience-based value of actor suitability, which comes into play whenever a given schema is identified as corresponding to a "nouny" constituent by the current sentence context. AE-schemata thus provide a natural means of incorporating word-based actor potency information which is, moreover, neurobiologically motivated by the more general function of the antero-ventral stream in the identification of successively complex auditory objects.

The postero-dorsal stream, by contrast, engages in the predictive processing of information for which sequential order is important. This includes prosodic segmentation and basic syntactic analysis (in the sense of syntactic processing entailing the analysis of a sequence of linguistic categories) as well as the identification of the actor for a given sentence (event). Actor identification in this sense must clearly be performed by the postero-dorsal as opposed to the antero-ventral stream since it presupposes processing of the linguistic input in time – i.e., the position in which

an argument appears within the category sequence constituting a sentence is clearly relevant to actor identification and this is the case in all languages, even though some may weigh this information more strongly than others. In this way, the lexically independent aspect of actor computation is also neurobiologically grounded within the latest version of the eADM.

In addition to the consequences for neurocognitive models of language processing discussed above, the present findings also have implications for models of the N400 component. Traditionally, prominent approaches to the N400 either stressed the role of lexical preactivation ("lexically based" approaches) or of integration into the current sentence context ("integration-based" approaches) in deriving N400 amplitude modulations (see Lau et al., 2008, for a review of both types of models). According to lexically based accounts (e.g., Kutas and Federmeier, 2000; Lau et al., 2008; Brouwer et al., 2012), N400 amplitude is reduced when an element is preactivated in semantic memory. In accordance with this view, it has been suggested that the language processing system establishes predictions about upcoming elements which, in constraining contexts, can be specific enough to lead to the anticipation of individual words (e.g., Wicha et al., 2004; DeLong et al., 2005; Van Berkum et al., 2005; Federmeier, 2007; Otten et al., 2007). The integration-based approach (e.g., Hagoort, 2008), by contrast, posits that N400 amplitude reflects the ease with which a word can be integrated into the current sentence and discourse context (though note that this does not necessarily presuppose that lexical access must have been completed in order for integration to begin). Notably, however, these two perspectives (preactivation due to top–down predictability versus bottom–up integrability) are not mutually exclusive. For example, Federmeier (2007) proposed an account of the N400 involving both information sources: top–down, predictive mechanisms (based on language production) operate primarily in the left hemisphere; the right hemisphere, by contrast, is assumed to process information in a more strongly feed-forward (bottom–up manner), thus ensuring that important stimulus-based information is not missed as a result of too strong predictive influences. More recently, Baggio and Hagoort (2011) offered a somewhat different suggestion regarding the integration of top–down and bottom–up information sources in the N400. In their view, top–down influences reflect unification requirements – processed in inferior frontal cortex – while bottom–up influences reflect the spreading of activation within semantic memory in temporal cortex. Finally, Lotze et al. (2011) demonstrated that bottom–up information need not be lexical to exert a profound effect on the N400, observing that the effects of predictability/integration can be almost entirely neutralized by paralinguistic orthographic cues (capitalization). Their "bidirectional coding account" thus stresses not only the integration of top–down and bottom–up information sources but also the degree of match between them.

The present results further support the idea that bottom–up/top–down integration is a crucial explanatory concept with regard to the N400. The fact that the lexical ACT effect was observed for all arguments (i.e., not just those that were actors in the current sentence context), calls for a purely bottom–up explanation. Nevertheless, as argued above, this effect can be amplified by top–down information, when prediction for an upcoming actor leads to lexical preactivation of good actor candidates. The prominence-based computation of actorhood, by contrast, generally relies on the integration between top–down (e.g., WO, case marking of previous arguments) and bottom–up (e.g., case marking and animacy of the current argument) information sources. This suggests that the overall N400 response could comprised a family of N400 effects, displaying differential sensitivity to the balance between top–down and bottom–up information sources (see Haupt et al., 2008, for the assumption of an N400 family). Furthermore, our findings indicate that predictability-based top–down influences on the N400 are not confined to the anticipation of individual words, but rather allow for the prediction of more abstract notions such as a generalized participant role (actor). In other words, predictability here is not driven by the build-up of a highly specific sentence context, but rather by more general cues regarding the nature of upcoming classes of participants.

To summarize, while most established neurocognitive models of sentence processing do not predict the lexicalization of actorhood, it appears that this observation could be incorporated into all approaches in a relatively straightforward manner. The distinction between lexicalized and prominence-based actorhood, by contrast, appears more difficult to integrate into most existing models with the exception of the eADM. With regard to models of the N400, the present findings support the notion of top–down/bottom–up integration, while additionally emphasizing the ability of the language comprehension system to predict not only individual words but also more general stimulus categories (cf. also Szewczyk and Schriefers, 2013).

CONCLUSION

We have presented a detailed investigation of how linguistically encoded actors – participants responsible for the event being described – are processed during language comprehension. On the basis of a questionnaire study and an associated structural equation model as well as an ERP study, we have argued that an individual's potency to act is encoded at the lexeme level for individual words and that this information is thereby considerably more fine-grained than previous investigations with macroscopic noun classes based on prominence scales (e.g., animacy) have suggested. Since the effect of the lexeme-specific actor potential is modulated by word frequency, we further propose that it is conditioned by the hearer/speaker's experience with a particular lexeme and, accordingly, the types of actions that the entity denoted by that lexeme is likely to undertake. We have argued that the present findings are indicative of a twofold influence of actorhood on language comprehension: (a) via a lexicalization of actorhood potential that is based on one's experience about the suitability of individual nouns to fill the actor role and that modulates lexical access whenever a "nouny" constituent is encountered; (b) competition for the actor role within a given sentence context, in which a noun's inherent suitability as an actor interacts with other information sources (e.g., WO, case marking). Thus, the effects of actorhood observed result from the interplay of bottom–up (lexical) and top–down (context-based expectation for an actor)

information sources. We suggest that the special status of the actor role may follow from domain-general properties of human cognition, particularly the independently required need to recognize the initiators of actions – and their intentions – in the world around us.

ACKNOWLEDGMENTS

Parts of the research reported here were conducted while Sabine Frenzel and Ina Bornkessel-Schlesewsky were at the Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany. This research was supported, in parts, by grants from the German Research Foundation (DFG; BO 2471/3-2) and the German state of Hesse (Loewe Program). We would like to thank Prof. em. Suitbert Ertel for providing information on the original scales introduced by Osgood and colleagues.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: http://www.frontiersin.org/journal/10.3389/fpsyg.2015.00001/abstract

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 10 October 2014; accepted: 02 January 2015; published online: 30 January 2015.

Citation: Frenzel S, Schlesewsky M and Bornkessel-Schlesewsky I (2015) Two routes to actorhood: lexicalized potency to act and identification of the actor role. Front. Psychol. ***6****:1. doi: 10.3389/fpsyg.2015.00001*

This article was submitted to Language Sciences, a section of the journal Frontiers in Psychology.

Supplementary Material A: List of nouns used in Experiment 1 and their factor values

Table A1 shows the nouns used in Experiment 1 together with their English translations, their mean ratings on the 9 scales that entered the best-fitting structural equation model and their factor values.

Table A2 shows separate ratings and factor values for the different noun types used (humans, animals, concrete objects, abstract concepts).

Table A3 shows mean actor ratings and standard deviations of validation test for the different noun types used (humans, animals, concrete objects, abstract concepts).

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Table A1: Factor values per noun

noun	translation	cond	logfreq	VAL2	PLE2	APP2	POW	STR	SIZ	ANI	CON	AIM	EVA	POT	HUM	ACT
Adler	eagle	B	7.51	1.68	1.57	2.46	2.36	2.36	1.71	2.79	1.75	2.04	3.72	3.37	1.59	9.17
Amme	wet nurse	A	3.61	2.00	1.42	0.91	0.97	1.06	0.24	1.79	2.03	1.88	2.91	1.20	1.62	6.19
Anstand	decency	D	6.14	2.26	2.12	1.47	0.94	0.94	0.79	-0.68	0.76	1.65	4.17	1.08	0.22	5.87
Anwalt	lawer	A	9.02	1.15	1.03	0.44	2.06	1.47	0.59	1.88	2.38	2.62	1.57	2.32	1.91	6.43
Ärger	trouble	D	8.49	2.09	2.34	1.94	1.03	0.66	0.78	0.94	0.56	0.94	4.55	0.88	0.36	6.01
Ärztin	physician	A	6.87	2.18	1.62	1.06	1.74	1.24	0.32	2.26	2.62	2.59	3.34	1.88	2.16	8.00
Autor	author	A	8.83	1.71	1.54	0.79	1.71	1.07	0.46	2.14	2.64	2.07	2.74	1.72	2.15	7.11
Becher	mug	C	6.05	1.47	1.19	0.84	-1.31	-0.56	-0.50	-2.38	-2.44	0.50	2.22	-1.86	-2.52	-2.04
Betrug	fraud	D	8.10	2.61	2.55	2.30	1.45	1.18	0.91	-0.21	0.24	2.18	5.37	1.65	-0.09	7.45
Bettler	beggar	A	5.27	1.21	1.65	1.44	-2.06	-2.03	-0.62	1.09	1.65	-1.00	2.84	-3.72	1.21	0.09
Biber	beaver	B	5.32	1.03	1.06	1.12	0.03	1.44	-1.03	2.38	1.50	1.79	1.90	0.89	1.33	4.55
Bleistift	pencil	C	5.52	1.71	1.41	0.91	0.29	-0.21	-1.32	-2.21	-2.32	1.38	2.67	-0.46	-2.40	0.15
Bombe	bomb	C	8.33	2.74	2.76	2.38	2.59	2.71	1.62	-2.00	-1.74	1.74	5.74	3.84	-1.92	8.08
Büffel	buffalo	B	4.41	0.97	0.91	1.25	1.81	2.44	2.59	2.66	1.28	0.97	1.77	3.09	1.21	6.30
Buntspecht	gr. sp. woodpacker	B	2.77	1.19	1.50	1.66	-0.81	-0.56	-2.03	2.56	1.28	1.00	2.80	-1.55	1.20	2.68
Bussard	buzzard	B	4.49	1.64	1.39	1.86	1.75	1.93	0.82	2.68	1.68	2.32	3.15	2.54	1.52	7.77
Dackel	dachs hund	B	5.16	0.73	0.94	1.18	-0.85	-0.82	-2.12	2.12	1.30	-0.61	1.58	-1.81	1.13	0.76
Dame	lady	A	8.00	1.53	1.76	1.88	0.62	-0.03	0.15	2.38	2.32	1.26	3.47	-0.04	1.95	5.69
Decke	blanket	C	7.64	2.30	2.36	1.73	-0.09	0.30	1.64	-1.61	-2.15	-0.64	4.61	-0.19	-2.16	2.10
Delphin	dolphin	B	4.61	1.84	2.00	2.16	0.44	1.13	1.16	2.88	2.25	1.47	4.12	0.92	1.99	7.38
Dichter	poet	A	7.64	1.89	1.82	1.18	0.79	-0.07	0.00	2.14	2.75	1.18	3.40	0.03	2.24	5.95
Diebin	thief	A	3.61	1.84	1.97	0.89	0.58	0.42	-0.74	2.34	1.63	2.32	3.36	0.33	1.42	5.66
Diener	buttler	A	6.19	1.53	1.65	0.62	-1.06	-0.56	-0.12	1.97	2.21	2.15	2.62	-1.68	1.79	3.25
Doktor	doctor	A	6.85	1.91	1.28	0.47	1.59	0.78	0.44	1.91	2.50	2.22	2.44	1.37	2.00	6.34
Dose	can	C	6.16	1.18	0.79	1.04	-1.32	-0.68	-1.39	-2.71	-2.57	-0.75	1.68	-1.99	-2.68	-3.17
Ehre	honor	D	8.21	2.00	1.86	1.75	2.18	2.07	1.71	0.75	0.29	1.14	3.86	2.98	0.11	7.22
Ehrgeiz	ambition	D	7.31	1.41	1.00	0.79	1.97	1.50	1.53	0.47	0.21	2.59	1.95	2.31	0.00	4.88
Eifer	eagerness	D	6.23	1.52	1.27	0.85	1.82	1.82	1.30	1.24	0.39	2.30	2.35	2.50	0.28	5.68
Ekel	disgust	D	5.63	2.24	2.85	2.48	1.03	1.55	0.70	0.70	-0.06	0.61	5.51	1.70	-0.16	7.19
Ente	duck	B	6.55	1.12	1.18	1.21	-1.33	-1.12	-1.21	2.21	1.18	-0.18	2.16	-2.40	1.06	0.77
Erfolg	sucess	D	10.39	2.18	2.50	1.95	2.24	2.18	1.79	0.97	0.47	2.66	4.79	3.13	0.30	8.85
Eule	owl	B	4.53	1.47	1.38	1.44	0.50	0.38	0.06	2.09	1.81	1.13	2.76	0.25	1.51	4.79
Falter	moth	B	5.39	1.24	1.38	1.76	-1.35	-1.53	-1.79	2.56	0.79	-0.09	2.78	-2.80	0.82	0.78
Faultier	sloth	B	3.18	0.81	0.78	1.19	-0.81	-0.44	-0.06	1.44	0.97	-0.25	1.48	-1.40	0.76	0.78
Ferkel	piglet	B	4.90	1.18	0.82	1.03	-1.15	-0.42	-1.67	2.79	1.06	-0.21	1.72	-1.65	1.07	1.09
Fleischer	butcher	A	6.01	1.21	1.30	0.88	1.06	1.91	1.33	2.24	2.15	1.67	2.16	2.06	1.80	6.42
Fliege	fly	B	6.16	1.00	1.91	1.67	-1.73	-1.82	-2.61	2.64	-0.33	-1.12	3.09	-3.34	-0.02	-0.54
Flunder	flatfish	B	3.78	0.70	0.76	1.48	-1.55	-1.00	-1.03	1.30	0.45	-0.64	1.54	-2.43	0.34	-0.70
Forscher	scientist	A	9.49	2.24	1.36	0.58	1.70	1.03	0.73	1.70	2.61	2.58	2.84	1.68	2.05	7.18
Fortschritt	progress	D	7.81	1.88	1.62	1.15	2.35	1.94	1.85	0.82	0.06	2.38	3.16	2.98	-0.05	6.67
Freude	happyness	D	9.10	2.76	2.79	2.76	1.71	1.92	1.84	2.39	1.47	0.42	6.01	2.53	1.31	9.95
Freundin	friend	A	8.84	2.68	2.82	2.36	1.57	1.36	0.36	2.68	2.68	1.61	5.74	1.88	2.28	10.29
Frieden	peace	D	8.76	2.91	2.70	2.70	0.88	0.97	1.55	1.03	0.79	1.33	5.99	1.08	0.54	7.93
Friseur	hairdresser	A	6.21	1.45	1.61	1.03	0.64	0.24	-0.06	2.36	2.24	1.79	2.75	0.21	1.89	5.29
Fruchtsaft	fruit juice	C	3.83	2.21	2.04	1.07	-0.54	0.43	-0.11	-0.07	-1.93	-0.36	3.81	-0.41	-1.72	1.60
Fußball	football	C	9.78	1.44	1.18	0.97	0.68	1.24	0.50	0.94	-0.32	1.79	2.26	1.17	-0.32	3.54
Gärtner	gardener	A	6.83	1.61	1.39	0.45	-0.47	0.97	0.32	1.89	1.89	1.76	2.31	0.14	1.54	4.41
Gefahr	danger	D	9.80	2.50	2.71	1.57	1.93	1.64	1.50	0.68	-0.82	0.64	5.04	2.41	-0.74	6.86
Gefühl	feeling	D	9.24	1.91	1.36	1.67	2.12	1.97	1.88	2.27	0.73	0.58	3.22	2.85	0.72	6.93
Geiger	violinist	A	6.71	1.93	2.14	1.43	0.50	0.14	0.43	2.50	2.68	1.75	3.91	0.04	2.25	6.62
Goldfisch	goldfish	B	3.99	1.21	1.55	1.64	-1.55	-1.64	-2.06	2.18	-0.12	-1.00	2.86	-3.04	0.06	-0.36
Greisin	old woman	A	3.71	1.29	1.04	1.25	-1.25	-2.11	-1.79	0.82	1.61	-0.64	2.15	-3.26	1.13	-0.14
Grille	cricket	B	3.00	0.72	1.06	0.91	-0.75	-1.31	-2.25	2.06	0.56	-0.50	1.54	-2.20	0.56	-0.22
Hammer	hammer	C	7.39	1.06	1.28	0.97	1.50	2.28	0.63	-2.00	-2.22	1.63	2.08	2.69	-2.29	2.87
Hamster	hamster	B	4.98	1.21	1.58	1.42	-1.97	-1.95	-2.50	2.26	0.66	-0.82	2.76	-3.62	0.67	-0.39
Hausschwein	domestic pig	B	3.04	1.32	0.93	1.14	-0.89	0.75	-0.29	2.64	1.25	-1.00	2.01	-0.36	1.19	2.59
Heldin	heroine	A	5.89	2.47	2.00	2.21	2.24	2.38	1.74	2.62	2.68	2.65	4.63	3.31	2.27	10.84
Hoffnung	hope	D	8.10	2.50	2.28	2.22	1.91	2.09	1.47	1.16	1.06	2.03	4.96	2.81	0.78	9.03
Holztisch	wooden table	C	4.30	1.65	1.82	1.62	-0.56	1.53	1.50	-2.00	-2.21	-0.82	3.47	0.62	-2.28	1.61
Hummel	bumblebee	B	5.83	1.74	1.44	1.74	-0.32	-0.21	-1.50	2.65	1.15	1.32	3.21	-0.88	1.11	3.75
Igel	hedgehog	B	5.76	1.86	1.68	1.71	-1.25	-1.43	-2.00	2.25	1.21	0.14	3.54	-2.64	1.09	2.01
Insekt	insect	B	5.19	1.15	1.64	1.45	-1.03	-1.30	-2.33	2.45	-0.21	-0.21	2.80	-2.39	0.04	0.40
Instinkt	instinct	D	3.43	2.18	1.67	1.24	1.91	1.73	0.91	1.94	0.48	1.30	3.50	2.47	0.48	6.76
Jagdhund	hound	B	3.53	1.09	1.38	1.28	1.31	2.09	1.25	2.78	1.66	2.34	2.38	2.40	1.52	6.86
Jähzorn	irascibility	D	3.91	2.38	2.44	2.16	1.31	1.09	1.09	1.19	0.00	0.25	4.99	1.48	-0.03	6.50
Kaffee	coffee	C	8.20	1.94	1.84	1.00	0.78	1.78	0.31	-0.41	-1.34	0.84	3.36	1.74	-1.33	3.96
Kakao	hot choclate	C	6.00	2.21	2.43	1.29	-0.71	0.68	-0.07	-1.04	-1.79	-0.25	4.35	-0.30	-1.78	2.20
Kämpfer	fighter	A	7.86	1.12	1.06	1.00	2.24	2.71	2.12	2.59	2.24	2.56	1.90	3.61	1.92	8.05
Kampfgeist	morale	D	6.11	2.15	1.82	1.45	2.64	2.67	2.42	2.09	1.70	2.58	3.76	3.85	1.43	9.66
Karpfen	carp	B	4.81	0.88	0.85	1.27	-0.88	-0.18	0.42	2.24	0.36	-0.42	1.66	-1.20	0.44	0.80
Karte	card	C	8.95	1.67	1.27	1.03	1.00	0.15	0.24	-2.12	-2.15	1.91	2.57	0.38	-2.26	1.15
Käse	cheese	C	6.89	1.72	1.69	0.97	-1.06	0.13	-0.25	-1.44	-1.91	-0.56	3.01	-1.05	-1.95	-0.13
Kasten	box	C	7.32	1.07	0.71	0.68	-0.82	0.25	0.46	-2.36	-2.64	-0.57	1.32	-0.76	-2.67	-2.25
Kater	tomcat	B	6.64	1.76	1.82	1.79	0.58	0.91	-0.09	2.15	1.39	0.39	3.65	0.79	1.21	5.74
Kätzchen	kitten	B	4.90	2.15	2.45	2.45	-1.73	-1.91	-2.61	2.67	0.61	-0.76	5.01	-3.42	0.70	2.10
Katze	cat	B	7.55	1.53	1.84	1.95	0.16	0.34	-0.61	2.34	1.53	1.32	3.59	-0.03	1.34	5.22
Kissen	pillow	C	6.25	2.26	2.74	1.58	-0.92	-0.79	0.34	-1.63	-2.42	-0.53	4.88	-1.79	-2.37	0.60
Kleidung	clothes	C	8.11	2.03	2.21	1.94	0.27	0.45	0.33	-0.30	-0.79	1.09	4.36	0.17	-0.89	3.90
Knoten	knot	C	6.83	1.29	1.61	0.93	1.29	1.82	0.54	-1.57	-1.54	1.36	2.57	2.12	-1.69	3.32
Köchin	chef	A	5.24	1.88	1.78	0.84	0.84	1.25	0.13	2.59	2.47	1.97	3.15	1.29	2.10	7.02
Kochtopf	pot	C	4.62	1.53	1.16	0.88	-0.69	0.31	0.31	-2.59	-2.50	0.53	2.25	-0.61	-2.61	-0.84
Koffer	suitcase	C	7.78	1.39	1.15	1.06	-0.70	0.09	1.27	-2.30	-2.39	0.39	2.25	-0.80	-2.47	-0.94
König	king	A	8.83	1.16	0.95	0.97	2.45	1.89	1.11	1.87	1.87	1.68	1.80	2.99	1.52	6.71
Krähe	crow	B	4.14	1.03	1.33	1.48	0.33	0.76	0.12	2.39	1.18	0.79	2.40	0.49	1.09	4.17
Küken	chick	B	5.86	2.03	2.09	2.15	-2.29	-2.38	-2.76	2.85	1.12	-0.85	4.35	-4.25	1.12	1.02
Künstler	artist	A	9.29	1.52	1.15	1.12	0.36	0.48	0.48	2.27	2.09	0.15	2.38	0.26	1.76	4.43
Lampe	light	C	6.44	2.15	1.85	1.15	-0.18	0.33	-0.76	-1.79	-2.39	0.12	3.62	-0.27	-2.38	0.99
Landwirt	farmer	A	6.86	1.64	1.03	0.55	0.42	1.85	0.94	2.67	2.48	1.85	2.01	1.57	2.13	6.15
Laubfrosch	tree-frog	B	2.71	1.21	1.15	1.33	-1.30	-1.18	-2.09	1.94	1.30	-0.48	2.27	-2.46	1.10	0.79
Läufer	runner	A	7.35	1.91	1.48	1.24	0.33	1.88	1.21	2.48	1.97	2.30	3.10	1.54	1.70	6.90
Lehrer	teacher	A	9.25	1.14	1.29	0.21	1.43	0.89	0.57	1.54	2.29	1.79	1.70	1.36	1.77	5.27
Liebe	love	D	9.37	2.64	2.75	2.93	2.68	2.54	2.07	2.61	1.32	0.89	5.97	3.76	1.23	11.17
Löffel	spoon	C	5.82	1.09	1.15	0.55	-1.06	-0.12	-1.00	-2.94	-2.64	-1.18	1.72	-1.29	-2.77	-2.63
Mädchen	girl	A	9.78	1.58	1.64	1.88	-0.33	-0.61	-1.12	2.70	2.30	0.52	3.37	-1.25	2.00	4.24

