Spatial demonstratives in brain and behavior

PhD dissertation

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Manuscripts

- Article 1.** Rocca, R., Coventry, K. R., Tylén, K., Staib, M., Lund, T. E., & Wallentin, M. (2019). Language beyond the language system: dorsal visuospatial pathways support processing of demonstratives and spatial language during naturalistic fast fMRI. *BioRxiv*, <https://doi.org/10.1101/651257>
- Article 2.** Rocca, R., Tylén, K., & Wallentin, M. (2019). This shoe, that tiger: Semantic properties reflecting manual affordances of the referent modulate demonstrative use. *PLOS ONE*, *14*(1), e0210333.
- Article 3.** Rocca, R., Wallentin, M., Vesper, C., & Tylén, K. (2019, May 27). This is for you: social modulations of proximal vs. distal space in collaborative interactions. <https://doi.org/10.31234/osf.io/tazhr>

English summary

The vast majority of everyday social practices involves a form of joint interaction with the environment which relies on establishing a shared attentional focus (Tomasello, Carpenter, Call, Behne, & Moll, 2005).

Languages mediate humans' ability to coordinate attention via a specific class of words: spatial demonstratives. Words like the pronouns “this” or “that”, or the adverbs “here” and “there” are among the few undisputed language universals (Diessel, 1999, 2014). They are developmental (Capirci, Iverson, Pizzuto, & Volterra, 1996) and evolutionary (Diessel, 2006; 2013) cornerstones of language, and they are among the most frequent words in the lexicon (Leech & Rayson, 2014).

Demonstratives are *deictic* expressions (from Ancient Greek *deixis*, “demonstration, indication”). They can in principle be used to indicate *any* object, and their meaning depends on the context of utterance (H. H. Clark & Bangerter, 2004; Diessel, 1999; S. C. Levinson, 1983a, 2004). Identifying their referent thus hinges on the availability of information on the perceptual context (which objects are perceptually available), multimodal cues (pointing gestures, gaze; Clark & Bangerter, 2004; Cooperrider, 2016; García, Ehlers, & Tylén, 2017; Stevens & Zhang, 2013), expectations (which objects are relevant for the present interaction; what the speaker may *intend* to refer to; Clark, 1996; Levinson, 1983) and cues provided by the use of specific demonstrative forms (e.g. a proximal “this” vs. a distal “that”). Yet, in spite of their semantically underspecified nature, these expressions function as powerful and effective coordination devices for social interaction.

But what are the neural and cognitive mechanisms that enable the integration of linguistic, perceptual and pragmatic information required for the comprehension of demonstratives? Which cues on the intended referent does the use of proximal *versus* distal demonstrative forms actually provide? And finally, how can demonstratives function as effective tools for social interaction, in spite of their semantic vagueness? In the present thesis, I report three studies where these questions were addressed

using novel experimental paradigms.

In Article 1, we investigated the neural underpinnings of spatial demonstratives using fMRI. This experiment relies on the combination of naturalistic stimuli (listening to a dialogue) with a fast multiband acquisition protocol (TR = 388ms) and FIR modelling of the hemodynamic response (Henson & Friston, 2007), which enabled us to look at how the brain processes spatial demonstratives within a rich linguistic context simulating real-life language use (Hamilton & Huth, 2018; Hasson, Eger, & Willems, 2018). We found that demonstratives engaged a largely bilateral brain network involving integration areas (AG and SMG), visuospatial processing areas (precuneus) and attentional-orienting circuits (MFG and FEF), results which are in line with previous literature on spatial language (H. Damasio et al., 2001; Noordzij, Neggers, Ramsey, & Postma, 2008; Wallentin, Kristensen, Olsen, & Nielsen, 2011; Wallentin, Roepstorff, & Burgess, 2008; Wallentin, Roepstorff, Glover, & Burgess, 2006; Wallentin, Weed, Østergaard, Mouridsen, & Roepstorff, 2008). Additionally, we provided evidence that the dorsal (“where”) visuospatial stream is generally involved in processing spatial language. These findings suggest that processing spatial demonstratives – which hinges upon the integration of linguistic, perceptual and pragmatic context – relies on a distributed network of *extralinguistic* areas. Involvement of such non-segregated architecture is likely not unique to spatial demonstratives, since a certain degree of context-dependence characterizes all linguistic expressions.