Table A1 continued

noun	translation	cond	logfreq	VAL2	PLE2	APP2	POW	STR	SIZ	ANI	CON	AIM	EVA	POT	HUM	ACT
Marder	marten	B	5.01	1.09	1.63	1.19	0.63	0.28	-1.34	2.41	1.19	1.06	2.59	0.22	1.10	4.15
Marktfrau	market-woman	A	3.04	1.32	1.15	0.97	0.03	0.94	-0.03	2.59	2.24	1.82	2.14	0.45	1.92	4.94
Masseur	masseur	A	4.87	2.26	2.47	0.97	0.38	1.74	0.50	2.21	2.18	2.32	4.25	1.43	1.81	8.05
Maultier	mule	B	3.33	1.24	0.88	0.85	-0.52	0.97	0.79	1.97	1.39	-0.27	1.72	0.12	1.17	2.95
Maulwurf	mole	B	4.85	0.88	0.88	1.31	-1.00	-0.78	-2.13	2.16	1.34	0.47	1.70	-1.88	1.17	1.10
Maurer	bricklayer	A	7.24	1.36	0.79	0.68	0.36	1.82	1.21	1.96	1.89	1.29	1.61	1.50	1.55	4.98
Mehlwurm	mealworm	B	0.00	1.82	2.43	2.61	-1.89	-2.11	-2.61	1.61	-0.36	-1.43	4.81	-3.72	-0.22	0.53
Meister	master	A	9.38	1.91	1.45	0.73	2.39	2.18	1.73	2.03	2.18	2.45	2.77	3.23	1.78	8.37
Messer	knife	C	7.99	0.97	0.97	0.76	1.52	1.91	0.06	-2.27	-2.27	0.58	1.55	2.35	-2.38	1.66
Milchkuh	dairy cow	B	3.09	1.76	1.18	0.97	-0.18	1.05	2.03	1.66	0.08	-0.76	2.52	0.44	0.12	2.89
Mörder	murderer	A	7.84	2.59	2.72	1.66	1.44	1.09	0.38	1.19	1.47	1.78	5.16	1.55	1.09	8.23
Mutter	mother	A	10.17	2.47	2.29	1.76	1.50	1.82	0.38	2.68	2.71	2.15	4.68	2.27	2.30	9.76
Nagel	nail	C	7.62	1.03	0.72	0.78	0.13	0.75	-1.78	-2.69	-2.22	1.13	1.35	0.30	-2.41	-0.49
Natter	viper	B	3.74	0.89	1.47	1.24	-0.13	-0.16	-0.76	1.68	0.61	0.55	2.30	-0.69	0.52	2.27
Nonne	nun	A	5.53	1.50	1.09	0.62	-0.65	-0.35	-0.38	1.50	2.59	1.94	2.01	-1.21	2.00	3.26
Oma	grandmother	A	7.20	2.18	2.27	1.03	0.64	-0.24	-1.09	1.70	2.48	1.15	4.01	-0.25	1.95	5.99
Onkel	uncle	A	7.30	1.61	1.64	0.70	0.45	1.03	1.03	2.06	2.12	0.82	2.71	0.84	1.74	5.49
Opa	grandfather	A	6.46	1.95	1.84	0.82	0.32	-0.11	0.05	1.34	2.00	0.61	3.26	-0.32	1.52	4.60
Panik	panic	D	7.95	2.21	2.48	1.79	1.45	1.27	2.00	1.73	-0.18	-0.36	4.70	1.76	-0.07	6.30
Papier	paper	C	9.08	1.39	1.06	0.97	0.00	-0.30	-0.64	-1.48	-2.00	-0.55	2.10	-0.73	-2.03	-0.79
Parfüm	parfume	C	5.81	1.37	1.82	1.61	0.63	0.24	-0.82	-0.18	-1.21	0.68	3.24	0.19	-1.19	2.40
Pavian	baboon	B	2.30	0.76	0.79	1.26	0.03	1.12	0.41	2.59	1.24	0.32	1.51	0.62	1.16	3.37
Pfarrer	pastor	A	8.01	1.06	0.94	0.38	0.76	0.38	0.12	1.91	2.53	1.94	1.38	0.43	2.03	4.30
Pfleger	nurse	A	6.49	2.31	1.66	0.78	0.94	1.22	0.72	2.53	2.72	2.00	3.32	1.33	2.28	7.42
Pottwal	spermwhale	B	3.22	1.56	1.25	1.53	1.88	2.44	2.88	2.47	1.94	0.97	2.75	3.14	1.68	7.80
Priester	priest	A	7.34	1.09	1.16	0.53	0.50	-0.19	-0.22	1.44	2.25	1.59	1.71	-0.28	1.73	3.55
Psyche	psyche	D	6.22	1.36	1.09	1.12	2.00	1.73	1.15	2.18	1.79	1.48	2.20	2.53	1.51	6.60
Putzfrau	cleaning lady	A	5.81	1.29	1.18	0.92	-0.97	-0.13	-0.97	1.84	1.82	1.00	2.12	-1.24	1.47	2.59
Ratte	rat	B	5.08	1.68	2.13	2.05	0.21	0.00	-1.21	2.32	0.82	0.37	4.08	-0.32	0.80	4.64
Raubtier	predator	B	5.14	0.95	1.13	1.76	2.16	2.55	2.00	2.47	1.47	2.24	2.29	3.42	1.33	7.57
Raupe	caterpillar	B	4.42	0.85	1.33	1.24	-1.48	-1.21	-2.48	2.61	0.24	0.58	2.12	-2.61	0.41	0.06
Redner	speaker	A	7.09	0.92	1.03	0.61	1.32	0.79	0.66	1.63	2.26	2.13	1.49	1.19	1.77	4.97
Rentier	reindeer	B	3.91	1.47	1.39	1.68	0.16	1.34	1.42	2.37	1.08	0.55	2.93	0.93	1.01	5.00
Rentner	pensioner	A	8.19	0.97	0.88	0.55	-0.61	-1.00	-0.58	1.73	2.27	0.36	1.34	-1.78	1.80	1.44
Respekt	respect	D	8.65	2.36	2.04	1.43	2.04	1.89	1.61	0.82	1.39	1.50	4.13	2.72	0.97	8.18
Richter	judge	A	9.76	1.26	1.29	0.58	2.53	2.03	1.32	1.58	2.39	2.47	2.01	3.17	1.86	7.64
Rotfuchs	red fox	B	0.69	1.03	1.06	1.41	0.00	0.65	-0.97	2.59	1.74	1.21	2.07	0.14	1.54	4.04
Schlange	snake	B	7.43	1.25	1.86	1.64	1.36	1.79	0.43	2.54	1.29	1.82	3.22	2.13	1.19	6.98
Schnecke	snail	B	5.12	0.84	1.25	1.59	-2.16	-1.91	-2.63	1.81	0.66	-0.16	2.24	-3.71	0.59	-0.93
Schönheit	beauty	D	7.86	2.06	2.24	2.61	2.03	1.64	0.85	1.67	0.24	0.30	4.80	2.46	0.24	7.58
Schüler	student	A	9.85	1.39	0.85	0.61	-0.94	-0.24	-0.73	2.39	2.30	0.61	1.67	-1.32	1.94	2.44
Schwager	brother in law	A	6.03	1.15	1.00	0.41	0.03	0.18	0.21	1.97	2.00	0.56	1.52	-0.25	1.63	3.04
Schwalbe	swallow	B	5.39	1.26	1.42	1.55	-0.92	-1.00	-1.87	2.47	0.74	0.97	2.72	-2.02	0.77	1.69
Schwester	sister	A	8.61	2.07	2.00	1.75	0.64	0.93	-0.14	2.64	2.50	1.11	4.06	0.85	2.14	7.31
Seele	soul	D	8.19	1.91	1.82	1.55	1.55	1.45	1.39	1.82	1.39	1.06	3.63	1.98	1.15	7.00
Segen	blessing	D	7.26	1.69	1.78	1.38	0.59	0.38	0.44	-0.66	-0.59	0.88	3.32	0.32	-0.81	3.04
Sittich	parakeet	B	2.08	1.00	1.21	1.29	-1.61	-1.61	-2.18	2.16	0.24	-0.82	2.14	-3.05	0.33	-0.78
Skorpion	scorpion	B	4.36	1.26	1.79	1.32	1.56	1.71	-1.15	2.32	1.44	1.21	2.98	2.17	1.27	6.70
Spieler	player	A	10.37	1.00	1.00	0.54	-0.07	0.14	0.32	2.07	2.11	1.25	1.48	-0.35	1.73	3.16
Spinne	spider	B	5.41	1.61	2.03	1.91	0.00	-0.33	-1.36	1.76	0.88	0.52	3.83	-0.77	0.74	3.92
Spitzmaus	shrew mouse	B	1.10	1.21	1.29	1.14	-1.68	-1.93	-2.61	2.57	0.96	0.64	2.30	-3.41	0.96	0.00
Sportler	athlete	A	8.24	1.45	1.45	1.34	0.74	2.24	1.66	2.71	2.24	2.50	2.76	2.15	1.95	7.46
Stinktier	skunk	B	2.64	1.09	1.79	1.33	0.09	-0.09	-0.82	2.21	1.21	0.39	2.84	-0.48	1.08	3.54
Streber	nerd	A	4.20	0.87	1.32	1.11	-0.45	-0.53	-0.39	0.79	1.84	2.45	2.04	-1.24	1.30	2.69
Tante	aunt	A	7.11	1.45	1.34	1.00	-0.05	0.13	-0.34	1.79	1.58	0.18	2.45	-0.36	1.28	3.42
Thunfisch	tuna	B	4.26	1.37	1.29	1.00	-0.97	-0.03	0.82	1.74	0.18	-0.29	2.34	-1.11	0.21	1.37
Tiger	tiger	B	7.47	1.27	1.09	2.30	2.24	2.61	1.94	2.85	1.64	1.79	2.81	3.52	1.52	8.28
Tischler	carpenter	A	5.15	1.54	1.32	0.43	0.50	1.93	0.96	2.32	2.39	2.00	2.17	1.69	2.00	6.34
Tochter	daughter	A	9.78	1.79	1.68	1.71	-0.06	-0.18	-0.65	2.74	2.59	0.59	3.48	-0.66	2.22	5.19
Trainer	coach	A	10.63	1.54	1.14	0.61	1.43	1.75	1.11	2.46	2.43	2.36	2.08	2.16	2.05	6.86
Triumph	triumph	D	8.05	2.00	2.24	1.67	2.33	2.12	1.91	0.85	0.15	2.00	4.21	3.14	0.03	7.86
Truthahn	gobbler	B	4.34	0.92	1.16	1.68	-0.79	0.26	0.79	2.29	0.74	-0.66	2.25	-0.72	0.73	2.11
Turner	gymnast	A	6.71	1.59	1.06	1.25	0.22	2.16	0.06	2.56	2.50	2.19	2.42	1.69	2.12	6.76
Uhu	eagle owl	B	4.70	1.29	1.26	1.71	0.47	0.50	0.34	1.92	1.13	0.82	2.66	0.35	0.97	4.17
Unmut	discontent	D	7.88	2.11	2.08	1.50	-0.05	-0.21	0.00	-0.74	-0.21	-0.79	4.02	-0.67	-0.53	2.63
Unschuld	innocence	D	7.36	1.69	1.50	1.44	0.25	0.34	-0.03	0.44	0.28	0.28	3.06	0.05	0.05	3.22
Vater	father	A	9.98	2.13	2.08	1.08	1.45	1.50	1.45	1.82	1.97	1.50	3.80	1.95	1.59	7.70
Vetter	cousin	A	6.38	1.27	1.21	0.55	0.15	0.42	0.67	2.00	2.12	0.58	1.92	0.07	1.73	3.86
Vogel	bird	B	7.95	1.52	1.42	1.82	-0.52	-0.48	-0.97	2.76	1.91	0.73	3.07	-1.26	1.71	3.69
Vorteil	advantage	D	8.72	2.15	2.18	1.36	1.85	1.76	1.24	-0.67	-0.55	1.79	4.09	2.46	-0.77	6.20
Wagen	vehicle	C	9.32	1.16	1.25	1.09	0.72	1.25	0.88	-1.69	-2.06	0.88	2.19	1.22	-2.11	1.50
Walross	walrus	B	2.48	0.87	0.89	1.34	1.42	2.11	2.42	1.82	0.95	-0.11	1.74	2.51	0.81	5.03
Wasser	water	C	10.06	2.36	2.36	2.04	2.64	2.32	1.36	2.11	-1.11	1.21	4.82	3.52	-0.70	7.93
Wespe	wasp	B	4.58	1.27	2.15	1.24	0.64	0.03	-1.67	2.52	0.06	1.00	3.31	-0.01	0.26	3.80
Whiskey	whiskey	C	4.94	1.36	1.68	1.25	0.54	1.96	-0.25	-1.29	-1.79	-0.39	2.88	1.73	-1.83	2.69
Widder	ram	B	6.03	1.00	0.79	0.97	0.91	1.85	1.06	2.36	1.73	0.76	1.51	1.90	1.50	5.09
Wiesel	weasel	B	4.45	0.91	0.85	0.85	-0.33	0.15	-0.82	2.55	1.06	0.88	1.43	-0.54	1.02	2.12
Wildschwein	boar	B	5.06	0.69	1.16	1.38	1.59	2.03	1.53	2.63	1.38	0.69	1.89	2.54	1.28	5.88
Winzer	vintner	A	6.60	1.47	1.32	0.50	0.50	1.08	0.50	2.00	2.03	1.92	2.16	0.90	1.66	5.18
Wissen	knowledge	D	10.25	2.61	2.30	2.12	2.85	2.52	2.09	1.12	2.00	2.03	5.01	3.85	1.48	10.83
Witwe	widow	A	7.15	0.93	1.11	0.86	-1.39	-0.79	-0.93	0.11	2.07	-0.82	1.72	-2.13	1.35	0.75
Witwer	widower	A	4.77	1.24	1.27	0.67	-1.33	-0.88	-0.15	0.00	1.27	-0.45	2.03	-2.16	0.73	0.49
Wohlstand	prosperity	D	7.33	1.82	2.15	1.44	2.21	1.56	1.44	-0.59	-0.68	0.91	3.84	2.52	-0.86	5.73
Wurzel	root	C	6.16	1.42	0.82	1.39	1.67	2.27	1.24	1.39	-0.67	0.97	2.11	2.81	-0.50	4.66
Zahnarzt	dentist	A	6.51	1.62	1.68	0.59	1.09	0.91	0.41	1.88	2.03	2.21	2.70	1.15	1.64	6.01
Ziege	goat	B	5.76	0.88	0.82	1.03	-0.73	-0.12	-0.24	1.97	1.00	-0.48	1.48	-1.05	0.87	1.19
		mean	6.36	1.57	1.55	1.31	0.43	0.65	0.15	1.38	0.86	0.92	2.95	0.46	0.66	4.29
		sd	2.15	0.51	0.54	0.55	1.24	1.23	1.29	1.50	1.48	1.05	1.14	1.94	1.36	3.08
		min	0.00	0.69	0.71	0.21	-2.29	-2.38	-2.76	-2.94	-2.64	-1.43	1.32	-4.25	-2.77	-3.17
		max	10.63	2.91	2.85	2.93	2.85	2.71	2.88	2.88	2.75	2.66	6.01	3.85	2.30	11.17

Table A2 Means, standard deviations (sd), minimum (min) and maximum (max) ratings and factor values per noun type (humans, animals, concrete things and abstract things).

		VAL	PLE	APP	POW	STR	SIZ	ANI	CON	GOA	EVA	POT	HUM	ACT
humans	mean	1.61	1.47	0.95	0.57	0.72	0.30	1.99	2.22	1.53	3.33	1.06	2.04	6.81
	sd	0.45	0.46	0.47	1.03	1.07	0.79	0.60	0.34	0.91	0.98	1.60	0.33	2.39
	min	0.87	0.79	0.21	-2.06	-2.11	-1.79	0.00	1.27	-1.00	1.99	-3.28	0.97	1.19
	max	2.68	2.82	2.36	2.53	2.71	2.12	2.74	2.75	2.65	6.39	4.05	2.54	12.17
animals	mean	1.23	1.37	1.50	-0.23	0.08	-0.58	2.31	1.03	0.38	3.25	-0.09	1.20	4.45
	sd	0.36	0.43	0.41	1.22	1.40	1.58	0.37	0.59	0.95	0.85	2.11	0.48	2.67
	min	0.69	0.76	0.85	-2.29	-2.38	-2.76	1.30	-0.36	-1.43	2.08	-3.81	0.02	0.40
	max	2.15	2.45	2.61	2.36	2.61	2.88	2.88	2.25	2.34	5.66	3.96	2.23	10.50
concrete things	mean	1.63	1.56	1.19	0.22	0.78	0.15	-1.40	-1.92	0.42	3.58	0.86	-1.71	2.83
	sd	0.48	0.60	0.43	1.10	1.01	0.93	1.26	0.61	0.92	1.18	1.61	0.67	2.74
	min	0.97	0.71	0.55	-1.32	-0.79	-1.78	-2.94	-2.64	-1.18	1.97	-1.55	-2.53	-1.84
	max	2.74	2.76	2.38	2.64	2.71	1.64	2.11	-0.32	1.91	6.39	4.28	-0.08	9.41
abstract things	mean	2.14	2.08	1.76	1.71	1.56	1.34	0.94	0.49	1.25	4.85	2.63	0.54	8.32
	sd	0.39	0.51	0.56	0.70	0.67	0.61	0.98	0.76	0.89	1.09	1.09	0.70	2.03
	min	1.36	1.00	0.79	-0.05	-0.21	-0.03	-0.74	-0.82	-0.79	2.60	-0.23	-0.62	3.96
	max	2.91	2.85	2.93	2.85	2.67	2.42	2.61	2.00	2.66	6.66	4.29	1.75	12.50

Table A3: Mean ratings and standard deviations of actor-ratings in order to test the construct validation of the model.

condition	mean	*sd*
human	3.11	0.95
animal	2.48	0.98
concrete	2.09	1.04
abstract	2.69	1.04

Supplementary Material B: Summary of the best-fitting structural equation model for the results of Experiment 1

The best-fitting linear mixed effects model of the data for human nouns only is summarized in Tables C1 (fixed effects) and C2 (random effects).

Table C1: Summary of results (fixed effects) of the Markov chain Monte Carlo sampling (MCMC) for human nouns only in order to evaluate p-values from posterior distributions for the best-fitting model with random slope but without random correlation parameters. Besides model estimates, MCMC mean and corresponding p-values, the highest posterior distribution (HPD) 95% confidence interval with the lower (HPD95lower) and upper (HPD95upper) bound of the degrees of freedom is reported.

	Estimate	MCMCmean	HPD95lower	HPD95upper	pMCMC	Pr(>|t|)
(Intercept)	-0.6720	-0.6645	-1.9567	0.6525	0.3122	0.3122
O-S	-1.0050	-1.0081	-1.3514	-0.6420	0.0001	0.0000
ROIright-post	-0.6324	-0.6339	-1.2929	0.0431	0.0642	0.0674
ROIleft-ant	0.6375	0.6398	-0.0471	1.2889	0.0652	0.0652
ROIright-ant	-0.2310	-0.2297	-0.9250	0.4234	0.5116	0.5041
O-S:ROIback-right	0.1761	0.1754	-0.0307	0.3822	0.0952	0.0945
O-S:ROIfront-left	-0.2347	-0.2348	-0.4287	-0.0159	0.0274	0.0259
O-S:ROIfront-right	-0.0600	-0.0607	-0.2730	0.1356	0.5534	0.5687
S-O:FRQ	0.1968	0.1957	-0.0042	0.3876	0.0536	0.0480
O-S:freq.log	0.3914	0.3911	0.1908	0.5855	0.0004	0.0001
ROIright-post:freq.log	-0.0380	-0.0376	-0.1445	0.0701	0.4912	0.4908
ROIleft-ant:freq.log	-0.1899	-0.1899	-0.2944	-0.0780	0.0004	0.0006
ROIright-ant:freq.log	-0.3558	-0.3561	-0.4642	-0.2483	0.0001	0.0000
FRQ:ACT	0.0127	0.0127	-0.0015	0.0268	0.0780	0.0756
S-O:case	0.4618	0.4560	-1.1493	1.9860	0.5628	0.5581
O-S:case	0.2059	0.1983	-1.3202	1.7920	0.7966	0.7939
ROIright-post:case	0.1005	0.1006	-0.7475	1.0149	0.8242	0.8257
ROIleft-ant:case	-0.1885	-0.1948	-1.0862	0.7026	0.6606	0.6797
ROIright-ant:case	-1.4707	-1.4738	-2.3239	-0.5275	0.0018	0.0013
O-S:FRQ:ACT	-0.0074	-0.0074	-0.0118	-0.0030	0.0012	0.0013
ROIright-post:FRQ:ACT	-0.0040	-0.0041	-0.0102	0.0023	0.1992	0.2110
ROIleft-ant:FRQ:ACT	-0.0081	-0.0081	-0.0142	-0.0015	0.0128	0.0123
ROIright-ant:FRQ:ACT	-0.0048	-0.0048	-0.0107	0.0017	0.1372	0.1396
ROIleft-post:FRQ:case	-0.0783	-0.0774	-0.2915	0.1349	0.4668	0.4680
ROIright-post:FRQ:case	-0.0697	-0.0687	-0.2842	0.1467	0.5192	0.5180
ROIleft-ant:FRQ:case	0.0154	0.0173	-0.1998	0.2306	0.8718	0.8861
ROIright-ant:FRQ:case	0.1709	0.1724	-0.0360	0.3963	0.1126	0.1131

Table C2: Summary of results (random effects) of the Markov chain Monte Carlo sampling (MCMC) for human nouns only in order to evaluate p-values from posterior distributions for the best-fitting model with random slope but without random correlation parameters. Besides model estimates, MCMC mean and corresponding p-values, the highest posterior distribution (HPD) 95% confidence interval with the lower (HPD95lower) and upper (HPD95upper) bound of the degrees of freedom is reported.

Groups	Name	Std.Dev.	MCMCmedian	MCMCmean	HPD95lower	HPD95upper
itm	(Intercept)	0.6208	0.6198	0.6269	0.5045	0.7629
subj	ACT	0.2084	0.2134	0.2165	0.1664	0.2656
subj	(Intercept)	1.5332	1.4303	1.4371	1.1755	1.7194
Residual		4.0024	4.0026	4.0026	3.9767	4.0289

Supplementary Material D: ERP analyses for the wh-pronoun position in Experiment 2

Figure D1 shows grand average ERPs at the position of the wh-pronouns in the subject-initial (pronoun "wer", red trace) and object-initial (pronoun "wen", blue trace) conditions, respectively. As is apparent from the plot, nominative and accusative wh-pronouns did not lead to differential ERP effects. This impression based on visual inspection was confirmed by a statistical analysis in the 300-500 ms time window (i.e. the only time window showing a very slight visual difference between the two conditions), which revealed neither a significant main effect of word order ($F(1,39) = 1.63$, $p > 0.2$) nor an interaction of word order and ROI ($F < 1$). Thus, the ERP effects at our critical NP2 position cannot be attributed to earlier changes elicited by the different wh-pronouns.

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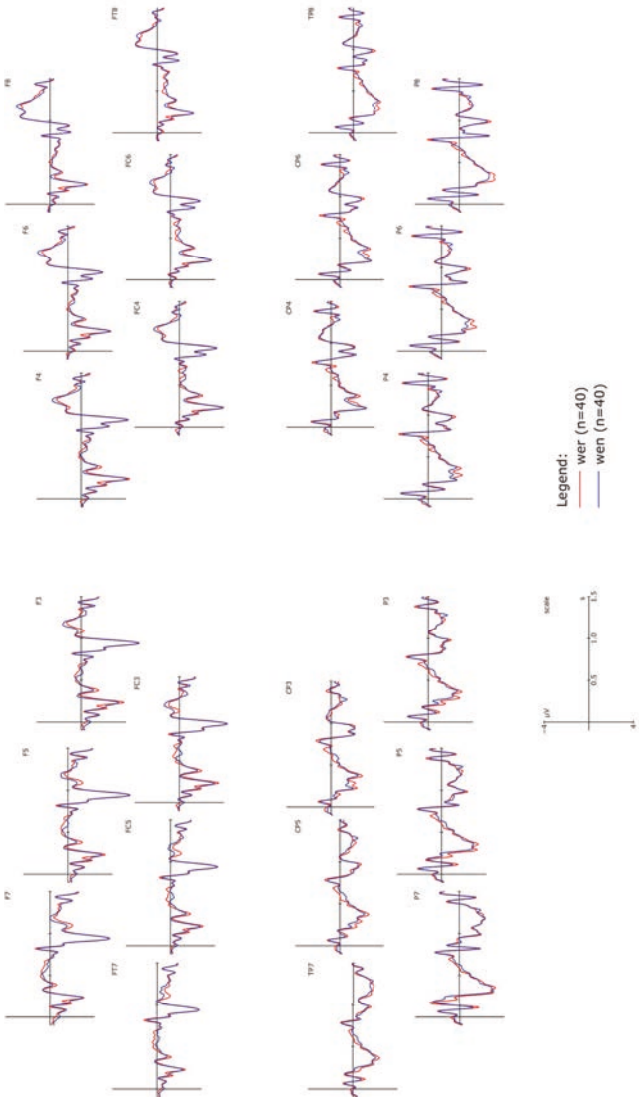
Figure D1: Grand average ERPs at the position of the wh-pronoun in Experiment 2. The plot contrasts the nominative wh-pronoun "wer" in the subject-initial condition (red trace) with the accusative wh-pronoun "wen" in the object-initial condition (blue trace). Negativity is plotted upwards.



3 About volitional actors and sentient experiencers

Volition and sentience are two fundamental human capabilities, which are essential for social cognition by enabling us to interpret the behavior and intentions of others. For the present publication, we used specific linguistic constructions in order to shed light on mental processes involved in the detection of volitional action and the experience of sentience. Specifically, we contrasted German sentences either describing an intentional event (Ich zerbrach die Vase. 'I broke the vase.'), an unintentional event (Mir zerbrach die Vase. '~The vase broke on me.') or a sentient state (Mir gefiel die Vase. '~I found the vase pleasing.'). We also manipulated the sentence initial pronoun by either referring to the self (1st person pronouns, I and me) or a third person (3rd person pronoun, he and him) in order to account for self-other distinctions related to our capability of experiencing our own mental states, but also those of others (ToM), as well as our ability to differentiate between ourselves or others as deliberately acting agents. To this end, the present experimental paradigm allowed us to examine the interplay between domain-general mechanisms related to action detection and experiencing mental states from a self versus other person perspective during online language comprehension in German. We found an overlap between neural correlates for the processing of volition and sentience from non-linguistic paradigms, which we counted as initial evidence that linguistic actor identification processes could be envisaged as following processes involved in information processing in general. This again provides initial neurophysiologic evidence towards an attractor-state of the linguistic actor role.

3.1 Publication

Peer-reviewed article: Frenzel, S., Nagels, A., Primus, B., Schlesewsky, M. & Bornkessel-Schlesewsky, I. (in preparation). Neural substrates of sentience and volition during online language comprehension.

Conference: Poster presented at the 10th Symposium of Psycholinguistics at the Basque Center for Brain and Language (BCBL), 2011, San Sebastian, Spain.

My contribution: For this publication I developed the stimulus material and programmed the fMRI experiment with the help of Ina Bornkessel-Schlesewsky. I conducted the fMRI experiment with the help of the imaging team at the Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany. I performed the data analysis of behavioral and imaging data by myself receiving advice from Arne Nagels. I wrote the entire manuscript and function as the corresponding author in the review process.

COMPREHENDING SENTIENCE AND VOLITION

Title: Neural substrates of sentience and volition during online language comprehension.

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COMPREHENDING SENTIENCE AND VOLITION

Abstract

In the present fMRI study we investigated the neural underpinnings of volition and sentience and their impact on language comprehension. Specifically, we contrasted German sentences either describing an intentional event (Ich zerbrach die Vase. 'I broke the vase.'), an unintentional event (Mir zerbrach die Vase. '~The vase broke on me.') or a sentient state (Mir gefiel die Vase. '~I found the vase pleasing.') in order to test how these notions affect language comprehension. The results showed that the comprehension of volition recruits neural activation posterior regions, which is unequivocally dissociable from that of a sentient state in fronto-temporal regions. With the current study we provide initial evidence that online language comprehension follows the basic neural processes underlying domain-general mechanisms of information processing.

Key Words:

Visual fMRI, agency, language comprehension, sentience, volition

Word count: 5141

COMPREHENDING SENTIENCE AND VOLITION

1 Introduction

The assumption that we can deliberately select between alternative choices is an essential component of our sense of self as human beings: the experience of the self as a volitional agent (Nichols, 2004; Haggard, 2008). Sentience, that is, our capability to experience our own mental states or those of others is one of the key prerequisites to attributing intention and, hence, to seeing ourselves or others as deliberately acting agents.

1.1 Neural correlates of volition

Neural correlates of volition have been discussed controversially since the early 1980s when Libet *et al.* (1983) reported an electrophysiological response that was elicited several hundred milliseconds before an action was performed, the so-called readiness potential (RP). The findings by Libet but also more recent ones (e.g. Cunnington *et al.*, 2002; Lau *et al.*, 2004a; Mueller *et al.*, 2007; Soon *et al.*, 2008; Desmurget *et al.*, 2009) are controversial as they contradict our immediate intuition that we act deliberately every day for instance when we chose to hit the snooze button on our alarm clock for the third time in the morning or when we decide to abstain from meat during lent. They further seem to put our moral standards at stake, which presuppose that a person can only be held responsible for what he or she has done if he or she chose to do so deliberately and in turn could have chosen otherwise (e.g. Kane, 2004; Nahmias *et al.*, 2007; Nichols and Knobe, 2007; Lampe *et al.*, 2008; Roth and Pauen, 2008; Roskies, 2012).

In a recent attempt to reconcile our naïve intuition with deterministic laws, Pierre (2014) suggested that this seemingly insuperable discrepancy arises from our cultural roots in Cartesian dualism, i.e. the mind-body dichotomy. If we were to abandon the notion of dualism and to replace it by an understanding of the self made up of both conscious and unconscious neural activity, findings such as those by Libet *et al.* (1983) would not contradict the concept of self-controlled action. Much like Haggard (2008, p. 936) who claims that "voluntary action is better characterized as a flexible and intelligent interaction with the animal's current and historical context than as an uncaused initiation of action", Pierre thus proposes that the traditional notion of free will should be given up in favor of a continuum of volitional control that is more consistent with determinism. In a similar vein, Brass and Haggard (2008) and Haynes (2011) have suggested that early neural effects might not be precursors of decisions but should rather be envisaged as cues, which bias later decisions.

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This free-will controversy is clearly associated with the timing of volitional actions (when). However, there are also studies that consider the *what* and *whether* components of volitional actions. All three components are reconciled in the www-model by Brass and Haggard (2008). Activation associated with the question of "when" a volitional decision was made is indexed in a fronto-parietal network spanning from the dorsolateral prefrontal cortex (DLPFC) and the supplementary motor area (SMA) to the intraparietal sulcus. The most consistent substrate for the *when* component of intentional actions is the SMA (Fried *et al.*, 1991; Lau *et al.*, 2004a, 2004b; Sirigu *et al.*, 2004; Haynes and Rees, 2006; Desmurget *et al.*, 2009; Fried *et al.*, 2011; Desmurget, 2013), which is suggested to be the source of the RP (Ball *et al.*, 1999; Cunnington *et al.*, 2003). The *what* component of volitional decisions refers to the decision for a specific response, such as pressing the right rather than the left button. It is proposed that this component is related to conflict resolution between different response options, with neural substrates reported in the fronto-median wall (e.g. Sumner *et al.*, 2007), the rostral cingulate zone (RCZ) (e.g. Ridderinkhof *et al.*, 2004; Rushworth *et al.*, 2004; Lau *et al.*, 2006) or the pre-SMA (Nachev *et al.*, 2005; Nachev *et al.*, 2007). Finally, the *whether* component is mainly associated with inhibition of a volitional decision or action such as overcoming impulsive behavior, which is crucial when we interact with others. According to a recent meta-analysis by Filevich *et al.* (2012), intentional inhibition, i.e. inhibition that is triggered internally in absence of an external cue, is associated with activation of the left dorsal frontomedian cortex (DFMC) and the left anterior cingulate cortex (ACC). By contrast, inhibition triggered by external stimuli (e.g. withholding a motor response when a stop signal occurs) evokes activation in a fronto-parietal network with a right hemispheric dominance (Swick *et al.*, 2011; Filevich *et al.*, 2012).

1.2 Neural correlates of sentience

According to Duncan (2006), sentience can be defined as the experience of positive or negative affective states and hence an important component of an emotional episode (cf. Moors, 2010). Emotions, in particular so-called primary emotions such as fear, disgust, anger and sadness, are robustly associated with amygdala, insula, orbito-frontal cortex (OFC) and anterior cingulate cortex (ACC) (e.g. Panksepp, 1998). However, neural substrates of emotions are very controversial. Locationist accounts assume that emotion categories such as *anger, disgust, fear, happiness, sadness* refer to natural (endowed) basic psychological components, each of which are associated with a certain neural region (Calder, 2003; Ekman and Cordaro, 2011) or a neural network (Panksepp, 1998; Ekman and Cordaro, 2011; Izard, 2011). Constructionist approaches on the other hand (e.g. Barrett, 2005, 2006; Lindquist *et*

al., 2006; Russell, 2009; Lindquist *et al.*, 2012, p. 123) envisage emotions as "[…] psychological events that emerge out of more basic psychological operations that are not specific to emotion." They assume that the experience of emotions is constructed by basic domains of psychological functions such as the mirroring of prior episodic experience, the retrieval of semantic concepts, as well as processes involving executive attention and working memory, all of which should ultimately be reduced to *psychological primitives*, i.e. psychological operations representing biological mechanisms, which cannot be reduced further. Accordingly, such approaches decline the existence of specific neural circuits for emotions.

Despite the very controversial approaches to the experience or perception of a mental state, there is consensus that mental states affect our behavior. Accordingly, experiencing sentience is closely linked with social cognition, because inferring intentions and beliefs and making attributions about the nature of internal mental states of both self and other motivates and guides goal-directed behavior (Premack and Woodruff, 1978; Dennett, 1989; Ochsner *et al.*, 2004; Frith and Frith, 2006).

1.3 Volition and sentience in language

In addition to their crucial role in social cognition, volition and sentience are also extremely important for characterizing properties of human language. In many cases, the coding of linguistically expressed events does not differentiate between volitional agents and sentient "experiencers": for example, in a sentence such as "Mary/the girl/she smacked/loved the boy who was being cheeky", the sentential subject ("Mary"/"the girl"/"she") can equally express a volitional agent (as in the case of "smack") or a sentient experiencer (as in the case of "love"). As this is the case in many languages of the world, Dowty (1991) and Primus (1999, 2011) propose that volition and sentience are basic features of a generalized semantic actor (or proto-agent) role, which refers to the participant that is primarily responsible for a linguistically expressed event. Under certain circumstances, however, the two properties are dissociated linguistically. For example, experiencers but not agents can be expressed as grammatical under certain circumstances, as in "The movie frightened Mary/the girl/her". In languages other than English, the dichotomy between non-volitional and volitional actions is sometimes expressed even more clearly, as exemplified by the German causative and anti-causative constructions in (1) and (2). For native speakers of German, sentences such as (1) describe a volitional event implying that the vase was broken intentionally by a volitional actor in subject position (marked with nominative case, "er"), while in sentences such as (2) a

switch in case marking from nominative to dative ("ihm") "reduces" the actor to a non-volitional participant that is not actively involved in the event of breaking the vase.