Integration of linguistic and contextual information is crucial for the comprehension of spatial demonstratives, but it is not the only resource to which the addressee can resort in order to identify the referent of a demonstrative expression. The use of specific demonstrative forms (a proximal “this” rather than a distal “that”) also provides information on the intended referent (Bonfiglioli, Finocchiaro, Gesierich, Rositani, & Vescovi, 2009; Coventry, Griffiths, & Hamilton, 2014; Coventry, Valdés, Castillo, & Guijarro-Fuentes, 2008; Gudde, Coventry, & Engelhardt, 2016; Peeters, Hagoort,

& Özyürek, 2015). The vast majority of natural languages has at least a proximal and a distal demonstrative form (Diessel, 1999). A series of experiments relying on the *memory game* paradigm has shown that the proximal/distal distinction maps onto the functional division of personal space into a peri- and an extra-personal region (Coventry et al., 2014, 2008; Gudde et al., 2016). Other studies have underlined that the relative distance of competing referents from the speaker (Bonfiglioli et al., 2009; Kemmerer, 1999, 2006) and the location of referents relative to the conversational dyad (Peeters et al., 2015; Peeters & Özyürek, 2016) play a role in demonstrative choice.

In Article 2, we addressed the question of which information is encoded in the contrast between proximal and distal demonstrative forms using a novel experimental paradigm, the Demonstrative Choice Task (DCT). In the DCT, participants are presented with nouns referring to objects, without any further spatial or linguistic context. Participants are simply asked to pair each word with either a proximal or a distal demonstrative. Using the DCT, we tested whether size, harmfulness and animacy, three semantic properties which determine the extent to which an object is manipulable, influence which demonstrative form is used to refer to it. We found that these dimensions do influence demonstrative choices, and that object manipulability is most likely the latent, shared dimension explaining these effects. This suggests that the proximal/distal contrast might lexicalize a functional distinction between high- and low-affordance objects that encompasses both space and semantics. The results were consistent across two experiments and three languages (English, Danish and Italian) with a dyadic demonstrative system. In this dissertation, I also present preliminary results from a large-scale (N = 2200) DCT follow-up experiment, where we explored the influence of 65 semantic dimensions (Binder et al., 2016) on demonstrative choice with the aim of providing a more comprehensive characterization of the relationship between semantics and demonstrative use. Crucially, as explained in the General Discussion, the potential of the DCT method goes beyond research on demonstratives. The DCT offers a simple and reliable linguistic proxy into the

relationship between semantics and other central aspect of human cognition and personality.

In Article 3, we investigated whether speakers always denote objects as proximal or distal from an egocentric perspective, or they rather adapt their use of demonstratives to the *addressee*'s perspective. In social interactions, the proximity and manipulability of objects are viewpoint-dependent. Objects can be close to one person but far from another, and therefore easier to reach for the former than for the latter. Over two studies, we observed that speakers tend to shift from encoding proximity from their *own* perspective to encoding proximity from the *addressee*'s perspective when they engage in a collaborative interaction. Arguably, this strategy is advantageous for a successful unfolding of the interaction. Providing cues to object location in a representational format that fits the partner's sensorimotor representations might facilitate her task of identifying the referent thereby smoothing action execution.

Taken together, the results of the three studies provide novel insights on the neural and cognitive underpinnings of demonstratives, as well as their key function in social interaction. However, their scope goes beyond an understanding of demonstratives *per se*. First, the highly deictic nature of spatial demonstratives is prototypical of the context-dependent nature of most linguistic expressions. Knowledge on the neural substrates of spatial demonstratives is therefore informative with respect to the bigger question of how the brain extracts meaning from linguistic input. Secondly, our findings on spatial demonstratives provide general insights on the relationship between language processing and extralinguistic cognition, highlighting its tight link to perception and attention (Article 1), to functional, action-oriented representations of the physical world (Article 2), and the role of partner-oriented adaptations of language use in successful social coordination (Article 3). Finally, this dissertation contributes to the development of new experimental methods for further research using demonstratives as a searchlight into core aspects of human cognition, and it outlines concrete suggestions in this direction.

Dansk resumé

De fleste sociale omgangsformer indebærer en form for fælles interaktion med objekter i omverdenen der bygger på et delt opmærksomhedsfokus (Tomasello, Carpenter, Call, Behne, & Moll, 2005).

Her spiller sprog spiller en nøglerolle. Ved brug af rumlige demonstrative pronomener (herefter kaldet demonstrativer) kan sproget udnyttes til at rette andres opmærksomhed mod bestemte objekter. Rumlige demonstrativer (dvs. ord som "her" og "der" på dansk, eller "this" og "that" på engelsk) er centrale i alle sprog. Demonstrativer er blandt de få ubestridte sproglige universaler (Diessel, 1999, 2014). De spiller en vigtig rolle i sprogudvikling (Capirci et al., 1996), er en hjørnesten i sprog evolution (Diessel, 2006; 2013), og er nogle af de hyppigst brugte ord (Leech & Rayson, 2014). Udtryk som "this" eller "that" kan i princippet bruges til at betegne en hvilken som helst genstand. Hvad et demonstrativt udtryk egentlig udpeger er helt afhængig af kontekst og kan kun forstås ved integration af information fra den perceptuelle kontekst (hvilke objekter er perceptuelt tilgængelige), multimodale signaler (pegende gestus, blik; H. H. Clark & Bangerter, 2004; Cooperrider, 2016; García, Ehlers, & Tylén, 2017; Stevens & Zhang, 2013), forventninger (hvilke objekter er relevante for opgaven; hvilke objekter kunne taleren ville udpege; H. H. Clark, 1996; S. C. Levinson, 1983) og yderligere information om referenten som formidles af taleren ved brug af en bestemt demonstrativ form (f.eks. den proksimale "this" frem for den distale "that"). Af denne grund kaldes disse udtryk også *deiktiske* (fra Oldgræsk *deiksis*, "demonstration"; H. H. Clark & Bangerter, 2004; Diessel, 1999; Levinson, 1983, 2004).

Men hvad er de neurale og kognitive mekanismer som gør det muligt at integrere sproglig, perceptuel og pragmatisk information i forståelsen af hvad et demonstrativt udtryk betegner i en bestemt kontekst? Hvilken slags information er indkodet i kontrasten mellem *proksimale* ("this") og *distale* ("that") demonstrativer? Og hvordan kan demonstrativer fungere som effektive hjælpemidler i sociale interaktioner, trods deres semantiske vaghed? Denne afhandling gennemgår tre undersøgelser, hvor

vi sigtede mod at svare på disse spørgsmål ved hjælp af nye eksperimentelle paradigmer.

I Artikel 1 undersøgte vi det neurale grundlag for forståelse af rumlige demonstrativer ved hjælp af funktionel magnetisk resonanstomografi (fMRI). I dette eksperiment kombinerede vi ”*naturalistiske*” stimuli med en metode til hurtig og simultan opsamling af fMRI-data (TR = 388ms) og FIR modellering af den hæmodynamiske respons (R. Henson & Friston, 2007), som gjorde det muligt at undersøge hvordan hjernen responderer til rumlige demonstrativer i en kompleks sproglig kontekst som minder om daglig sprogbrug (Hamilton & Huth, 2018; Hasson et al., 2018). Vi fandt at demonstrativer rekrutterer en netværk af hjerneområder som inkluderer supramodale integrationsområder (AG og SMG), såvel som områder involveret i rumlig repræsentation (precuneus) og opmærksomhed (MFG og FEF) i både den venstre og højre hjernehalvdel. Disse fund er forenelige med resultater fra tidligere undersøgelser af det neurale grundlag for rumligt sprog (H. Damasio et al., 2001; Noordzij et al., 2008; Wallentin et al., 2011; Wallentin, Roepstorff, et al., 2008; Wallentin et al., 2006; Wallentin, Weed, et al., 2008). Desuden fandt vi at den bredt definerede ”dorsale, visuospatiale informationsstrøm” (eller ”hvor”-strømmen) generelt var involveret i bearbejdning af rumligt sprog. Disse fund indikerer at bearbejdning af rumlige demonstrativer – en proces som kræver integration af sproglig, perceptuel og pragmatisk kontekst – er afhængig af et *distributeret* netværk af ikke-sproglige områder. Rekruttering af en sådan overlappende arkitektur sker sandsynligvis ikke kun i bearbejdning af rumlige demonstrativer, da betydningen af størstedelen af sproglige udtryk til en vis grad er afhængig af konteksten hvori de bliver brugt.

Integrationen af perceptuel, pragmatisk og sproglig information er grundlæggende for at forstå rumlige demonstrativer, men det er ikke den eneste ressource der kan udnyttes til at identificere referenten af et deiktisk udtryk. Brugen af en bestemt demonstrativ form (f.eks. en proksimale ”this” hellere end en distale ”that”) siger noget om hvilket objekt taleren henviser til (Bonfiglioli et al., 2009; Coventry et al., 2014, 2008; Gudde et al., 2016; Peeters et al., 2015). De fleste sprog har faktisk

mindst to demonstrativer, som svarer til de proksimale "this/here" og de distale "that/there" på engelsk (Diessel, 1999). En række eksperimenter udført med det såkaldte "memory game" har fundet at kontrasten mellem proksimale og distale demonstrativer svarer til den funktionelle opdeling af talerens rum i et "peripersonalt" og et "ekstrapersonalt" område (inden for eller uden for personens rækkevidde). Imidlertid understreger andre undersøgelser at både relativafstanden mellem forskellige mulige referenter og taleren og deres position i forhold til begge samtalepartnerne også spiller en rolle i valget af et demonstrativ frem for et andet.