(1) Causative:

Er zerbrach die Vase.

He$_{[NOM]}$ broke the vase.

(2) Anti-Causative:

Ihm zerbrach die Vase.

Him$_{[DAT]}$ broke the vase.

Approximate translation: "The vase broke on him."

Interestingly, anti-causatives such as (2) have a similar structure to so-called object-experiencer (OE) constructions as in (3), which describe a mental state. In contrast to other mental states such as love or hate, OEs require the grammatical object to be primarily responsible for the event being described. In other words: "a particular mental state is produced by the experiencer [object] in reaction to an external stimulus and, notably, […] the mental state can be cognitively regulated by the experiencer." (Primus, 2011)

(3) Object-Experiencer (OE):

Ihm gefiel die Vase.

Him$_{[DAT]}$ pleased the vase.

Approximate translation: "He found the vase pleasing."

All in all, the dative case marking in the context of an action (breaking) indicates the loss of volition of the event participant (2). The dative case marking in the context of a mental state (pleasing) indicates sentience.

To our knowledge a direct comparison of OEs in comparison to active object-initial constructions has not yet been reported. However, Bornkessel *et al.* (2005) compared dative-initial constructions describing a mental state (4)(b) or an active event (5)(b) with their subject-initial counterparts (4)(a) and (5)(a).

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(4) Mental state (auffallen 'notice'):

(a) Subject-initial (SO):

... dass der Junge den Lehrern auffällt.

'... that [the boy]$_{nominative}$ [the teachers]$_{dative}$ notices.'

'~... that the teachers notice the boy.'

(b) Object-initial (OS):

... dass dem Jungen die Lehrer auffallen.

'... that [the boy]$_{dative}$ [the teachers]$_{nominative}$ notice.'

'~... that the boy notices the teachers.'

(5) Active event (helfen 'help'):

(a) Subject-initial (SO):

... dass der Junge den Lehrern hilft.

'... that [the boy]$_{nominative}$ [the teachers]$_{dative}$ helps.'

'~... that the boy helps the teachers.'

(b) Object-initial (OS):

... dass dem Jungen die Lehrer helfen.

'... that [the boy]$_{dative}$ [the teachers]$_{nominative}$ help.'

'~... that the teachers help the boy.'

While object-initial active events (4)(b) elicited increased activation in the left pSTS and the left inferior parietal sulcus (IPS) in comparison to their subject-initial counter parts, object-initial mental states evoked a reversed activation pattern suggesting that object-experiencers are processed in a similar manner as subject-actors and that the pSTS is in some way involved in actor identification. The pSTS is robustly associated with ToM processing (e.g. Frith and Frith, 1999; Saxe, 2006), suggesting that linguistic actor identification recruits similar processes to those involved in the interpretation of emotions and intentions of others. Since it is also linked with the processing of non-linguistic agency such as the detection of biological motion (e.g. Grossman *et al.*, 2000; Grèzes *et al.*, 2001; Vaina *et al.*, 2001; Beauchamp *et al.*, 2003; Saygin *et al.*, 2004) it has been proposed that it might be an

interface between neural language processing and action understanding (Bornkessel-Schlesewsky and Schlesewsky, 2013).

1.4 The present study

For the present study we used specific linguistic constructions in order to shed light on mental processes involved in the detection of volitional action and the experience of sentience. The current study is thus an extension of previous studies by investigating how domain-general processing mechanisms affect/relate to language comprehension. These assumptions can be couched within the extended Argument Dependency Model (eADM) a neurobiological model of language (e.g. Bornkessel-Schlesewsky and Schlesewsky, 2013; Bornkessel-Schlesewsky and Schlesewsk, 2015), which postulates that language processing follows the basic principles of information processing. In the discussion we will describe the eADM in more detail and elaborate on the significance of the findings for recent neurocognitive models of language comprehension.

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2 Materials and Methods

The study complies with the principles of the Declaration of Helsinki. The local ethics committee approved the protocol.

2.1 Participants

A total of eight women and eleven men (mean age 25; age range 19–30 years) took part in the fMRI study. All participants were monolingually raised native speakers of German, had normal or corrected-to-normal vision, and were right-handed as indicated by a German version of the Edinburgh Inventory (Oldfield, 1971). One male participant was excluded from the analysis due to technical problems during the second session of the main experiment. Two female and two male participants were excluded from analyses due to more than 30% of timeouts during the behavioral task, suggesting that these participants did not attend to the stimuli during the experiment. Ultimately, the data of six women and nine men (similar mean age and age range as total amount of participants) was included in the final analysis.

2.2 Materials

Participants read a total of 210 critical sentences (3 x 70 triplets) as well as 90 filler sentences. To improve statistical evaluation of the data (Miezin *et al.*, 2000), 30 null events (blank screens) were introduced. Critical sentences contrasted minimally differing German sentences either describing causative event (+VOL) such as (6) an anti-causative event (-VOL) such as (7) or a mental state (+SEN) such as (8). Since social cognitive processing is mostly associated with the interpretation of emotions and intentions of others (Frith and Frith, 1999; Saxe, 2006), each sentence was either presented with a sentence initial first person pronoun (a) or third person pronoun (b). In order to prevent systematic response strategies of the participants to dative initial sentences, 30 of the 90 filler sentences started with a dative and involved a volitional action (e.g. Mir half der Tänzer. 'Me$_{[DAT]}$ helped the dancer.' "The dancer helped me.").

(6) Causative event (+VOL):

(a) 1st Person: Ich zerriss die Jeans.

'I tore the jeans'

(b) 3rd Person: Er zerriss die Jeans.

'He tore the jeans'

(7) Anti-causative event (-VOL / -SEN):

(a) 1st Person: Mir zerriss die Jeans. ()

'Me$_{[DAT]}$ tore the jeans'

Approximate translation: "The jeans tore on me."

(b) 3rd Person: Ihm zerriss die Jeans.

'Him$_{[DAT]}$ tore the jeans'

Approximate translation: "The jeans tore on him."

(8) Psychological state (+SEN):

(a) 1st Person: Mir stand die Jeans.

'Me$_{[DAT]}$ suited the jeans'

Approximate translation: "I found the jeans suitable."

(b) 3rd Person: Ihm stand die Jeans.

'Him$_{[DAT]}$ suited the jeans'

Approximate translation: "He found the jeans suitable."

2.3 Procedure

Stimuli were projected onto a screen and viewed by the participants via a mirror mounted on the head-coil. In order to control for reading strategies, all sentences were presented in a word-by-word manner with the exception of common nouns (short: NP for noun phrase), which were presented as one segment with their corresponding definite article (PRONOUN | VERB | NP). Every segment was presented for 400 ms (NPs for 500 ms) in the center of the screen with an inter-stimulus interval (ISI) of 100 ms. Each trial began with an asterisk, which was presented for 400 ms and ended with an inter-block interval (IBI) of 500 ms. After 12 percent of trials (critical and filler sentences), a question mark signaled participants that they are required to judge the intentionality of the event described in the preceding sentence (1 =

eher mit Absicht 'more likely to be intentional, 0 = eher ohne Absicht 'more likely to be unintentional'). The participants accomplished this judgment task by pressing one of two push-buttons with their right index and middle finger and were given maximally 2000 ms to respond (cf. Fig. 1). The assignment of fingers to buttons corresponding to intentional and unintentional responses was counter-balanced across participants. Trials were presented with variable onset delays of 0, 400, 800, 1200, or 1600 ms in order to improve the efficiency of the functional design (Miezin *et al.*, 2000). Every trial had a length of 6 s, resulting in a total measurement time of 33 min, which was separated into two functional runs. Each participant completed a short practice session before scanning. Stimuli used for training purposes were not used in the subsequent experiment.

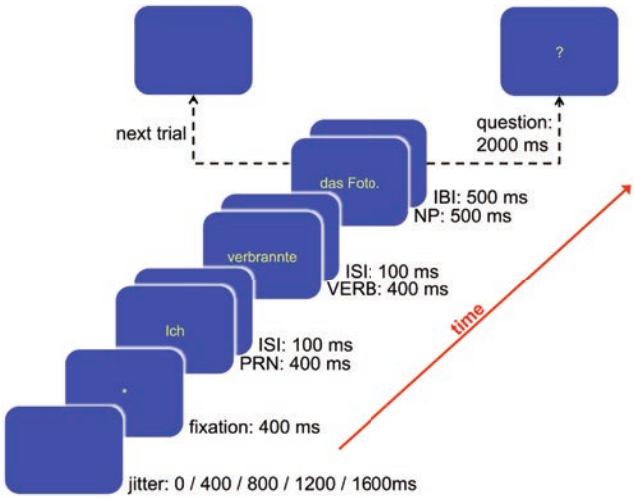

Fig 1: Exemplary trial scheme of scanning session

2.4 fMRI data acquisition

The experiment was carried out on a 3T scanner (Medspec 30/100, Bruker, Ettlingen) at the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig, Germany. Twenty axial slices (19.2 cm FOV, 64 by 64 matrix, 3.5 mm thickness, 0.5 mm spacing), parallel to the AC-PC plane and covering the whole brain were acquired using a single shot, gradient recalled EPI sequence (TR 2000 ms, TE 30 ms, 90° flip angle). Two functional runs of 300 time points were collected, with each time point sampling over the 20 slices. Prior to the

functional runs, 20 anatomical T1-weighted MDEFT (Uğurbil *et al.*, 1993) images (data matrix 256 x 256, TR 1.3 s, TE 7.4 ms) were obtained with a non slice-selective inversion pulse followed by a single excitation of each slice (Norris, 2000). For registration purposes, a set of T1-weighted spin-echo EPI images (TE 14 ms, TR 3000 ms) were taken with the same geometrical parameters (slices, resolution) and the same bandwidth as used for the fMRI data. A slice-selective inversion pulse was applied with an inversion time of 1200 ms.

2.5 fMRI data analysis

Functional scans were analyzed using Statistical Parametric Mapping (SPM8; www.fil.ion.ucl.ac.uk) implemented in MATLAB R2006b (Mathworks Inc., Sherborn, MA). To correct for their different acquisition times, the signal measured in each slice was shifted relative to the acquisition time of the middle slice using a slice interpolation in time. All images of one session were realigned to the first image of a run and normalized into standard stereotaxic anatomical MNI-space by using the transformation matrix calculated from the first EPI-scan of each subject and the EPI-template. Additionally, movement parameters were entered as a parametric regressor into the design matrix in order to correct for movement artifacts on the single subject level. Afterwards, the normalized data with a resliced voxel size of 3 × 3 × 3 mm were smoothed with a 8 mm FWHM isotropic Gaussian kernel to accommodate inter-subject variation in brain anatomy. Proportional scaling with high-pass filtering was used to eliminate confounding effects of differences in global activity within and between subjects. The expected hemodynamic response at the onset of each event-type was modeled with a canonical hemodynamic response function.

At the subject level a t-contrast for each experimental factor volition and sentience (+VOL, -VOL/-SEN, +SEN) and person (PER1, PER3) was computed. For the group level analysis we calculated two separate 2x2 ANOVAs (VOLxPER and SENxPER) as implemented in SPM8 in which subjects are treated as random variables. A Monte Carlo simulation with 10000 iterations of the brain volume of the current study was conducted to establish an appropriate voxel contiguity threshold (Slotnick *et al.*, 2003). Assuming an individual voxel type I error of $p < .001$, a cluster extent of 10 contiguous re-sampled voxels was necessary to correct for multiple voxel comparisons at $p < .005$. Thus, voxels with a significance level of $p < .001$ uncorrected, belonging to clusters with at least 10 voxels are reported. The reported voxel coordinates of activation peaks are located in MNI space. Visualization of local maxima was carried out with MRIcron, version June 1, 2015 (Rorden and Brett, 2000).

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3 Results

3.1 Behavioral results

For the intentionality ratings, neither of the ANOVAs VOLxPER or SENxPER yielded any significant main effects or interactions. Nevertheless, the results show the expected tendency for participants to rate +VOL sentences as most intentional while -VOL are rated as least intentional (cf. Table 1 left). Only the reaction times of the intentionality ratings (SENxPER) revealed a main effect of SEN ($F(1, 13) = 11.18$, $p = 0.005$). Accordingly, intentionality ratings for -VOL sentences are less costly yielding shorter RTs than for +SEN sentences evoking longer RTs (cf. Table 1 right). RTs of the ANOVA VOLxPER do not yield a main or interaction effect.

Table 1: Mean and standard deviations (SD) of response to intentionality ratings (1 = intentional; 0 = unintentional) and the corresponding reaction times.

	Responses		Reaction times (RT)	
	mean	SD	mean	SD
+VOL	0.66	0.48	974.92	248.71
-VOL / -SEN	0.33	0.47	1004.11	239.40
+SEN	0.42	0.50	1067.70	242.16

3.2 fMRI results

3.2.1 Main effect of volition (VOL) and sentience (SEN)

Both ANOVAs yielded a main effect for all critical factors but no interaction effects. The main effect of VOL evoked activation within the right posterior cingulate cortex (PCC) extending towards the lateral ventricle. The main effect of SEN activated the middle part of the left caudate nucleus (CN), sub-gyrally the right middle temporal gyrus (MTG) as well as the left middle orbital gyrus (MOG) extending towards the rostral part of the CN (cf. Fig. 2 and Table 1).

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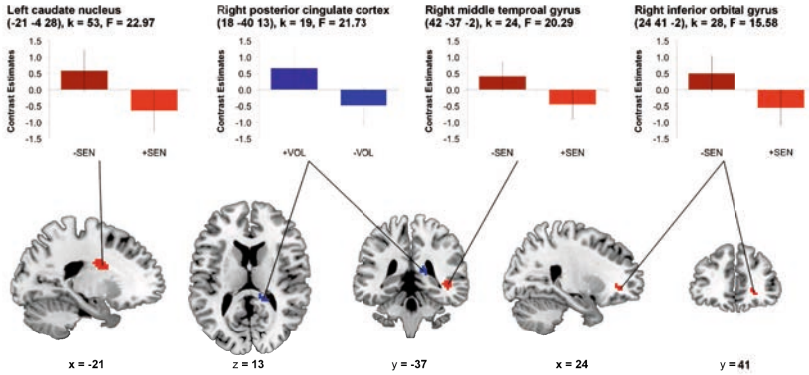

Fig. 2: Visualization of voxels sensitive for main effect of volition (+/-VOL; blue) and sentience (+/-SEN; red) respectively. The numbers in parenthesis represent x, y and z coordinates in MNI space. The measuring unit of the cluster size k is voxels.

3.2.2 Main effect of person (PER)

A main effect of person (PER) for the ANOVA VOLxPER activated the left sub-gyral temporal lobe at the junction of planum temporale parietal operculum cortex and posterior superior temporal gyrus (cf. top of Fig. 3). The ANOVA SENxPER revealed a main effect of PER in the left middle frontal gyrus extending to the anterior cingulate cortex (cf. bottom of Fig. 3).

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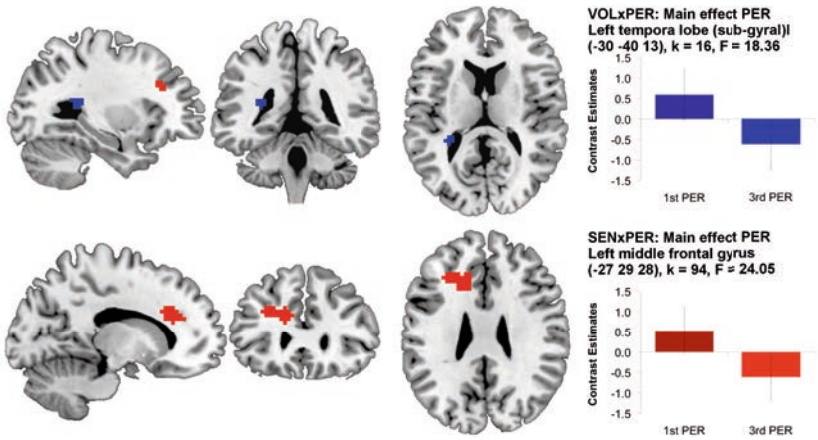

Fig. 3: Visualization of voxels sensitive for main effect of person (PER). Blue clusters result from a main effect of PER for the 2x2 ANOVA VOLxPER. The corresponding contrast estimates are depicted in blue on the top right. Red clusters result from the main effect of PER for the 2x2 ANOVA SENxPER. The corresponding contrast estimates are depicted in red on the bottom right.

4 Discussion

The present study investigated neural correlates of the psychological functions associated with the detection of intentional action (volition) and the experience of a mental state (sentience) both of which are encoded by distinct linguistic constructions in German as exemplified in sentences (6) through (8) in the materials section 2.2. In order to account for self-other distinctions related to our capability of experiencing our own mental states but also those of others (ToM), as well as our ability to differentiate between ourselves or others as deliberately acting agents, we manipulated the sentence initial pronoun by either referring to the self (1st person pronouns, *I* and *me*) or a third person (3rd person pronoun, he and him). To this end, the present experimental paradigm thus allowed us to examine the interplay between domain-general mechanisms related to action detection and experiencing mental states from a self versus other person perspective during online language comprehension in German.

4.1 Main effect of volition (VOL): The role of the posterior cingulate cortex during language comprehension

Activation of the posterior cingulate cortex (PCC) was evoked for the contrast between intentional (+VOL) and unintentional action (-VOL). This result corroborates the findings by Soon *et al.* (2008), who associated PCC activation with unconscious processes related to the preparation of a motor response (right or left index finger). A similar network was elicited in a control experiment during which the timing of the motor response was externally (consciously) triggered, suggesting that the network is involved in conscious and unconscious preparation of decisions. With respect to volitional decisions, Bode *et al.* (2014) propose that activation of the PCC should be envisaged as a correlate of updating processes informed by previous choices.

Activation of the PCC is also suggested to be part of the so-called cortical midline structure (CMS) indexing self-evaluative processes (e.g. Northoff and Bermpohl, 2004) and associated with the Default Mode Network (DMN) (e.g. Buckner *et al.*, 2008; Greicius *et al.*, 2009; Margulies *et al.*, 2009; Leech and Sharp, 2011), i.e. it is activated in passive tasks for instance when autobiographic or semantic memories are retrieved, when individuals daydream or when they make plans for the future (Binder *et al.*, 1999; Gusnard *et al.*, 2001; Addis *et al.*, 2007; Mason *et al.*, 2007; Buckner *et al.*, 2008). The recruitment of self-evaluative processes during linguistic actor identification is not surprising if one assumes a self-centered proto-actor as put forward for instance by Dahl (2008). We thus suggest that

the PCC is an important correlate of self-evaluatiion, which biases future decision-making with regard to actor identification during online language comprehension.

Furthermore, the posterior cingulate cortex (PCC) is associated with action inhibition (e.g. Campbell-Meiklejohn *et al.*, 2008). In their fMRI study using a gambling task, they compared trials when participants decided to quit playing in order to prevent further losses in contrast to the decision to chase losses. A peculiarity about the (anti-)causative constructions is that they are typically associated with negative events such as *burn, break* or *destroy,* which is the reason why we tend to express them in a manner that allows us to emphasize on their accidental nature in order to prevent punishment. Therefore, the elicitation of neural activation in areas associated with action inhibition nicely fit our results. Accordingly, the negative connotation of the causative events described automatically triggered processes involved in action inhibition in order to prevent future punishment, which is not necessary in the anti-causative events. Specifically, the increased activation for +VOL in comparison to –VOL in this area can be envisaged as a bias, which renders the volitional actor as less compatible with the self due to the negative association with the event described and hence triggering processes that are related to (volitional) action inhibition.