I Artikel 2 undersøgte vi hvilken information der formidles ved brug af kontrasten mellem proksimale og distale demonstrativer med et nyt eksperimentalt paradigme: "The Demonstrative Choice Task" (DCT). I DCT præsenteres deltagere for ord som betegner konkrete objekter, uden yderligere rumlig eller sproglig kontekst. Deltagernes opgave er simpelthen at koble ordet med enten et proksimalt eller et distalt demonstrativ. Med DCT undersøgte vi om tre bestemte semantiske egenskaber ved objekter (størrelse, farlighed, og *animacy* som afgør i hvilket omfang et bestemt objekt kan håndteres), påvirker hvilket demonstrativ det kobles med. Som forventet viste resultaterne at disse semantiske dimensioner spiller en vigtig rolle, og at de gør det fordi de alle påvirker objekters *manual affordances* (manuelle anvendelsesmuligheder). Resultaterne var forenelige på tværs af to eksperimenter og tre sprog (engelsk, dansk, og italiensk). I afhandlingen beskrives også præliminære resultater fra et efterfølgende eksperiment (N = 2200), hvor vi udforskede hvordan 65 andre semantiske dimensioner påvirker valget af proksimale vs. distale demonstrativer med det formål at give et mere omfattende overblik over forholdet mellem semantik og demonstrativer. Som det diskuteres i afhandlingen (General Discussion), er DCT-metodens potentiale ikke begrænset til forskning i demonstrativer. DCT kan formodentlig også bruges som en simpel metode til at undersøge interaktionen mellem semantik og andre centrale aspekter af menneskelig kognition og personlighed.

I Artikel 3 undersøgte vi om sprogbrugere altid betegner referenter som proksimale eller distale fra

et egocentrisk perspektiv, eller om de i nogle tilfælde tilpasser deres brug af demonstrativer til lytterens perspektiv. I sociale interaktioner kan et bestemt objekts *affordances* være forskellige for forskellige individer. Objekter kan være tæt på én person, men langt fra en anden, og derfor nemmere at nå for den ene end for den anden. Vi fandt, at i kontekster der kræver samarbejde mellem samtalepartnere, skifter taleren fra et egocentrisk til et allocentrisk perspektiv, så brugen af proksimale og distale demonstrativer angiver afstanden mellem referenten og lytteren, i stedet for afstanden til taleren. Sandsynligvis er denne strategi fordelagtig for udførelsen af opgaven. At referentens position formidles fra lytterens perspektiv gør det nemmere for hende at finde referenten og udføre sin del af opgaven.

Sammenlagt giver resultaterne af de tre undersøgelser nye indsigter i det neurale og kognitive grundlag for forståelse og brug af demonstrativer og deres nøglerolle i social interaktion. Men betydningen af resultaterne rækker ud over forståelsen af demonstrativer.

For det første er demonstrativers deiktiske profil et eksempel på en form for kontekst-afhængighed som gennemsyrrer alle sproglige udtryk. Undersøgelser af det neurale grundlag for rumlige demonstrativer er derfor oplysende med hensyn til det større spørgsmål om hvordan hjernen skaber mening ud af sprog.

For det andet giver vores fund om rumlige demonstrativer generel indsigt i sprogets rolle i menneskelig kognition, bl.a. dets forbindelse til perception og opmærksomhed (Artikel 1), med funktionelle repræsentationer af rum og objekter (Artikel 2), og om den rolle som lytter-orienterede tilpasninger af sprogbrug spiller i sociale interaktioner (Artikel 3).

Afhandlingen bidrager også til udvikling af nye eksperimentale metoder som kan bruges til yderligere forskning i både demonstrativer og andre centrale aspekter af menneskelig kognition, og den fremlægger konkrete forslag hertil.

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Abbreviations

AAL: automated anatomical labelling

AG: angular gyrus

ANOVA: analysis of variance

AUC: area under the curve

BOLD: blood oxygenation level dependent

DCT: demonstrative choice task

EPI: echo-planar imaging

EEG: electro-encephalography

ERP: event-related potentials

FEF: frontal eye field(s)

FIR: finite impulse response

fMRI: functional magnetic resonance imaging

GLM: general linear model

HRF: hemodynamic response function

LASSO: least absolute shrinkage and selection operator

MFG: middle frontal gyrus

ROI: region of interest

SMG: supramarginal gyrus

SFT: sensory-functional theories

SVR: support vector regression

TR: time to repetition

TE: time to echo

0. Introduction

0.1 Preliminary remarks

The unfolding of many everyday practices – from running errands, to playing games, giving directions, or taking part in a celebration – involves a form of joint interaction with the environment which rests upon humans’ ability to coordinate attention and mutually adapt their behavior (Tomasello et al., 2005).

The ability to align attention on relevant objects during social interaction is mediated by the availability of a class of linguistic expressions called *spatial demonstratives* (or *deictics*). Spatial demonstratives are words like *this* and *that*, or *here* and *there*, which are used in combination with pointing gestures so to function as ostensive devices (Bühler, 1934; Cooperrider, 2016; Diessel, 1999; Levinson, 1983).