4.2 Main effect of sentience (SEN): The role of the prefrontal cortex during language comprehension

The main effect of sentience evoked activation in dorsal and ventral regions of the prefrontal cortex (PFC) as well as activation in the right temporal gyrus. Specifically ventral activation in the right orbital gyrus of the PFC extended to the rostral caudate nucleus (CN). Just like the posterior cingulate cortex (PCC), the orbital gyrus is part of the CMS and associated with self-representation, i.e. the labeling of stimuli as self-referential (Northoff and Bermpohl, 2004). Typically activation within orbital and ventral regions is evoked, when participants compare their abilities, traits or attitudes to those of others (e.g. Johnson *et al.*, 2002; Kelley *et al.*, 2002; Kjaer *et al.*, 2002) but also when emotional stimuli are processed in general as they are regarded as “implicitly self-referential” (Northoff and Bermpohl, 2004). The fact that we see activation in these regions for sentences in the -SEN condition suggests that actor identification processes are impeded due to a deviation from a prototypical sentient actor.

Activation of the left middle and right rostral caudate nuclei, which form part of the dorsal striatum as part of the basal ganglia are considered to belong to the emotion-generative system along with the ventral striatum and the amygdala. Especially the latter regions are associated with emotion regulation and particularly with the reappraisal of negative emotions

(e.g. Ochsner *et al.*, 2004; Goldin *et al.*, 2008; Buhle *et al.*, 2014, (metaanalysis); Gross, 2014). Activation within the dorsal striatum is associated with apathy (Levy and Dubois, 2006), i.e. 'a state of indifference, the absence of feelings and a lack of activity and responsiveness' (translation of the definition by Fröhlich, 2005). For instance, focal lesions of the caudate nuclei, the internal pallidum and the medial-dorsal thalamic nuclei are frequently associated with apathy (Laplane *et al.*, 1989; Mendez *et al.*, 1989; Bhatia and Marsden, 1994; Engelborghs *et al.*, 2000; Ghika-Schmid and Bogousslavsky, 2000). This nicely converges with our findings that show increased activation in this region for the -SEN condition and deactivation for +SEN condition. However, the caudate nuclei are also associated with goal-directed behavior in response to reward (O'Doherty *et al.*, 2004; Wrase *et al.*, 2007; Katahira *et al.*, 2015), when imagining emotional events in the near as opposed to the far future irrespective of their valence (D'Argembeau *et al.*, 2008) or predicting future face preference decisions (Ito *et al.*, 2014). These findings suggest, that activation of the caudate nuclei biases emotionally loaded decisions including the identification of a sentient experiencer in a linguistically expressed event, which is impeded in the -SEN condition. Thus, in the absence of a volitional actor, the processing system recruits mechanisms that are relevant for the detection of a sentient entity that functions as the highest-ranking semantic role in a linguistically expressed event.

Interestingly, activation of the CN was also reported by Campbell-Meiklejohn *et al.* (2008) as a substrate of action inhibition. Our findings suggest that distinct regions might serve different sub-processes involved in action inhibition. While the posterior cingulate cortex was suggested to have a predictive function in biasing future behaviour, the function of the CN might be more involved in evaluative processes of action inhibition by incorporating affective states, which triggered inhibition leading to a change in a biological state (Damasio and Carvalho, 2013).

4.3 Right hemispheric dominance during language comprehension

Both main effects show a right hemispheric dominance. Generally, bilateral activation or at least an increase in right hemispheric activation during language processing is typically associated with higher-level language tasks, which require extra-linguistic processes such as attention, working memory, visual imagery, ToM or aspects of social cognition (Xu *et al.*, 2005). Accordingly, activation in the right hemisphere has been reported for the processing of jokes (Goel and Dolan, 2001; Coulson and Wu, 2005; Taber *et al.*, 2007; Feng *et al.*, 2014), severed pronoun-referent-linking (Nieuwland *et al.*, 2007; McMillan *et al.*, 2012), or

when integrating speech and gesture information (Straube *et al.*, 2010). In light of the simple sentences under investigation, it is unlikely that the right-hemispheric dominance was triggered by additional extra-linguistic processes. Rather, we propose that language processing is constructed of general psychological operations which are not special to language. Thus, different linguistic operations (such as the identification of a linguistic actor) are assumed to recruit domain-general networks, which are associated with more basic mental processes such as self-reference, the detection of biological motion or experiencing a mental state. Accordingly, we see distinct activation patterns when comparing intentional action with unintentional action (volition) with mental states (sentience).

4.4 Main effect of person (PER): The role of self-referential regions during language comprehension

The medial prefrontal cortex (MPFC) and the anterior cingulate cortex (ACC) belong to the cortical midline structures (CMS) (e.g. Northoff and Bermpohl, 2004), which are associated with self-referential processing. In the current study, activation related to the main effect of PER for the ANOVA SENxPER recruited the left middle frontal gyrus extending to the ACC. In a recent overview by Heinzel (2014), activation of the ACC was associated with an interaction of emotional valence and self-relatedness of stimuli. For instance Heinzel *et al.* (2010) investigated the effect of emotional pictures on patients with alexithymia (patients who have difficulties in identifying subjective feelings and relating them to themselves). Accordingly, activation in the ACC correlated positively with the individual degree of alexithymia. Due to the negative connotation of the stimuli under investigation, we saw an increase in ACC activation for a self versus other person perspective suggesting that self-reference is impeded in this condition.

5 Conclusion and future directions

With the current study we provide initial evidence that online language comprehension recruits neural networks that are associated with domain-general processing mechanism. Specifically, we showed that the identification of volitional actors recruited neural activation of the right posterior cingulate cortex (PCC) that is unequivocally dissociable from that of sentient experiencers, which elicited activation in the right prefrontal cortex and bilateral caudate nuclei. The results provide converging support that the detection of volitional action and the experience of a mental state are independent psychological notions, which are evaluated during actor identification, a rapid and automated processes of language comprehension.

The present study should be envisaged as a first step towards answering the question of which basic psychological operations are recruited during online language comprehension. In order to account for the cross-linguistic stability of our findings, it will be necessary to investigate typologically different languages from German. Furthermore, it is also essential for our hypothesis to apply to language in general if a similar paradigm is applied to investigate language production. Last but not least, future research is necessary in order to identify concrete psychological primitives, which are underlying higher cognition including language processing.

Acknowledgements

The research reported here was performed while S. F. and I. B. S. were at the Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig. We are grateful to the wonderful team of medical technical assistants of the Nuclear Magnetic Resonance Unit including Anke Kummer, Annett Wiedemann and Simone Wipper. We thank Sylvia Krauspenhaar for invaluable assistance in data acquisition.

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4 The perception of actors with mass appeal

The way actors are perceived in society depends not only on their behavior but also on the social norms their fan community finds appealing. After having focused on actor inherent traits thus far, the last experiment investigates socio-cultural effects on actorhood. As outlined in 1.1.1, a self-concept is only possible in comparison with others, and hence affected by inter-group relations. For instance, it has been shown that people rather relate to socially relevant groups, which are considered self-enhancing, than to socially disregarded groups (e.g. Tajfel, 1982). Accordingly, it seems worthwhile to investigate whether inter-group relations affect linguistic actor identification processes. For this purpose, we manipulated the degree of self-relatedness via a minimal group paradigm and linguistic actorhood via animacy and specificity in order to capture the neural network underlying their interplay. We further modeled linguistic actorhood parametrically in order to account for the discrete ranking of the underlying prominence scales. Neural activation in response to the parametric modulations would provide initial evidence that the social speaker-hearer relationship directly affects the ease at which we identify the actor, and hence, attribute causality during auditory language comprehension.

4.1 Publication

Peer-reviewed article: Frenzel, S., Nagels, A., Dröge, A., Schlesewsk, M., Kircher, T., Wiese, R., & Bornkessel-Schlesewsky, I. (in preparation). The right angular gyrus as an interface between social categorization and actor identification during online language comprehension.

My contribution: I developed the stimulus material and programmed the fMRI study as well as the pretests with the help of Alexander Dröge. I conducted the fMRI experiment with support by Alexander Dröge and the core unit Brain-Imaging of the Department of Psychiatry and Psychotherapy at the University of Marburg, Germany. I analyzed the pretests and main fMRI experiment including the parametric modulation by myself receiving feedback from Arne Nagels. I wrote the first manuscript submitted for publication on my own and function as the corresponding author in the review process.

Title: Social cognition during rapid and automated processes of language comprehension: Neural substrates for effects of social categorization on actor identification

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Abstract

In today's increasingly multicultural societies, an understanding of inter-group dynamics, such as the classification of fellow humans into a socially relevant in-group (IG) or a socially disregarded out-group (OG) are vital for peaceful co-existence. In previous neuroimaging studies, social categorization typically evoked activation within self-referential regions as well as regions related to social cognition, such as Theory of Mind processing or mentalizing. Here, we examined the impact of social categorization on core cognitive processing by investigating how the relation between the social status of a speaker and that of a hearer influences rapid and automated aspects of language comprehension. In an auditory fMRI study, we examined how social categorization affects causal attributions during sentence comprehension, i.e. the identification of the entity that is primarily responsible for a linguistically expressed event (actor). Sentences were uttered from a first person ("I") perspective (i.e. the speaker was the actor) and varied in their degree of competition for the actor role. We observed an interaction between speaker group and actor competition in the right angular gyrus, with the OG high competition condition showing an activation increase and the IG high competition condition showing an activation decrease in comparison to medium and low competition sentences. This result provides initial evidence that the social speaker-hearer relation affects the attribution of causality during auditory language comprehension, and that the integration between social and linguistic information is supported by the angular gyrus – a region that is known to play a key role in the integration of multisensory information in the interpretation of events. A further manipulation of emotional valence of the events described revealed increased activation in the left posterior cingulate cortex (PCC), bilateral postcentral gyri (PCG) and inferior parietal lobule (IPL) for negative events uttered by an IG speaker and positive events uttered by an OG speaker in contrast to positive events uttered by an IG speaker and negative events uttered by an OG speaker. These findings converge with previous results on the processing of self-reference within cortical midline structures (PCC) and auditory imagery in parietal structures (PCG, IPL).

Key Words: Minimal group, auditory processing, agency, self-reference, causal attribution

1. Introduction

Like many other mammals, humans are social beings that prefer to live in a group rather than in isolation. What distinguishes humans from other species is our capability of self-reflection and perspective taking, which enables us to understand the beliefs and desires of our conspecifics. This ability is both boon and bane for a peaceful coexistence with others, as we tend to automatically categorize our world into an emotionally relevant social in-group (IG) and an out-group (OG) (e.g. Tajfel, 1978; Tajfel, Billig, Bundy, & Flament, 1971; Tajfel & Turner, 1979; Turner, 1975; Turner & Giles, 1981). On the one hand, social categorization is important in order to structure our world in terms of social relations; on the other hand, it is a driver for discriminatory behavior (Tajfel, 1981; Tajfel & Billic, 1974; Tajfel & Turner, 1979; Turner, 1975). Discriminatory behavior, i.e. IG favoritism or OG discrimination is driven by the idea that individuals tend to derive their personality partially from the groups to which they belong, and hence identify more closely with IG than OG members. This so-called IG bias due to a strong association with one's own identity enhances the social status of IG members and thereby of the self (e.g. Tajfel & Turner, 1979). As will be outlined in section 1.2., the self also plays a crucial role in language. Accordingly, with the present study we aimed to test the hypothesis that social categorization has a direct impact on rapid and automated processes during language comprehension.

1.1. Neural correlates of social categorization

Social categorization has been shown to engage neural circuits that are known to be relevant for social cognition and mentalizing. For instance, face recognition tasks of IG versus OG members show increased activation of the fusiform face area (FFA) when recognizing an IG face in comparison to an OG face, which is interpreted as a result of more in-depth processing of IG members (Lieberman, 2005; van Bavel, Packer, & Cunningham, 2008, 2011). Van Bavel (2011, p. 3352) concludes that, "group membership has a top-down influence on the FFA and may be enhancing the subordinate level encoding of minimal in-group members." Other tasks that evoke discriminatory behavior towards OG members or favoring IG members – for instance when distributing money (Volz, Kessler, & von Cramon, 2009) – or the mere categorization of IG in comparison to OG words (Molenberghs, Halász, Mattingley, Vanman, & Cunnington, 2013; Morrison, Decety, & Molenberghs, 2012) yield increased activation in the medial prefrontal cortex (MPFC), a region that is associated with self-referencing (cf. for an overview Amodio & Frith, 2006; Buckner, Andrews-Hanna, & Schacter, 2008; Craik et al., 1999; D'Argembeau et al., 2007; Johnson et al., 2002; Mitchell, Banaji, & MacRae, 2005; Northoff & Bermpohl, 2004; Northoff et al., 2006; Vogeley et al.,

2001; Vogeley & Fink, 2003). This finding supports the idea that personality traits of IG members are more closely related to the self.

Furthermore, observing IG members as opposed to OG members in physical pain leads to an activation of prominent parts of the pain matrix (e.g. Cikara, Botvinick, & Fiske, 2011; Hein, Silani, Preuschoff, Batson, & Singer, 2010; Morrison et al., 2012), which are also activated when participants directly experience a painful stimulus (Singer et al., 2004). When participants observe IG in contrast to OG members in emotional pain, cognitive empathy regions such as the temporo-parietal junction (TPJ) and the precuneus are activated (e.g. Cheon et al., 2011; Mathur, Harada, Lipke, & Chiao, 2010). The involvement of emotional and cognitive empathy regions in distinguishing IG and OG members has been interpreted as evidence that social categorization affects processes of perspective taking, for instance when individuals simulate physical or emotional pain (Molenberghs et al., 2013). Consequently, increased activation in emotional and cognitive empathy regions supports the assumption that individuals generally tend to empathize more with IG than OG members.

1.2. The first-person perspective in language and linguistic actor identification

The importance of the first-person (self) perspective is not confined to social cognition; it also plays a key role in other cognitive abilities such as language. In spite of the highly diverse characteristics of the world's over 6000 languages, research on the neurocognition of sentence understanding across languages of different types has revealed a general importance of the event instigator (actor) in a linguistically expressed event (Bornkessel-Schlesewsky & Schlesewsky, 2009, 2013a, 2013b). Just as there is an attentional bias towards potential causers of events in visual processing (i.e. humans and animals; New, Cosmides, & Tooby, 2007), sentence understanding across different languages is focused on quickly and unambiguously identifying the person or thing primarily responsible for the state of affairs being described. The most prototypical actor is the self: humans typically feel that they have control over their own actions (e.g. Haggard, 2008) and can use this self-as-actor perspective to understand other actors and their actions (Frith & Frith, 2010). Accordingly, we perceive other humans as being "like myself, individuals who can perceive the world and act upon it" (Dahl, 2008, p. 149). This observation suggests that actor identification in language may rely, at least in part, on processes related to self-referencing or mimicry – fundamental aspects of social categorization.

1.3. Neural correlates of linguistic actor identification

During language comprehension, each event participant is considered as a potential candidate for the actor role (for a review, see Bornkessel-Schlesewsky & Schlesewsky,

2014). When there are multiple good candidates (e.g. two humans as opposed to a human and an inanimate entity), competition for the actor role results (Alday, Schlesewsky, & Bornkessel-Schlesewsky, 2014). For instance, Grewe et al. (2007) compared sentences such as (1) and (2) in an fMRI study. Results revealed increased activation in the left posterior temporal sulcus (pSTS) for sentences with two human event participants (1) in comparison to sentences with a human and an inanimate participant (2). Accordingly, the authors proposed that the pSTS is involved in actor identification in language comprehension, a role that is congruent with this region's well-known sensitivity for non-linguistic agency cues such as biological motion (e.g. Beauchamp, Lee, Haxby, & Martin, 2003; Grèzes et al., 2001; Grossman et al., 2000; Saygin, Wilson, Hagler, Bates, & Sereno, 2004; Vaina, Solomon, Chowdhury, Sinha, & Belliveau, 2001).

(1) Wahrscheinlich hat **der Mann den Direktor** gepflegt.

probably has **the**$_{[nominative]}$ **man the**$_{[accusative]}$ **director** taken care of

'**The man** probably took care of **the director**.'

(2) Wahrscheinlich hat **der Mann den Garten** gepflegt.

probably has **the**$_{[nominative]}$ **man the**$_{[accusative]}$ **garden** taken care of

'**The man** probably took care of **the garden**.'

According to Bornkessel-Schlesewsky and Schlesewsky (2013b), actor computation in the brain follows basic principles of perceptual decision-making (Deco, Rolls, Albantakis, & Romo, 2013; Deco, Rolls, & Romo, 2009), with the actor role constituting a stable attractor category. Within neurobiological attractor network models, attractor states are associated with (stable) high firing rates. "Which state 'wins' during decision making is determined by the current input and the initial stochastic firing behavior of the network [...] We could assume, then, that an attractor network for actor categorization exists independently of language and that, as a result of the general human ability to recognize goal-directed action and to differentiate between self and other, it is universal" (Bornkessel-Schlesewsky & Schlesewsky, 2013a, p. 241f).

1.4. Effects of social categorization on language processing?

A possible interaction between language processing and social categorization appears plausible for several reasons. Firstly, language is a highly powerful means of interpersonal communication in humans. Secondly, as described above, there is good evidence to suggest that the self versus other categorization plays a crucial role both in language processing and

in social cognition. Nevertheless, to the best of our knowledge, possible effects of social categorization on language processing – and their neural correlates – have not been investigated to date. There is, however, some initial fMRI evidence for the effect of the social status of a speaker on the overall plausibility of an utterance. Tesink et al. (2009) observed increased activation for incongruent speaker–sentence combinations (upper-(social)class speaker: "I have a large **tattoo** on my back.") in comparison to congruent combinations (lower-(social)class speaker: "I have a large **tattoo** on my back.") in the left inferior frontal gyrus (IFG), the right cerebellum, the left middle temporal gyrus (MTG), the bilateral superior temporal sulcus (STS), the left middle frontal gyrus (MFG) as well as the left frontal operculum. They proposed that the incongruence between the speaker and the semantic content of the utterance impedes associations between the speaker's voice and the retrieval of word-level semantics. While these previous findings suggest that the neural processing of language is modulated by social information, they do not speak to possible effects of inter-group categorization on automatic processes of language comprehension.

1.5. The present study

With the present fMRI study, we aimed to provide evidence that the social status of the speaker and hearer influences actor identification during auditory language comprehension. Assuming that the self is the prototypical actor, we propose that the degree of self-relatedness induced via social categorization of the speaker (IG>OG) should have a direct impact on actor identification processes in order to comprehend the utterance. To test this hypothesis, we presented native speakers of German with well-formed simple transitive German sentences (see examples (3)-(5)). Sentences were spoken from a first-person perspective (i.e. the subject was always the pronoun *I*). Accordingly, sentences uttered by an IG speaker should strengthen the prototypicality of the first participant ("*I*") as the actor, while those uttered by an OG speaker should weaken it. The second event participant was either another pronoun (PRN: you), a human (ANI: the researcher) or an inanimate entity (INA: the report), thus inducing increasing competition for the actor role with the first participant (INA < ANI < PRN). With regard to more direct effects of social categorization such as IG favoritism and OG discrimination, we used verbs with emotional valence (VAL) ratings provided by Keil and Ihssen (2004) to construct the critical sentences. This allowed us to test whether the minimal group paradigm employed here elicits the expected IG bias. Furthermore, it allowed us to control for possible interaction effects of emotional valence on actor identification.

(1) Positive valence: Ich rühme … ('I praise …')
  (a) PRN: … dich. ('you')
  (b) ANI: … den Forscher. ('the researcher')

(c) INA: … den Aufsatz. ('the essay')

(2) Negative valence: Ich hasse … ('I hate …')

(a) PRN: … dich. ('you')

(b) ANI: … den Maler. ('the painter')

(c) INA: … den Kaffee. ('the coffee')

(3) Neutral valence: Ich betrachte … ('I look at …')

(a) PRN: … dich. ('you')

(b) ANI: … den Geiger. ('the violinist')

(c) INA: ... den Bericht. ('the report')

We expected to observe activation in temporo-parietal regions related to the interaction of social categorization (GR) and competition for the actor role (COMP). Demonstrating this interaction would provide evidence for the direct interplay between social cognition and language comprehension. Furthermore, the interaction of GR and VAL was expected to evoke an IG bias associated with a fronto-parietal network encompassing self-referential regions as well as emotional and cognitive empathy regions.

2. Materials and Methods

2.1. Participants

Thirty-two healthy, right-handed (Edinburgh Inventory of Handedness by Oldfield, 1971) native speakers of German (17 male; 15 female; mean age: 24.72 years; range: 21-35 years) were included in this study after giving written informed consent. They were paid 15 Euro for participation. Fifteen participants were arbitrarily assigned to the group of conclusive problem solvers and 17 to the group of sequential problem solvers (see below). Two further participants (1 male / 1 female) were discarded from the imaging analyses due to movement artifacts (> 9mm). The study was conducted in accordance with the principles of the Declaration of Helsinki and the experimental protocol was approved by the ethics committee of the Faculty of Medicine of the University of Marburg.

2.2. Materials

Each participant listened to a total of 192 critical German sentences, 48 filler sentences and 34 null events (blank screen). The sentences were either uttered by an IG or an OG speaker in order to manipulate social categorization (GR; see below for the group assignment procedure). Furthermore, we investigated IG biasing effects by controlling the emotional valence of the critical sentence material (VAL). Accordingly, each participant listened to an equal number of positive (POS) (example (1)), negative (NEG) (example (2)) or neutral events (example (3)). All critical sentences consisted of well-formed German transitive sentences starting with a first person singular pronoun unambiguously marked for nominative case (NP1 – ich 'I') followed by a verb (V) and a second event participant (NP2). NP2 was either realized as a second person singular pronoun (PRN) (examples (3)/(4)/(5)(a)), or a full-fledged noun phrase, which either referred to an animate (ANI) event participant (examples (3)/(4)/(5)(b)) or an inanimate (INA) event participant (examples (3)/(4)/(5)(c)). According to our hypotheses, severity of actor identification, i.e. competition (COMP) for the actor role between NP1 and NP2 should increase the less distinct the event participants are in terms of their actor features (a > b > c). NP2 was always unambiguously marked for accusative case in order to ensure that actor identification was not influenced by case-marking effects. In order to examine the plausibility of the stimulus material and check the sensitivity of the minimal group paradigm in light of our sentence manipulation, we conducted two pretests prior to the fMRI study. A detailed description of the experimental procedures for the pre-tests along with report and discussion of the results is provided in the supplementary materials.

2.3. Procedure

In order to evoke social categorization, a minimal group paradigm was used (e.g. Tajfel, 1970). Participants were told that we were interested in how individual problem solving strategies would affect language production and comprehension. Prior to the fMRI scanning, participants filled in a fictitious personality questionnaire and received random feedback about their problem solving strategy (classifying them as either a sequential or a conclusive problem solver). During the fMRI experiment, participants listened to German sentences uttered by a male or a female speaker. In order to create the minimal group paradigm, participants were told in the instructions that the speakers were either sequential or conclusive problem solvers. During the experiment, a colored frame (blue or green) would indicate a speaker's problem-solving strategy. For the analysis, trials were coded with IG, if problem-solving strategies of the speaker and the participant matched or OG if they did not match. Speakers' gender and problem-solving strategies were crossed with those of the participants in order to avoid gender effects.

An experimental session began with reading the written instructions, which reminded participants of their problem-solving strategy. Subsequently, each participant had a short practice session outside the scanner. The stimuli used for training were not included in the fMRI experiment. The trials were presented with variable onset delays of 100, 500, 900, 1300, or 1700 ms, in order to improve the efficiency of the event-related design (Miezin, Maccotta, Ollinger, Petersen, & Buckner, 2000). Each trial began with a fixation-cross, which was presented for 500 ms before the stimulus sentence was audible and presented on a screen where it remained visible until 300 ms after the end of the auditory stimulus. A colored frame (blue or green counterbalanced across participants) indicated the group affiliation (sequential or conclusive) of the corresponding speaker. 26 out of 240 sentences (eleven percent) ended with a task, during which participants had to decide who was more likely to have caused the state of affairs that had just been uttered. In this case, "Ursache?" (cause?) and underneath "SprecherIn – andere Person / Situation" (speaker – other person / situation) appeared on the screen. After five percent of the sentences participants had to state whether the speaker they had just heard was a conclusive or sequential problem solver. Accordingly, "Problemlöser?" (problem solver?) and below "konklusiv – sequentiell" (conclusive - sequential) appeared on the screen. Responses were accomplished by a button-press either with their right index or middle finger. Key assignments corresponded to the order of the response options on the screen (left lower corner = right index finger; right lower corner = right middle finger) and were counter-balanced across participants. The time penalty for responses was 2000 ms. A 500 ms blank screen preceded task trials (cf. Fig. 1). Task trials

were modeled as an effect of no interest so that a total of 168 critical sentences were examined.

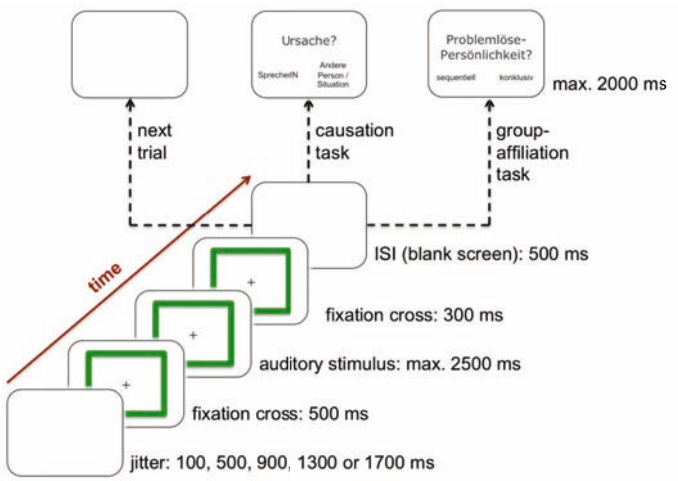

Fig. 1: Scheme of stimulation procedure.

Prior to the scanning procedure, a button box was fixed to the upper right leg of the participants with a strap. For auditory stimulation and in order to attenuate scanner noise, circumaural closed-back earphones were used. Stimulus presentation was controlled by a computer using the Presentation 11.0 software package (Neurobehavioral Systems, Albany, CA, USA, http://www.neurobs.com/). Stimuli were displayed via projection onto a screen that was visible via a mirror mounted on the head-coil. In order to ensure optimal visual acuity, participants were offered fMRI-compatible glasses. Once in the scanner, participants were reminded of the procedure and some key aspects of the instructions such as color-coding and layout of the button box on four consecutive screens (9000 ms per screen). After a pause of 18000 ms, stimulation started.

2.4. Analysis of behavioral data

For each task, identification of problem-solving strategy of the speaker ("problem solver?") and attribution of causality ("speaker / other / situation"), the answers along with the corresponding reaction times were recorded. The data was analyzed using mixed-effects models with subjects and items as crossed random effects (Baayen, Davidson, & Bates, 2008) in order to ensure better comparability to the fMRI data and to account for the relatively small sample size of the behavioral data (only 16 percent of the total trials include a

judgment). Group affiliation of the speakers in relation to the participants (IG vs. OG) served as a binomial fixed effect. While reaction times were analyzed using restricted maximum likelihood estimation (REML), answers were analyzed using Laplace approximation in order to account for the binomial character of the measure. The analysis was performed with the lme4 package (version 0999375-39) for R (version 2.13.0), developed by Bates, Sarkar, Bates, and Matrix (2007). Results are reported including coefficient estimates (CE) and 95 percent confidence intervals (CI).

2.5. fMRI data acquisition

MRI data acquisition was performed on a 3T Siemens scanner (Siemens MRT Trio series). Functional data were acquired with echo planar images in 38 transversal slices (repetition time [TR] = 2250 ms; echo time [TE] = 30 ms; flip angle = 90°; slice thickness = 3 mm; interslice gap = .30 mm; field of view [FoV] = 220 mm x 199 mm, voxel resolution = 3.44 x 3.44 mm, matrix dimensions 64 x 58 mm). Slices were positioned to achieve whole brain coverage. The data was acquired in one functional run with 1150 volumes per participant.

2.6. fMRI data analysis

Functional scans were analyzed using Statistical Parametric Mapping (SPM8; www.fil.ion.ucl.ac.uk) implemented in MATLAB 8.5 (Mathworks Inc., Sherborn, MA). To correct for their different acquisition times, the signal measured in each slice was shifted relative to the acquisition time of the middle slice using a slice interpolation in time. All images of one session were realigned to the first image of a run and normalized into standard stereotaxic anatomical MNI-space by using the transformation matrix calculated from the first EPI-scan of each subject and the EPI-template. Additionally, movement parameters were considered as a relevant factor in order to correct for movement artifacts on the single subject level. Afterwards, the normalized data with a resliced voxel size of 3×3×3 mm were smoothed with a 8 mm FWHM isotropic Gaussian kernel to accommodate inter-subject variation in brain anatomy. Proportional scaling with high-pass filtering was used to eliminate confounding effects of differences in global activity within and between subjects. The expected hemodynamic response at the onset of each event-type was modeled with a canonical hemodynamic response function.

In the group level analysis we calculated a 2x3x2 ANOVA with the factor group (GR: IG, OG), competition (COMP: PRN, ANI, INA) and valence (VAL: POS, NEG) as implemented in SPM8 in which subjects are treated as random variables. For this purpose, we computed 12 simple t-contrasts for the experimental conditions at the subject level. The resulting beta weights were used as the input for the ANOVA at in the second level analysis. A Monte Carlo

simulation with 10000 iterations of the brain volume of the current study was conducted to establish an appropriate voxel contiguity threshold (Slotnick, Moo, Segal, & Hart, 2003). Assuming an individual voxel type I error of $p < .001$, a cluster extent of 23 contiguous re-sampled voxels was necessary to correct for multiple voxel comparisons at $p < .005$. Thus, voxels with a significance level of $p < .001$ uncorrected, belonging to clusters with at least 23 voxels are reported. The reported voxel coordinates of activation peaks are located in MNI space. Labeling of local maxima was carried out with SPM Anatomy Toolbox v1.8 (Eickhoff, Heim, Zilles, & Amunts, 2006; Eickhoff et al., 2007; Eickhoff et al., 2005). Notice that main effects of COMP and VAL are only reported and briefly discussed in the supplementary materials, as they are confounded by the length of the critical stimulus word (one syllable pronoun vs. three syllable noun phrases).

In order to account for fine-grained gradation of actor features (INA < ANI < PRN), we analyzed COMP for the actor role as a parametric modulation (INA = 1, ANI = 2, PRN = 3) for IG and OG conditions. Generally, we expect increasing COMP to correlate positively in the IG as well as the OG condition. OG conditions, respectively. At the second level, two separate one-sample t-tests were conducted in order to identify regions showing higher activation with increasing COMP in the IG and OG conditions. In order to identify regions in which the parametric competition effect differed between IG and OG, we computed an additional two-sample t-test comparing the IG and OG effects.

3. Results

3.1. Behavioral results

3.1.1. Identification of problem solver strategy

Five percent of the trials were excluded because reaction times were below 50 ms. All in all, 94 percent of the responses were correct and the participants had no problem deciding if the sentence they heard was uttered by a sequential or a conclusive problem solver. A model with group (GR) as a binomial factor was fit to reaction time data. Accordingly, RTs were significantly longer (CE = 79.27, CI = 27.60 - 130.50, $p < 0.002$) when participants had to detect an OG speaker (mean = 1072.31 ms, sd = 323.96 ms) in comparison to an IG speaker (mean = 1000.19, sd = 326.14 ms). A mixed effects model with accuracy of the participants' responses (correct vs. incorrect) as the dependent measure and the binomial GR did not yield a significant accuracy difference between IG and OG speakers.

3.1.2. Attribution of causality

For this task, participants had to state if they causally attributed the events to the speaker or to another person or the situation respectively. Seven percent of the trials were excluded because RTs exceeded the 2000 ms timeout penalty. A mixed-effects model of the reaction times yielded no significant difference between causal attributions to IG or OG speakers (mean IG = 1094.89 ms, sd = 366.43 ms; mean OG = 1105.40 ms, sd = 360.24 ms). However, causal attributions were assigned more frequently to IG speakers (mean = 0.69, sd = 0.46) then to OG speakers (mean = 0.56, sd = 0.50) (CE = -0.62, CI = 0.59 - 0.66, $p < 0.000$).

3.2. fMRI results

3.2.1. Interaction GR x VAL

The interaction between group (GR) and valence (VAL) activated the postcentral gyrus as well as the inferior parietal lobule (IPL) bilaterally. Furthermore, it showed activation of the left posterior cingulate cortex (PCC) (cf. Fig. 2 and Table 1).

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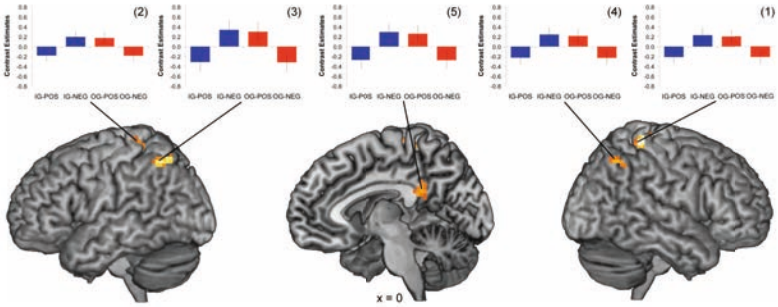

Fig. 2: Visualization of local maxima along with the corresponding contrast estimates for the interaction of GR x VAL. Numbers in parentheses correspond to the numbering of the local maxima in table 1.

Table 1: Details about local maxima for interaction between GR and VAL (F > 11.00)

	Anatomical region	hem.	x	y	z	F	voxels
(1)	Postcentral gyrus	R	30	-37	67	17.16	63
		R	18	-37	61	13.77	
(2)	Postcentral gyrus	L	-27	-31	49	14.46	62
		L	-18	-37	67	14.16	
(3)	Inferior parietal lobule	L	-45	-58	52	15.90	53
		L	-36	-64	55	14.80	
(4)	Inferior parietal lobule	R	36	-52	43	15.23	43
		R	48	-58	49	12.91	
(5)	Posterior cingulate cortex	L	0	-43	25	13.59	36

3.2.2. Interaction GR x COMP

The interaction between group (GR) and competition (COMP) activated the right angular gyrus (AG; size = 40 voxels) as depicted in Fig. 3.

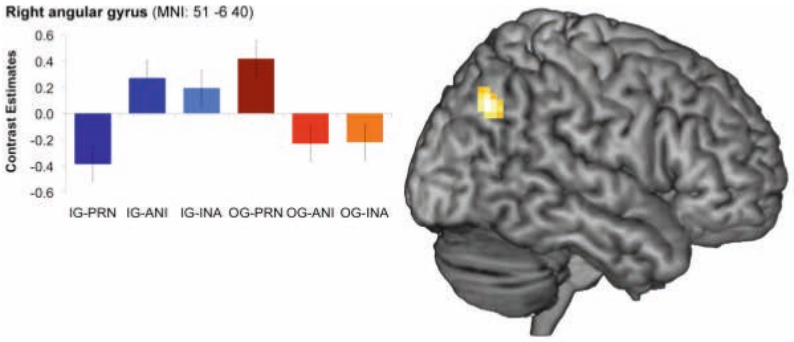

Fig. 3: Contrast estimates per condition for the interaction GR x COM at right angular gyrus (F = 9.41).

3.2.3. Parametric modulations

In order to identify clusters that showed a correlation between increasing competition for the actor role (COMP) and the social status of the speaker (IG vs. OG), we analyzed COMP as parametric modulation of the IG and OG condition respectively (cf. Fig. 4 and Table 2). In the prefrontal cortex, both conditions elicited activation in a network comprising the left SFG and MFG as well as the left middle orbital gyrus. In the IG additional activation was found in the pars orbitalis of the IFG, while additional activation in the OG condition included the right posterior cingulate cortex (PCC) right MFG and bilateral ACC. In the parietal cortex, both conditions elicited activation in the bilateral precuneus as well as the left inferior parietal lobule (IPL). Additional activation clusters for the OG condition were found in the right AG and the right IPL.

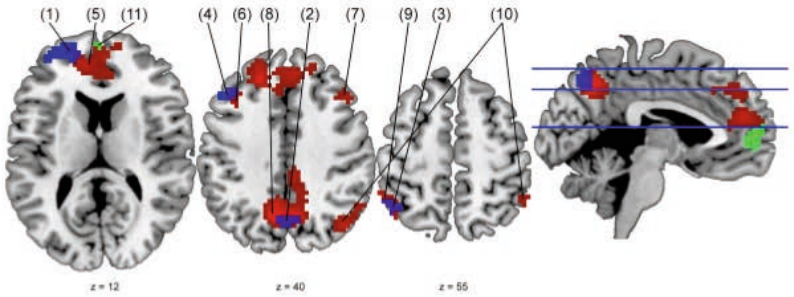

Fig. 4: Visualization of activated voxels for IG (blue) and OG (red) condition that correlate positively with COMP (+COMP), i.e. are sensitive to increased competition for the actor role. Cluster 11 (green) resulted from the two-sample t-contrast OG+COMP > IG+COMP. Numbers on top of the figure in parentheses correspond to the numbering of the local maxima in table 2.

Table 2: Details about local maxima sensitive to increasing COMP in the IG and OG condition (T > 3.37).

	Anatomical region	hem.	x	y	z	T	voxels
IG+COMP (one-sample t-test)							
(1)	Superior frontal gyrus	L	-21	53	7	5.12	180
	Middle orbital gyrus	L	-33	53	-2	4.58	
	Inferior frontal gyrus (pars orbitalis)	L	-39	50	-8	3.92	
(2)	Precuneus	R	6	-67	46	4.71	106
		L	-3	-67	46	4.62	
(3)	Inferior parietal lobule	L	-42	-55	61	5.11	45
(4)	Middle frontal gyrus	L	-42	26	43	4.65	43
OG+COMP (one-sample t-test)							
(5)	Superior frontal gyrus	L	-18	38	40	5.55	684
		L	-18	53	10	4.68	
		L	-12	47	34	4.43	
	Frontal superior medial gyrus	L	-9	47	16	4.61	
		R	6	41	40	4.41	
	Middle orbital gyrus	L	-33	50	-8	4.27	
		L	-30	53	-2	4.01	
	Anterior cingulate cortex	L	-9	32	25	4.16	
		R	6	35	7	4.05	
	Middle frontal gyrus	L	-21	50	37	4.45	
		L	-36	44	31	4.03	
(6)	Middle frontal gyrus	L	-39	23	43	4.33	46
(7)	Middle frontal gyrus	R	45	23	40	3.89	45
		R	30	20	43	3.82	
		R	33	23	46	3.78	
		R	27	29	43	3.74	
		R	27	29	49	3.69	
(8)	Precuneus	L	-6	-61	43	6.06	440
		R	3	-64	40	5.52	
	Posterior cingulate cortex	R	6	-34	37	4.54	
(9)	Angular gyrus	R	42	-70	43	4.48	171
		R	51	-58	40	3.89	
	Inferior parietal lobule	R	51	-52	49	4.30	
		R	45	-52	61	3.64	
(10)	Inferior parietal lobule	L	-54	-46	52	4.66	95
		L	-51	-58	49	4.54	
OG+COMP > IG+COMP (two-sample t-test)							
(11)	Frontal superior medial gyrus	L	0	56	1	3.91	105
		L	-3	62	10	3.48	
	Medial orbital gyrus	R	6	53	-14	3.77	

4. Discussion

In summary, the interaction of group (GR) and valence (VAL) yielded activation in the posterior cingulate cortex (PCC) and the inferior parietal lobule (IPL) as well as activation of the bilateral postcentral gyri (PCG). The interaction of GR and competition (COMP) activated the right angular gyrus (AG). The parametric modulation of the factor COMP in the IG condition activates an almost exclusively left lateralized fronto-parietal network. In the OG condition, the fronto-parietal network has a broader bilateral distribution. In the IG, increasing COMP activated the left superior frontal gyrus (SFG), the left middle orbital gyrus (MOG) and the left inferior frontal gyrus (IFG). In parietal regions we found activation in the bilateral precuneus (PRC) as well as the left inferior parietal lobule (IPL). In the OG condition, increasing COMP evoked activation in the frontal cortex comprising the left SFG, the left MOG, the bilateral superior medial gyri (SMG), the anterior cingulate cortex (ACC) and the bilateral middle frontal gyri (MFG). Parietally, the activation network encompassed bilateral PRC extending to the posterior cingulate cortex (PCC), the right AG as well as the bilateral IPL.