Demonstratives are not the only linguistic tools that can be used to direct attention towards relevant objects or locations. In particular contexts, the expressions “*this* needs water” and “the carnivorous plant in the corner needs water” would yield the same result, a shift of the addressee’s attention towards the plant, and possibly an encouragement to take action. However, there is a fundamental difference in the way nouns and demonstratives manipulate the addressee’s attentional spotlight. Expanding on the light metaphor, the former expression operates like a floor lamp: it singles out a *specific* object in the environment that match a well-defined semantic profile. Demonstratives function as a flashlight: they are extremely “portable” and flexible devices, that can be used to draw attention to *any* object. However, what they shed light upon is contingent on the position and orientation of whoever is using them.

Speaking out of metaphor, expressions like “this one” do not convey any specific information on the intended referent. What they denote changes on a case-by-case basis, according to the context in which they are uttered. Their communicative power lies not in their semantic content, but in their

ostensive, attention-grabbing function. It is precisely their function as devices for joint attention management which makes them foundational to humans' ability to do things together.

But what are the cognitive and neural mechanisms that support this interaction between language, perception and attention characterizing demonstrative reference? Which cognitive processes enable the addressee to pick out the correct referent, in the absence of any explicit semantic specification? And how does the use of demonstratives concretely facilitate social interactions? As I will show in this dissertation, answering these questions is not only central for an appreciation of the cognitive significance of demonstratives. It is also more generally instrumental to a deeper understanding of the place of language in human cognition and social behavior.

In this thesis, I address these questions over three articles reporting a series of neuroimaging and behavioral experiments. In the first article, we investigated the neural underpinnings of spatial demonstratives using fMRI. We found that the interaction between demonstratives and extralinguistic cognition underlying demonstrative use is mediated by direct recruitment of visuospatial and higher-order integration areas. In the second article, we addressed the question of which information is encoded in the contrast between proximal and distal demonstratives. Here, we showed that the proximal/distal contrast lexicalizes a functional distinction between low- and high-affordance referents, a result which hints at a tight link between demonstrative use and action. In the third article, we zoomed in on demonstrative use in social interaction. Over two studies, we showed that, in joint action contexts, speakers shift from signaling proximity from their *own* perspective, to encoding proximity from the *addressee's* perspective, a strategy that might facilitate swift action execution.

These results provide novel insights on the neurocognitive underpinnings of demonstratives and their significance for social interaction. However, their scope goes beyond that. The deictic nature of spatial demonstratives is in fact prototypical of the context-dependent nature of most linguistic expressions. Knowledge on the neurocognitive foundations of demonstrative use is thus informative

with respect to the fundamental question of how the brain extracts meaning from linguistic input. Furthermore, our findings tap into more general aspects of the relationship between language and extralinguistic cognition, highlighting its strong ties to perception, attention, and functional representations of the physical world, as well as the key role of flexible adaptations of language use for successful social coordination. These studies thus provide concrete examples of how demonstratives function as a searchlight into core organizational and functional principles of human cognition, and outline concrete suggestions for further work in this direction.

0.2 Structure

The present dissertation is organized as follows.

Section 1 outlines the background for the three studies, providing an overview of existing research on spatial demonstratives and motivating the core research questions guiding the present work.

Sections 2, 3 and 4 describe the three studies, with a focus on the methodologies and the main results.

Section 5 discusses the main implications of the findings, and it highlights outstanding questions and perspectives for future work.

Finally, Section 6 provides a concise summary of the results and overall conclusions.

The full manuscripts of the three articles are appended to the present thesis. All of them are also publicly available on open access journals or preprint servers.

Article 1 is available as a preprint on BioRxiv (<https://doi.org/10.1101/651257>). Code, materials and behavioral data are available on OSF (<https://osf.io/j9fm5/>). This manuscript has been submitted for publication and it is currently in review.

Article 2 is published on PlosOne (<https://doi.org/10.1371/journal.pone.0210333>). Data, code, and materials are publicly available on OSF (<https://osf.io/gnh5s/>).

Article 3 is available as a preprint on PsyRxiv (<https://doi.org/10.31234/osf.io/tazhr>). Data, code and

materials are publicly available on OSF (<https://osf.io/qjxg9/>). The manuscript has been submitted for publication and it is currently in review.

1. Background

1.1 A cornerstone of language

The centrality of demonstratives for natural languages has been repeatedly highlighted across several research domains. Regardless of whether one looks at language in evolutionary, developmental, cross-linguistic, or purely distributional terms, demonstratives stand out as foundational.

To begin with, spatial demonstratives are among the very few truly universal features of languages. Universality in language is among the topics that have been most hotly debated in the literature (Evans & Levinson, 2009; Greenberg, 2010). Still, it is undisputed that all languages are endowed with demonstrative expressions (Diessel, 1999; 2014), although the number of distinct demonstrative forms and the type of information they encode varies cross-linguistically (Levinson et al., 2018).

Secondly, demonstratives are very ancient from an evolutionary perspective. Contrary to all other *function* words, with which they share core semantic characteristics, their roots cannot be traced back to any content word. On the other hand, it is known that many grammatical markers for discourse organization have arisen via grammaticalization of demonstrative forms (Diessel, 2006; 2013).

Furthermore, acquisition of demonstratives is one of the first milestones in development (Diessel, 1999). *That* is the most frequent word in the speech of 1- to 2-year-old children from the CHILDES corpus (Diessel, 2006). Crucially, the acquisition of spatial demonstratives bootstraps further stages of language acquisition (Capirci et al., 1996), although full mastery of the contrast between different demonstrative forms is only achieved during pre-school years (Clark & Sengul, 1978; Küntay & Özyürek, 2006; Küntay & Özyürek, 2002).

Demonstratives remain pervasive in language use well beyond acquisition. *This* and *that* are in fact among the most frequent words in adults' lexicon (Leech & Rayson, 2014), especially in spoken contexts. Both demonstrative pronouns are more frequent in spoken than in written language, although relative frequency between the two modalities differs across the two forms. *That* is 5.5 times

more frequent in spoken than in written language, and *this* is 1.2 times more frequent (Leech & Rayson, 2014).

The prominence of spatial demonstratives in evolution, development, and adults' language use is arguably a reflection of their pivotal function in social interaction. Used to align interlocutors' attention on relevant objects in the environment (Diessel, 1999), demonstratives create the conditions for a range of social practices, spanning from simple conversations to complex cultural rituals (Tomasello et al., 2005).

1.2 Demonstrative reference as a *deictic* process

As mentioned in the introduction, demonstratives are not the only linguistic tools that can be used to orient attention towards specific items in the environment. In certain contexts, a semantically explicit utterance like “I would like to have a scoop of dark chocolate” and a demonstrative expression such as “*This* one!” would be equally suitable for the purpose of directing the attention of the addressee (here, the ice cream shop assistant) towards a certain object (the flavor of your choice), triggering the desired sequence of actions.

There is, however, a fundamental difference in the semantic characteristics of these expressions. In the case of the sentence “I would like to have a scoop of dark chocolate”, the addressee needs little extralinguistic information to pick out the right referent. Contrarily, the demonstrative utterance “this one” is *per se* opaque. Understanding what the speaker means hinges on the processing of multimodal cues (what you are pointing to and gazing at; see Clark & Bangerter, 2004; Cooperrider, 2016; García, Ehlers, & Tylén, 2017; Stevens & Zhang, 2013), pragmatic and social knowledge (what you might want the shop assistant to do, given the specific buying frame; see Levinson, 1983) and common ground (Clark, 1996), which are all specific to the context of utterance.

The radically context-dependent, or *deictic* (from Ancient Greek *deixis*, “demonstration, indication”)

nature of spatial demonstratives carries important implications with respect to the cognitive processes and neural infrastructure involved in their comprehension. If identifying their meaning relies on contextual information, then the comprehension of these expressions is likely mediated by extralinguistic perceptual and cognitive processes. This leads to the hypothesis that, at the neural level, processing of spatial demonstratives relies on a distributed set of areas that are not specific to linguistic computations.

Critically, reliance on context for comprehension is far from unique to spatial demonstratives. Perceptual and pragmatic information plays a key role in understanding the vast majority of linguistic expressions. Irony, metaphors, and polysemous words, are the most obvious examples. But even seemingly transparent sentences such as “I would like to have a scoop of dark chocolate” require context. A surface understanding of the utterance can be gathered from the sentence itself. But comprehension of its pragmatic implications – that is, that the speaker is not just expressing a desire for chocolate, but for chocolate ice cream, and meanwhile also instructing the addressee to *do* something – is contingent on awareness of what a shop assistant is expected to do in a buying frame. The question of the cognitive and neural correlates of demonstrative reference, addressed in Article 1, is therefore not only a question about demonstrative reference itself. All language use is – at least in part – deictic. In this respect, demonstratives are paradigmatic of a wider range of processes characterizing language comprehension at large.

1.3 Lexical contrasts and their function

Due to the deictic nature of demonstrative expressions, contextual information is heavily involved in their comprehension. Yet, reference resolution is not entirely dependent on the addressee’s educated guess. The use of specific demonstrative forms (for example, *this* instead of *that* in English) conveys important cues that guide the addressee in his/her search for the intended referent.

Demonstrative systems in the overwhelming majority of languages have multiple distinct forms (Diessel, 1999). Figure 1 provides an overview of the number of demonstrative contrasts in 178 languages forming a geographically and genetically representative sample (Breunese, 2019). Languages with only *one* demonstrative are very rare (only two languages in the sample). Languages with more than three exist, but they are also infrequent. In most systems, speakers have a choice between two or three distinct forms. Specific demonstrative forms can fall out of use (such as in the case of the English *yonder*), but the distinction between a *proximal* (*this/here* in English) and a *distal* (*that/there*) form tends to be ultimately retained.