4.1. Interaction GR x VAL

The interaction of GR x VAL yielded activation in the IPL and the PCC, in line with previous neuroimaging findings on social categorization (Molenberghs & Morrison, 2014).According to Northoff and Bermpohl (2004), the PCC belongs to the so-called cortical midline structures (CMS), which are activated when processing the self as opposed to others. Within the CMS, the PCC is suggested to be a substrate of self-reflection tasks (e.g. Johnson et al., 2002), which require the integration of a self-referential stimulus in the context of personal attitudes, goals and traits. Accordingly, activation of the PCC and the precuneus is elicited when participants had to decide if a word or statement was self-descriptive (Fossati et al., 2003; Johnson et al., 2002; Kircher et al., 2000) or when they had to reflect on their own traits as opposed to the traits of another person (Kjaer, Nowak, & Lou, 2002). In line with these findings, activation in the PCC for negative events by an IG speaker as well as positive events by an OG speaker replicate the expected IG bias for internal evaluation processes such as judging the self-relatedness between the speaker and hearer (participant) and recruiting the retrieval of autobiographic (episodic and semantic) memory (Kjaer et al., 2002).

A similar activation pattern is found in bilateral parietal regions, which overlap with the so-called human mirror system (e.g. Fadiga, Roy, Fazio, & Craighero, 2007; Grèzes & Decety, 2002; Mainieri, Heim, Straube, Binkofski, & Kircher, 2013; Pohl, Anders, Schulte-Rüther, Mathiak, & Kircher, 2013). Involvement of this system is hypothesized for auditory imagery

related to speech processing (Fadiga et al., 2007; Watkins & Paus, 2004) or the visual perception and execution of lip forms (Nishitani & Hari, 2002). Accordingly, it has been suggested that increased excitability of these areas during speech processing (e.g. listening to continuous speech) in comparison to the processing of a control stimulus (e.g. white noise) results from internal speech, i.e. the imitation of the movement of the articulators in order to "improve the listener's ability to understand and even anticipate the heard speech" (Watkins & Paus, 2004, p. 938). In line with these findings, we propose that activation of the bilateral postcentral gyri and inferior parietal lobule reflect an IG bias during auditory imagery as a deviation from a positively connoted IG speaker (IG-NEG > IG-POS) and a negatively connoted OG speaker (OG-POS > OG-NEG) leads to an increased processing load (i.e. additional information resources are recruited) in comparison to a self-enhancing positive IG and negative OG.

4.2. Interaction GR x COMP

The behavioral results demonstrate that social categorization has a direct impact on language comprehension. Reaction times during the group detection task showed an IG bias, indicating that participants had more difficulty in detecting the problem solver strategy of OG in comparison to IG speakers. The results showed further that participants attributed causation more frequently to the IG speaker than to the OG speaker suggesting that IG speakers are perceived as generally more potent to be the causer of the state of affairs described by the sentences (cf. Bornkessel-Schlesewsky, Krauspenhaar, & Schlesewsky, 2013).

The neuroimaging data revealed increased activation in the right AG when actor competition was maximal, namely in sentences with two pronominal event participants uttered by an OG speaker. These findings are in line with findings by Seidel et al. (2010) and Blackwood et al. (2003) who found that increased activation in the right AG correlates with external causal attributions. In a similar vein, the results of a meta analysis by Sperduti, Delaveau, Fossati, and Nadel (2011) showed increased activation of bilateral AG for external versus internal agency attribution. However, the AG is associated with a variety of different processing aspects such as out-of body experiences (e.g. Blanke, Ortigue, Landis, & Seeck, 2002), the perception of self-produced movement (e.g. Leube et al., 2003), memory retrieval (e.g. Kim, 2010; Spaniol et al., 2009; Spreng, Mar, & Kim, 2009; Vilberg & Rugg, 2008), the default mode network (short: DMN, e.g. Laird et al., 2009; Mazoyer et al., 2001; Shulman et al., 1997; Spreng et al., 2009) or ToM processing (e.g. Ferstl & von Cramon, 2002; Mar, 2011). In a recent review of the multiple functions and subdivisions of the AG, Seghier (2013, p. 52) proposed a unified framework which envisages the AG as a "cross-modal integrative hub that

gives sense and meaning to an event within a contextualized environment, based on prior expectations and knowledge, and toward an intended action." This assumption is supported by our findings, which show that language comprehension is affected by social categorization effects in this area. Accordingly, we propose that the right AG indexes the integration of linguistic and extra-linguistic information in order to compute self-other-distinctions associated with an activation increase for the computation of the actor role in the OG condition in contrast to activation decreases in the IG condition.

4.3. Parametric modulation of COMP for IG and OG condition

With the parametric modulation we wanted to provide evidence that the social speaker-hearer relation affects the neural network that correlates with fine-grained gradations of actor features (INA < ANI < PRN), which successively increase the competition for the actor role interpretation during online language comprehension.

4.3.1. Hemispheric asymmetry

The most striking difference when comparing increasing COMP with IG and OG respectively is the hemispheric asymmetry. While the network for increasing COMP in the IG condition was almost exclusively left lateralized, the network for increasing COMP in the OG condition had a broader bilateral distribution. Generally, bilateral activation or at least an increase in right hemispheric activation during language processing is typically associated with higher-level language tasks that require extra-linguistic processes such as attention, working memory, visual imagery, ToM or aspects of social cognition (Xu, Kemeny, Park, Frattali, & Braun, 2005). Accordingly, activation in the right hemisphere has been reported for comprehending metaphors (Diaz & Hogstrom, 2011; N. Mashal, Faust, & Hendler, 2005; Nira Mashal, Faust, Hendler, & Jung-Beeman, 2007; Schmidt & Seger, 2009)[1], processing of jokes (Coulson & Wu, 2005; Feng, Ye, Mao, & Yue, 2014; Goel & Dolan, 2001; Taber, Redden, & Hurley, 2007), severed pronoun-referent-linking (McMillan, Clark, Gunawardena, Ryant, & Grossman, 2012; Nieuwland, Petersson, & van Berkum, 2007), or when integrating speech and gesture information (Straube, Green, Jansen, Chatterjee, & Kircher, 2010). We thus assume that the broader bilateral network evoked in the OG condition is associated with increased processing load due to additional social categorization information that are integrated during language comprehension.

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[1] Note that it is controversial whether right hemispheric activation is due to the processing of metaphors per se or a correlate of salience, novelty or semantic distance of the metaphors (Rapp, Leube, Erb, Grodd, & Kircher, 2007)

4.3.2. Neural substrates related to self-referencing

Processing the self as opposed to others is robustly associated with activation of the CMS (e.g. Northoff & Bermpohl, 2004). The CMS comprises the orbital and adjacent medial prefrontal cortex (OMPFC), the anterior cingulate cortex, particularly the supragenual part (SAC), the dorso-medial prefrontal cortex (DMPFC) and the posterior cingulate cortex (PCC) including the adjacent retrosplenium and precuneus. In the current study, we observed activation of a fronto-parietal network that largely overlaps with the CMS with the exception of local maxima in the IPL and the dorso-lateral prefrontal cortex (DLPFC), which will be discussed below.

According to Northoff and Bermpohl (2004), activation in the orbital gyrus is associated with self-representation, i.e. the labeling of stimuli as self-referential. Typically activation within orbital and ventral regions of the frontal cortex is evoked when participants compare their abilities, traits or attitudes to those of others (e.g. Johnson et al., 2002; Kelley et al., 2002; Kircher et al., 2000; Kjaer et al., 2002) but also when emotional stimuli are processed in general as they are regarded as "implicitly self-referential" (cf. Fig. 2A Kircher et al., 2000; Northoff & Bermpohl, 2004, p. 104). While we only found one local maximum within the orbital gyrus in the IG condition, we found two local maxima in the OG condition suggesting that self-representation recruits additional information sources for OG stimuli.

Activation in more dorsal areas of frontal CMS is associated with self-evaluation processes, such as evaluating self-referential judgments such as "I like Leipzig" (Zysset, Huber, Ferstl, & von Cramon, 2002), judging which traits best describe oneself (Fossati et al., 2003) or moral judgments (Greene & Haidt, 2002). Activation in the middle and superior parts of the frontal CMS is thus assumed to index self-evaluative processes. Although participants were only asked to evaluate about 16 percent of the trials in the present study, we assume that covert evaluation processes took place in order to be prepared for overt evaluation, which could not be expected due to the randomization of the trials. Once again, the network recruited in the OG condition is broader, also comprising the right hemisphere in the middle part of the frontal CMS suggesting that evaluation takes additional information sources into account.

The ACC is associated with conflict monitoring, error detection and performance monitoring. As already outlined before, the PCC and precuneus are associated with tasks which require the integration of a stimulus that is self-referential in the context of personal attitudes, goals and traits (Johnson et al., 2002). Within the IG condition, activation is limited to the bilateral precuneus. In the OG condition, increasing COMP also elicits activation of the PCC. Our results thus nicely complement previous findings about the CMS suggesting that the OG

condition induces a conflict between the self-referential stimulus and the lack of self-reference with the speaker.

4.3.3. Neural correlates related to memory retrieval and mirroring action

Beyond the CMS, we also found increased activation within more dorso-lateral regions of the prefrontal cortex (PFC). Several studies associate lateral prefrontal regions with memory retrieval processes (e.g. Mark D'Esposito & Postle, 1999; Marc D'Esposito & Postle, 2000; Manoach, Greve, Lindgren, & Dale, 2003). Following Jonides et al. (2008), we assume that dorso-lateral structures in the PFC are associated with control processes of retrieval and interference resolution during actor identification processes. Once again, the broader bilateral network in the OG condition suggests that these processes recruit additional information sources than in the IG condition. We also found activation in the left IPL for the IG condition and in the bilateral IPL for the OG condition. Similar activation patterns are reported in a study by Molenberghs and Morrison (2014), who induced a minimal group by randomly assigning participants either to a red or a blue team based on a fictitious team allocation test similar to the procedure by Tajfel et al. (1971). During the fMRI study participants watched video clips displaying hand movements of either IG or OG members. The speed of the movements differed by 67, 0, or -67 ms. In one third of the trials participants were asked to make an overt judgment whether their team member (IG) or the member of the other team (OG) was faster via a button press. The behavioral results show that 13 of the 24 participants showed an IG bias, perceiving more than 50 percent of the trial as faster, when an IG member executed the movements, although the latencies were actually identical. The neuroimaging data of these 13 participants show increased activation of the left IPL. This activation was interpreted as an effect of mirroring the actions of others, which has been shown to be sensitive to social relationships (Molnar-Szakacs, Wu, Robles, & Iacoboni, 2007; Rizzolatti & Fabbri-Destro, 2008). As outlined before, the IPL is a prominent area related to mirroring action (Fadiga et al., 2007; Watkins & Paus, 2004). Accordingly, our findings suggest, that increased activation in the IPL reflects the recruitment of additional information source during auditory imagery if sentences are uttered by an OG speaker in comparison to an IG speaker. Furthermore, asymmetric lateralization of IPL is evoked when participants distinguish consequences of actions generated by the self from those initiated by others (Chaminade & Decety, 2002; Decety, Chaminade, Grezes, & Meltzoff, 2002; Ruby & Decety, 2001). Our findings extend these results, suggesting that activation in the IPL is not just associated with action but rather with the dissociation between agency detection and therewith also linguistic actor identification of the self vs. another person.

4.4. Limitations

The present study provides initial evidence for a direct impact of social categorization on rapid and automated processes during online language comprehension. In order to keep the experimental design for this primary investigation as simple as possible, we decided to keep the participant sample rather homogeneous with a focus on students with a rather similar social and educational background. However, for future investigations it would be very intriguing to examine the robustness of the effects in a more representative sample by considering for instance age groups or the social and educational background of the participants.

5. Conclusion

The present study provides evidence for an involvement of the right angular gyrus in the integration of social cognitive categorization and online auditory language processing. We showed that the relation between the social status of speaker and hearer affects actor identification and hence, causal attributions in linguistically expressed events. Furthermore, our results converge with previous neurophysiologic investigations employing a minimal group paradigm eliciting activation in regions related to self-referencing (CMS), memory retrieval (DLPFC) and mirroring action (PCG and IPL).

Acknowledgements

The present study was conducted as part of the interdisciplinary project "Cultural Neurosciences" at the Philipps-Universität Marburg funded by a LOEWE grant from the government of the federal state of Hessen, Germany. Arne Nagels is funded by the Deutsche Forschungs Gemeinschaft (Projektnummer DFG: KI 588 / 6-1). We thank the Department of Psychiatry and Psychotherapy, Marburg and particularly the core unit BrainImaging, Andreas Jansen, Mechthild Wallnig and Rita Werner, who made the realization of the present study possible. We further thank Ulrich Wagner for his helpful comments about the theoretical background of social categorization, Henriette Schneider-Haßloff for her assistance during the preparation phase, and Axel Krug for his support during data analysis. We are especially thankful for the support of Frank and Ulrike Domahs, who kindly took the time to record the stimulus material.

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Supplementary Material

1. Pretests

1.1. Pretest 1: Plausibility of stimulus material

With the first pretest, we wanted to ensure that effects of competition (COMP) or valence (VAL) are not driven by systematic variation of the plausibility of the sentence material. For this purpose, a total of 200 sentences were constructed (cf. examples (3)-(5)). Each verb was presented with two different animate and inanimate noun phrases resulting in 40 quintets. The overall plausibility of the stimulus material was assessed via an online questionnaire with the open source survey software LimeSurvey. A total of 62 native speakers of German participated in the study (mean age: 24.47 years; range: 18-39 years) rating the overall plausibility of the sentences on a four-point analogue scale (1 = unplausibel 'implausible', 2 = eher unplausibel 'rather implausible', 3 = eher plausible 'rather plausible', 4 = plausible 'plausible'). The material was split into 5 different randomized lists with 40 sentences each. All relevant conditions (positive and negative valence, argument competition via pronoun, animate and inanimate NP2) were pseudo-randomized and equally distributed across lists. Each participant only rated one list. The mean plausibility ratings are 3.33 indicating that sentences are rated as rather plausible. A 2x2 ANOVA with the factor COMP (PRN / ANI / INA) and VAL (POS / NEG)[1] only yield a main effect of COMP ($F(2:78) = 3.72$ $p = 0.03$). We thus discarded 32 sentences with an average plausibility score below 2.5. An ANOVA with the remaining sentence material does not yield any significant effect suggesting that differences between the sentence materials are not caused by its overall plausibility.

[1] We transformed the item-specific valence information into a binominal factor with a mediansplit (values > median = positive; values < median = negative).

1.2. Pretest 2: Inspection of minimal group paradigm via acceptability ratings of sentence materials and likability judgments of speakers' voices

In a second pretest, we tested the minimal group paradigm with a reaction time experiment. The experiment was conducted in a laboratory of the University of Marburg. A total of 40 students (16 male, 24 female; mean age: 24.48 years; range: 20-31) participated in the study. Two male participants were excluded because they missed more than 20 percent of the trials. Experimental procedures were similar to the fMRI experiment. Since all critical sentences were grammatically acceptable, we constructed a set of ungrammatical filler sentences as well as grammatical fillers that did not start with a first person singular pronoun in order to prevent an automatic response bias. For the experiment we used 72 critical sentences and 48 filler sentences that were recorded by a male and a female voice respectively. The material was split into three lists consisting of 48 critical sentences and 48 filler sentences. After hearing a sentence, participants first rated the acceptability of the sentence (ACCEPT) and subsequently the likability (LIKAB) of the speakers' voices on a four-point analogue scale (1 = überhaupt nicht akzeptabel / angenehm 'not at all acceptable / absolutely unpleasant', 2 = weniger akzeptabel / angenehm 'less acceptable / pleasant', 3 = eher akzeptabel / angenehm 'rather acceptable / pleasant', 4 = sehr akzeptabel / angenehm 'very acceptable / pleasant'). We performed four separate ANOVAs for acceptability and likability ratings as well as the corresponding reaction times (RTs) with the factors group (GR; levels: IG / OG), valence (VAL; levels: POS / NEG) and competition (COMP; levels: PRN / ANI / INA).

1.2.1. Results pretest 2: Acceptability rating

Sentences uttered by the IG speaker were rated more acceptable than those uttered by the OG speaker (mean ratings IG = 1.92, OG = 1.71) as indicated by a main effect for GR ($F(1, 37) = 21.28$, $p = 0.00$). Further, sentences describing a positive event were rated more acceptable than sentences describing a negative event (mean ratings POS = 1.88, NEG = 1.75) yielding a main effect of VAL ($F(1, 37) = 4.81$, $p = 0.03$). Sentences with low competition between the arguments for the actor role were rated to be less acceptable than sentences with higher competition between the arguments (mean ratings PRN = 1.82, ANI = 1.95 and INA = 1.68) which is supported by a main effect of COMP

($F(2, 74) = 11.71$, $p = 0.00$). We further found an interaction between GR and VAL ($F(1, 37) = 7.06$, $p = 0.01$), GR and COMP ($F(2, 74) = 10.87$, $p < 0.00$) as well as VAL and COMP ($F(1, 37) = 9.10$, $p = 0.00$). A resolution by GR for the first interaction yielded an effect of VAL only in the OG condition (OG: $F(1, 37) = 17.79$ $p = 0.00$) suggesting that sentences uttered by an OG speaker were rated to be less acceptable if the event described was negative rather than positive (mean ratings for OG condition: NEG = 1.66, POS = 1.86). A resolution by COMP for the second interaction yielded an effect of GR only in the INA condition (INA: $F(1, 37) = 36.94$ $p = 0.00$). Accordingly, only acceptability ratings of the INA condition differed, yielding sentences of the IG speaker as more acceptable than those of the OG speaker (IG = 1.91, OG = 1.45). A resolution by COMP for the third interaction yielded an effect of VAL in all COMP conditions (PRN: $F(1, 37) = 13.61$ $p = 0.00$; ANI: $F(1, 37) = 6.37$ $p = 0.02$; INA: $F(1, 37) = 4.48$ $p = 0.04$). A comparison of the mean ratings showed that for the PRN and ANI conditions, sentences describing positive events were rated as more acceptable than those describing negative events (mean ratings of PRN: POS = 2.03 NEG = 1.56; ANI: POS = 2.12, NEG = 1.67). The reverse pattern was evoked in the INA condition (POS = 1.43, NEG = 1.48).

A main effect of GR ($F(1, 37) = 8.44$ $p = 0.01$) indicated that reaction times for IG speakers were significantly shorter than for OG speakers (IG = 853 ms vs. OG = 785 ms). The results further showed that RTs of acceptability ratings of sentences with an inanimate NP2 were shorter (INA = 764 ms) than of those with an animate (ANI = 849 ms) or pronominal (PRN = 845 ms) NP2 yielding a main effect of COMP ($F(1, 37) = 13.61$ $p < 0.00$). No interaction effects for the reaction times were found.