Figure 1. Number of demonstrative contrasts over a geographically and genetically representative sample of 178 languages. Only two languages in the sample have one demonstrative form. Languages with more than 3 are also infrequent. The majority of languages in the sample has either two or three demonstrative forms.

But *which* cues does the use of a proximal vs. a distal demonstrative actually convey? And *how* do these cues help the addressee pick out the intended referent?

The question of what type of information is encoded in demonstrative contrasts has been a central one in the literature on spatial demonstratives (Coventry et al., 2014, 2008; Gudde et al., 2016; Peeters et al., 2015; Peeters & Özyürek, 2016). A large portion of the literature has supported an *egocentric* and *distance-based* view on the proximal/distal distinction. These accounts maintain that speakers choose proximal *versus* distal demonstrative forms based on the distance of the referent from themselves. The so-called *deictic center*, i.e. the anchoring point or *origo* of the reference frame against which distance is evaluated (Levinson, 2004; Lyons, 1977), coincides with the speaker's body.

However, the claim that it is *distance* that drives speakers' choices for proximal or distal forms is not unproblematic. How is this continuous metric converted into a discrete coding of spatial locations as either *near* or *far*? Where is the line between *near* and *far* space to be drawn?

In a series of experimental studies, Coventry and colleagues investigated this question using the *memory game* paradigm (Coventry et al., 2014, 2008; Gudde et al., 2016). In their experiments, participants were presented with objects placed at varying distances along a table (see Figure 2). At every trial, a disc depicting a shape was placed at one of 12 potential locations (marked by colored dots), then removed after a short memory encoding phase. After a (variable) number of trials, participants were presented with one of shapes and asked to indicate at which location it had previously been placed. Participants had to indicate the correct location by pointing at it while producing phrases consisting of a demonstrative, an adjective and a noun (e.g. "this yellow dot"). Although demonstrative production was the only behavior of interest, framing the task as a memory test was meant to ensure that participants remained naïve to the purpose of the experiment, and therefore produced spontaneous lexical choices.

Figure 2. Illustration of the setup for the *memory game* experiment (from Coventry et al., 2008). Participants sat by the shorter edge of a table. At every trial, an object was placed at one of the 12 possible locations (denoted by dots), then removed after a short memory encoding phase. Participants were asked to keep in mind the location of each object. After a number of trials, they were presented with one of the objects and asked to indicate at which location it had previously been placed. Participants were instructed to indicate the location by pointing at it and producing a phrase consisting of a demonstrative, a color adjective, and a noun (e.g. “that red dot”).

Using this paradigm, Coventry and colleagues showed that the contrast between proximal and distal demonstratives maps onto the distinction between *peripersonal* and *extrapersonal* space. Referents placed *within* reach were in fact more likely to be indicated using proximal demonstratives, while objects *outside* reach were more likely to elicit distal demonstratives. Additionally, demonstrative use was systematically influenced by some of the same parameters modulating peripersonal space (e.g. tool use), as well as by object familiarity and visibility (Gudde et al., 2016). These results suggest that the use of proximal vs. distal demonstrative forms relies a dichotomous *functional* representation of distance, rather than a continuous metric one.

Demonstratives, however, are often used in settings where multiple referents are present at the same time. In these contexts, the contrast between proximal and distal demonstratives can be used to differentiate between two objects placed at millimeters distance from each other (such as in “This speck is smaller than that speck”), just as well as between referents placed at definitely more substantial distance (“This planet is smaller than that planet”; see Talmy, 1983). On the basis of this,

Kemmerer (1999, 2006) has argued that the contrast between proximal and distal forms codes for a *relativistic* semantic distinction in remoteness (rather than an absolute one), that can be implemented in a pragmatically flexible way so to code for spatial distinctions at any scale.

The relativistic nature of the proximal/distal distinction has also been addressed in experimental work. Bonfiglioli and colleagues (Bonfiglioli et al., 2009) investigated whether demonstrative contrasts code for relative distance of two referents from the speaker even when both referents are located within peripersonal space. In the experiment, participants were primed with either a proximal or a distal demonstrative, then asked to perform reach movements towards objects located at either of two possible distances within their peripersonal space. Semantic interference effects on movement initiation were detected, which supported the initial hypothesis. Participants were *slower* in performing reach movements when the demonstrative prime and the location of the object were incongruent, that is when they were primed with distal forms before reaching for the closer target location, and when primed with proximal forms before reaching for the farther location.

1.4 Demonstratives, action and semantics

These results constrain the validity of the idea of an absolute mapping between the proximal/distal distinction and the peri-/extrapersonal dichotomy to specific contexts. Nonetheless, the memory game studies raise an interesting point which is central to the studies reviewed in this work. Results from Coventry and colleagues namely suggest that demonstrative use might be grounded on spatial encoding strategies, based not on purely *perceptual* representations of objects, but chiefly on *functional*, sensorimotor ones (di Pellegrino & Làdavas, 2015; Làdavas, 2002).