1.2.2. Results pretest 2: Likability judgement of speaker voice

The likability judgments only yielded a three-way interaction between GR, VAL and COMP ($F(2, 74) = 3.41$ $p = 0.04$). A resolution by GR yielded a significant interaction between VAL and COMP only in the IG condition ($F(2, 74) = 5.08$ $p = 0.01$). A further resolution by COMP did not yield any significant main effect of VAL. A comparison of mean judgments suggests that the effect were driven by the PRN condition yielding a

tendency to judge the voice of IG speakers as more pleasant when the event described was positive (2.16) rather than negative (1.92). Reaction times of the likability judgment did not yield any significant main or interaction effects.

1.3. Discussion pretests

With this first pretest, we wanted to ensure that the sentence material was equally plausible in order to avoid effects that are caused due to differences in plausibility. Accordingly we excluded sentences with a mean plausibly rating below 2.5. The absence of an effect of COMP or VAL suggests that plausibility does not affect these critical factors in the remaining stimulus sentences.

The second pretest indicates that the minimal group paradigm evokes the expected IG bias even in an offline task after sentence processing is completed. The results showed that sentences uttered by an IG speaker were generally perceived as more acceptable than similar sentences uttered by an OG speaker. The interaction between GR and VAL, indicated that sentence acceptability is downgraded if the sentence described a negative event only when it is uttered by an OG speaker. Sentences uttered by an IG speaker are generally perceived as more acceptable and participants did not differentiate between negative or positive events (mean acceptability rating NEG = 1.93, POS = 1.91). The longer reaction times for IG speakers indicate that they are judged more thoroughly than OG speakers, which is in line with previous findings (Lieberman, 2005; van Bavel, Packer, & Cunningham, 2008, 2011) suggesting that self-referential processes are more costly for IG than OG members. The results also indicate that sentences in the INA condition and hence lowest in competition for the actor role were also least costly (PRN = 845 ms, ANI = 849 ms, INA = 764 ms). At first glance this finding seems to contradict the results from the behavioral results of the fMRI study, which elicited shorter RTs when participants made a decision about the problem solver strategy of the speaker. However, evaluation processes between the two tests differed qualitatively. In the pretest, participants subjectively judged the content of an utterance without any given right or wrong answers. In the group detection task during fMRI scanning, participants simply stated if they correctly remembered the problem solving strategy of the speaker. Their

judgment was aided by the color-coding (blue vs. green) of the frame around the screen while the fixation cross was present. We presume that processing in the latter task was less costly because top-down evaluation processes (e.g. whether the content uttered is congruent with the self or even self-enhancing) were not necessary.

Likability ratings showed a more complicated pattern as we only find a three-way interaction. A resolution of the interaction indicates that the effect was driven by a difference of the likability rating only in the IG condition. A speaker's voice was considered most pleasant when he or she uttered a sentence with a pronoun (mean likability judgment PRN = 2.16, ANI = 2.01, INA = 1.87) where self-reference is highest as in *I look at you* (PRN) in contrast to *I look at the violinist* (ANI) / *the chit* (INA). In the OG condition, the sentence condition (COMP) did not matter with a tendency to judge a speaker's voice as least pleasant in the PRN condition (PRN = 1.95, ANI = 2.02, INA = 1.97).

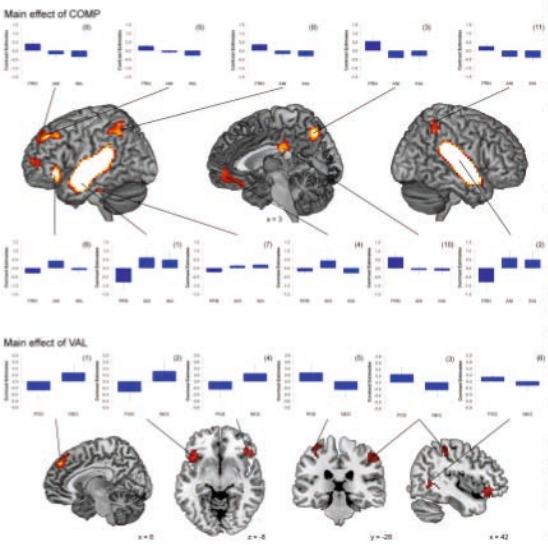
2. Additional results fMRI experiment

2.1. Main effect COMP

The full factorial analysis yielded a main effect of competition (COMP) activating a widespread neural network encompassing bilateral fronto-temporal regions, the parietal lobe and the left cerebellum (cf. Fig. S1 top). The largest activation clusters were evoked in bilateral temporal gyri. While the activation maximum found in the left hemisphere was medial, local maxima in the right hemisphere were more superior. In the ventral part of the PFC we found activations in both hemispheres of the orbital gyrus, the left IFG and the right rectal gyrus. In more dorsal regions of the frontal cortex (FC) we found a dominance of activation clusters in the left hemisphere encompassing the left IFG, left middle frontal gyrus (MFG) and the left superior medial gyrus (SMG). Activation clusters in the parietal cortex (PC) showed a left-hemispheric dominance. Sub-gyrally we found activation in the left fusiform gyrus extending to the left cerebellum as well as a cluster in the posterior cingulate gyrus. We further found a cluster in the left IPL and a smaller cluster in the right supramarginal gyrus (SMarG) (cf. Fig. S1 top).

2.2. Main effect of VAL

A main effect of valence (VAL) activated a frontal network with a left-hemispheric dominance in bilateral SMG and bilateral IFG. Additionally bilateral parietal areas comprising the right IPL, bilateral postcentral gyrus and left precentral gyrus as well as white matter in the right temporal gyrus were activated (cf. Fig. S1 bottom).



Local maxima sensitive to main effect COMP (F > 7.04)

	Anatomical region	hem.	x	y	z	T	voxels
(1)	Middle temporal gyrus	L	-54	-16	-2	103.60	1732
(2)	Superior temporal gyrus	R	60	-16	10	70.58	1193
		R	57	-25	16	70.16	
		R	57	-4	-2	66.87	
(3)	Precuneus	L	-6	-64	43	16.28	283
		R	9	-64	46	15.39	
(4)	Medial orbital gyrus	R	9	53	-5	10.16	158
		L	-3	50	-2	9.91	
		R	3	50	-5	9.42	
	Rectal gyrus	R	3	41	-14	8.16	
		R	3	35	-14	8.06	
(5)	Superior frontal gyrus	L	-21	41	43	13.27	142
	Middle frontal gyrus	L	-36	29	43	11.46	
	Superior medial gyrus	L	-6	47	46	8.28	
(6)	Inferior frontal gyrus (pars orbitalis)	L	-42	29	-8	16.61	105
(7)	Fusiform gyrus	L	-42	-43	-14	15.39	105
		L	-39	-37	-20	13.10	
	Cerebellum	L	-27	-34	-26	11.83	
(8)	Inferior parietal lobule	L	-54	-55	46	11.39	91
		L	-45	-55	58	10.83	
		L	-57	-43	49	10.13	
(9)	Superior frontal gyrus	L	-21	59	10	9.94	71
	Middle frontal gyrus	L	-27	59	10	9.66	
		L	-30	56	7	8.63	
(10)	Posterior cingulate cortex	L	0	-25	28	12.94	67
(11)	Supra-marginal gyrus	R	51	-49	49	10.34	49

Local maxima sensitive to main effect of VAL (F > 11.86)

	Anatomical region	hem.	x	y	z	T	voxels
(1)	Superior medial gyrus	R	6	47	40	26.75	261
		L	-3	38	49	26.04	
		L	-6	23	58	21.41	
(2)	Inferior frontal gyrus (pars orbitalis)	L	-42	20	-8	31.79	229
	Inferior frontal gyrus (pars triangularis)	L	-48	17	13	15.98	
(3)	Postcentral Gyrus	R	48	-31	49	19.25	99
	Inferior parietal lobule	R	36	-43	55	12.38	
(4)	Inferior frontal gyrus (pars orbitalis)	R	45	29	-8	23.32	66
(5)	Precentral gyrus	L	-33	-25	67	17.68	50
	Postcentral gyrus	L	-33	-28	52	12.32	
(6)	Middle temporal gyrus (white matter)	R	42	-55	4	14.66	26
	Temporal gyrus (white matter)	R	39	-46	-2	12.73	

Fig. S1: Visualization of local maxima along with the corresponding contrast estimates for the main effect of COMP (top) and main effect of VAL (bottom). Details about the corresponding anatomic labels, coordinates of local maxima in MNI space as well as the cluster size in voxels are provided in the tables on the right.

5 Conclusion and outlook

All in all, the results presented in the publications described in this dissertation provide initial evidence for a variety of different neural underpinnings of linguistic actorhood, all of which are related to general cognitive mechanisms rather than purely linguistic operations. The first publication provided electrophysiological evidence that fine-grained semantic features, which determine an argument's actorhood potential, affect linguistic actor identification in a bottom-up manner. The second publication showed how neural correlates of basic psychological operations related to the detection of volitional action and the experience of sentience are recruited during online language comprehension. With the third publication, we demonstrated how even the social speaker-hearer relation affects online language comprehension. Taken together, we found a range of different indicators, electrophysiological and neurophysiological in nature, which provide a ground for the assumption that language processing is nothing special to the brain.

The first publication showed that lexical access during actor-event (AE) schemata activation is affected by bottom-up information about an event participant's actorhood potential as reflected in an N400 manipulation for both subject and object initial sentences. Furthermore, the stronger effect for object initial sentences nicely converges with cross-linguistic findings of increased competition between two event participants at the position of a second event participant (e.g. Bornkessel & Schlesewsky, 2006; Bornkessel-Schlesewsky & Schlesewsky, 2009b; Frenzel et al., 2011; Frisch & Schlesewsky, 2001; Schlesewsky & Bornkessel, 2004).

With the second experiment we could provide initial evidence that neural correlates associated with the detection of volitional action (posterior cingulate cortex) and the experience of sentience (right prefrontal cortex and bilateral caudate nuclei) are recruited during the comprehension of simple transitive sentences in German. This suggests that identifying the actor in a sentence recruits dissociable neural networks, depending on the relevant proto-actor entailments (volition versus sentience). Thus, the processing system recruits matching domain-general mechanism rather

than linguistic-mechanisms, for instance, related to purely syntactic functions. Furthermore, we could show that the comprehension of pronouns either referring to the self (*I* / *me*) in contrast to those referring to others (*he* / *him*) activated prominent areas within the so-called cortical midline structures (CMS), which are related to self-referential processes, such as the evaluation of the self-relatedness of a stimulus. All in all, the results of this second experiment provide further support that language processing seems to follow more general psychological mechanisms and, therewith, provide additional neurophysiologic ground for the modulation of actorhood along the lines of attractor networks.

The third experiment goes beyond argument inherent features by manipulating the social speaker-hearer-relation. This study provides compelling evidence that intergroup relations have a direct impact on causal attributions during online language comprehension as implicated in activation of the right angular gyrus (AG). This region is considered to be a cross-modal integration hub (Seghier, 2013), which is robustly associated with self-other distinctions (Blackwood, Bentall, Simmons, Murray, & Howard, 2003; Seidel et al., 2010; Sperduti, Delaveau, Fossati, & Nadel, 2011). Accordingly, activation of the right AG nicely converges with the idea that actor computation is accomplished along a postero-dorsal processing stream, and recruits neural activation associated with domain general processes. Furthermore, a parametric modulation of actor-prototypicality activated regions, which are related to self-referencing (CMS), memory retrieval (DLPFC) and mirroring action (PCG and IPL). The recruitment of neural networks robustly associated with general cognitive tasks provides additional support for the actor role as a cognitive and neutral attractor category. The recruitment of a fronto-parietal network can further be regarded as a first fragile indicator for the interplay between antero-ventral and postero-dorsal processing streams, which must be investigated more thoroughly in future research.

So far, Alday et al. (2014) compellingly showed how a language-specific weighting of the prominence features case, person, number, definiteness and position could reliably predict N400 modulations during online language comprehension in German, in accordance with the underlying mechanisms proposed within the eADM framework. If the actor-role really is a cognitive and neutral attractor category, the implementation of the actorhood features examined in the present dissertation could provide a more nuanced picture of the interplay between top-down and bottom-up information involved in actor computation during language processing.

Furthermore, a systematic investigation of the herein mentioned actorhood notions should systematically be investigated in other languages in order to attest for the cross-linguistic stability of its effects. After all, if the actor role really is a cognitive and neutral attractor category, fine-grained aspects such as actorhood potential (but also inter-cultural relations) should recruit similar neural resources irrespective of the language under investigation. Despite these shortcomings, which are object to future investigations, the results of the present dissertation show that actor identification during online language processing recruits more basic psychological operations. Thus, suggesting that language processing is nothing special to the brain. Rather, the underlying mechanisms are proposed to follow more basic ones involved in information processing in general. Consequently, the herein presented results provide initial neurophysiologic evidence how the core of human language comprehension, namely, the question of *who is doing what to whom* might be accomplished by the brain.

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Zusammenfassung

Die vorliegende Dissertation untersucht neuronale Korrelate der Identifizierung eines sprachlichen Handlungsverursachers bzw. Hauptverantwortlichen (im Folgenden auch als Actor bezeichnet). Unter Actor im linguistischen Sinne versteht man dabei den Teilnehmer, der als der wahrscheinlichste Verursacher eines sprachlich ausgedrückten Ereignisses angesehen wird. Handlungsverursacher werden während der Sprachverarbeitung besonders gut erkannt, wenn sie bestimmte Prominenzmerkmale besitzen, anhand derer sie sich von einem möglichen zweiten Handlungsteilnehmer unterscheiden lassen. Typische, linguistische Prominenzmerkmale sind beispielsweise Kasusmarkierung und Wortstellung, sowie eher allgemein-kognitive Merkmale wie Belebtheit, Definitheit / Spezifität und Selbst-Referenz. Eine Reihe von sprachübergreifenden Experimentalstudien konnte zeigen, dass eine Abweichung von einem möglichst prototypischen Actor zu Problemen bei der Sprachverarbeitung führt, wenn dieser zum Beispiel nicht durch Nominativ gekennzeichnet ist oder einen unbelebten Gegenstand beschreibt. Effekte, die mit der sprachlichen Verarbeitung eines Actors in Verbindung gebracht werden, sind sprachübergreifend zu finden und demnach sehr stabil. Der starke Einfluss allgemein-kognitiver Prominenzmerkmale lässt vermuten, dass Sprache keinen Sonderstatus in unserem Gehirn innehat. Vielmehr ist davon auszugehen, dass zur Sprachverarbeitung allgemeine neuronale Prozesse herangezogen werden wie etwa Aufmerksamkeit, Gedächtnis oder Entscheidungsfindung. Diese Hypothese, ist wiederum eine wichtige Voraussetzung für die Annahme, dass man die Rolle des Actors während der Sprachverarbeitung mithilfe von Attraktor-Netzwerken modellieren kann. Als Voraussetzung hierfür ist es jedoch wichtig herauszufinden, welche konkreten neuronalen Prozesse bei der Identifikation eines Actors herangezogen werden. Die vorliegende Dissertation hat sich dies zur Aufgabe gemacht und befasst sich dementsprechend mit allgemein-kognitiven Prozessen, die bei der Erkennung des Actors berücksichtig werden und damit die Bedeutung eines Satzes maßgeblich bestimmen.

Die erste Publikation beschreibt wie semantische Informationen auf der Wortebene (erhoben mithilfe eines online Fragebogens und ausgewertet mit einem Strukturgleichungsmodel) das Potential eines Handlungsteilnehmers als Actor bestimmen. Dieses errechnete Potential wurde in der Analyse eines zweiten elektrophysiologischen Experiments genutzt, um dessen Einfluss auf die Actor-Erkennung während der Sprachverarbeitung zu überprüfen. Die Ergebnisse zeigen, dass das Actor-Potential ein wichtiger Prädiktor (bottom-up) für die Actor-Identifizierung darstellt. Im zweiten Manuskript wird beschrieben wie sich zwei typisch menschliche Eigenschaften nämlich die des freien Willens und des Empfindungsvermögens auf die sprachliche Actor-Identifizierung neuronal auswirken. Die Ergebnisse des zugrundeliegenden visuellen Experiments basierend auf funktioneller Magnet-Resonanz-Tomographie (fMRT) zeigen, dass beim direkten Vergleich von Sätzen, die eine willentliche oder eine versehentliche Handlung beschreiben, neuronale Korrelate evoziert werden, die als Substrat zukünftiger, willentlicher Entscheidungen sowie der willentlichen Inhibition einer Handlung gelten. Beim Vergleich von Handlungen mit Empfindungen zeigten sich neuronale Korrelate, die mit der Evaluation selbst-referenzieller und emotionaler Stimuli in Verbindung gebracht werden. Das dritte Manuskript beschreibt den Einfluss sozio-kultureller Effekte (z.B. Diskriminierung oder Bevorzugung durch die Zugehörigkeit zu einer sozialen Gruppe) auf die Sprachverarbeitung bzw. die Bestimmung eines sprachlichen Handlungsverursachers. Dieses auditive fMRT-Experiment zeigt, dass bei der Erkennung eines Actors, neuronale Netzwerke aktiviert werden, die typischerweise mit neuronalen Prozessen zur Selbst-Referenz in Zusammenhang gebracht werden. Darüber hinaus, wurden Netwerke aktiviert, die mit der Fähigkeit, sich in die Gefühlswelt einer anderen Person hineinzuversetzen (in der Fachsprache aus als *Theory of Mind* bezeichnet) assoziiert sind. Alles in Allem zeigen die vorliegenden Ergebnisse aller dieser Dissertation zugrundeliegenden Studien, dass eine strikte, modulare Auffassung neuronaler Sprachverarbeitung (d.h. neuronale Module, die ausschließlich für die Sprachverarbeitung zuständig sind), die vorliegenden Ergebnisse nicht erklären kann. Die Ergebnisse zeigen vielmehr, dass Sprache kein Sonderfall für unser Gehirn ist, sonder deren Verarbeitung allgemeinkognitiven Verarbeitungsmechanismen zu folgen scheint.

Erklärung

Hiermit versichere ich gemäß Paragraph 9 Absatz 2c der Prüfungsordnung vom 10. Dezember 2008 des Fachbereichs 09, Germanistik und Kunstwissenschaften der Philipps-Universität Marburg, dass ich bisher an keiner anderen in- oder ausländischen Hochschule den Versuch einer Promotion unternommen habe.

Ort, Datum: Unterschrift:

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Eidesstattliche Versicherung

Hiermit versichere ich, dass ich die vorgelegte Dissertation mit dem Titel

How actors become attractors: A neurocognitive investigation of linguistic actorhood

selbst und ohne fremde Hilfe verfasst, keine andere als die in ihr angegebenen Quellen oder Hilfsmittel benutzt (einschließlich des World Wide Web und anderen elektronischen Text- und Datensammlungen), alle vollständig oder sinngemäß übernommene Zitate als solche gekennzeichnet sowie die Dissertation in der vorliegenden oder einer ähnlichen Form noch keiner anderen in- oder ausländischen Hochschule anlässlich eines Promotionsgesuches oder zu anderen Prüfungszwecken eingereicht habe.

Ort, Datum: Unterschrift:

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Curriculum Vitae

Ausbildung

Promotion	Fachbereich 09 Germanistik und Kunstwissenschaften, Institut für Germanistische Sprachwissenschaft, Arbeitsgruppe Neurolinguistik, Philipps-Universität, Marburg, Deutschland	seit 04/2009
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Publikationen

Frenzel, S., Nagels, A., Dröge, A., Schlesewsk, M., Kircher, T., Wiese, R., & Bornkessel-Schlesewsky, I. (in preparation). The right angular gyrus as an Interface between social categorization and actor identification during online language comprehension. Cortex.

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