Yet, these studies have only gone so far as to claim that functional representations of object *location* are reflected in demonstrative use, regarding non-spatial properties as largely irrelevant. Space is, however, not the only dimension affecting the functional profile of objects. Their semantic features

also play a major role in determining the extent to which objects are graspable or manipulable. Relevant functional features are, for example, perceptual attributes such as size: smaller objects are generally easier to manipulate, while bigger objects are more difficult to manipulate. But objects also differ in the degree to which manual interaction is *desirable*. Harmless objects lend themselves to interaction more than harmful objects. Harmfulness has also been shown to directly affect non-linguistic spatial representations. The presence of a dangerous object can in fact shrink peripersonal space boundaries, and alter perceptual judgements of reachability (Bufacchi, Liang, Griffin, & Iannetti, 2015; Graziano & Cooke, 2006; Valdés-Conroy, Román, Hinojosa, & Shorkey, 2012).

Animacy is another key semantic parameter shaping the functional profile of objects. The distinction between animate and inanimate entities has played a prominent role in the debate on human semantic memory. Double dissociations in performance for naming and comprehension tasks involving animate and inanimate objects have been observed in neuropsychological studies, and the origin of such dissociations has been widely debated (Hart, Berndt, & Caramazza, 1985; Hillis & Caramazza, 1991). In *domain-specific* interpretations, such dissociations have been explained in terms of an evolved modular organization of semantic memory into domain-specific systems supported by separate neural substrates (Caramazza & Shelton, 1998). On the other hand, *sensory-functional theories* (SFT) have explained such dissociations in terms of differences in the relative importance of *functional* and *sensory* attributes for mental representations of animate and inanimate entities (Allport, 1985; Farah & McClelland, 1991; Martin & Chao, 2001; Warrington & McCarthy, 1987; Warrington & Shallice, 1984). More concretely, *sensory* features, but not *functional* features, are thought to be central to representing animate objects and differentiating between instances of this category. To tell apart a lynx from a tiger it is likely not relevant to consider what one could *use* them for. On the other hand, their size, their color and the texture of their fur are highly informative for this purpose. In general, animate beings are rather uniform in terms of functional features, while they vary

significantly in sensory characteristics.

Inanimate objects, on the other hand, are thought to be primarily represented by their functional features, i.e. with an emphasis on the amount and type of interaction they afford. Representations of a pencil and a twig might overlap with respect to many sensory characteristics, but they are clearly distinct when it comes to the types of actions they do (or do not) afford. Not only are functional features generally more prominent when representing inanimate object than animate beings. Inanimate entities also vary significantly more in the amount and type of interaction they afford.

Given these considerations, if the proximal/distal contrast reflects a general, functional distinction between high- and low-affordance objects (rather than a purely spatial one), then animals and inanimate objects should elicit systematically different patterns of demonstrative use. More specifically, inanimate referents should elicit more within-category variation in demonstrative choice, as a result of higher prominence of their functional characteristics, and therefore of increased sensitivity to the distinction between low- and high-affordance referents.

These questions and hypotheses are the background of the studies reported in Article 2.

1.5 Social adaptations of demonstrative use

Manual affordances of an object, however, are not fully determined by the combination of its spatial locational and semantic features. In contexts where multiple individuals are co-present and engaging in joint practices, objects can be easier to reach for some individuals compared to others, they can be more or less relevant for the ongoing action, or more or less salient against competing referents. The extent to which an object affords interaction thus *also* depends on the perspective one adopts, as well as on the characteristics of the ongoing action. Linguistic coding of referents as *proximal* or *distal* may therefore change substantially depending on whether the speaker considers object location from his/her own perspective or from the addressee's.

The question then becomes whether and how speakers actually modulate their choice of perspective when using demonstratives in social interaction. Do speakers *always* signal affordances from their own perspective? Do they adapt to the partner's in interactive contexts? Or do they flexibly adapt their reference frame according to what is more advantageous for the specific situation? And if the latter is the case, under which conditions is each encoding strategy then used? These questions are the focus of the experiments reported in Article 3.

The hypothesis that demonstratives do *not* reflect an egocentric encoding of space has previously been put forward in the literature. Based on the results from their EEG/ERPs study, Peeters and colleagues (Peeters et al., 2015) have argued that the proximal/distal contrast maps onto a distinction between referents located within vs. outside the regions of space shared between two interlocutors in an interaction. In their experiment, participants were shown pictures representing a person – the speaker, sitting by the opposite edge of a table – and two referents. In the *sagittal* condition, the referents were located at different distances from the speaker on the sagittal axis, but still both within the region of space shared by the speaker and the addressee. In the *lateral* condition, referents were located at different distances from the speaker on the *lateral* axis, with one object being located outside shared space and the other being located within shared space (see Figure 3).

Figure 3. Experimental design and stimuli from Peeters et al. (2015). At each trial, participants were shown an introductory picture, then a target picture in which the speaker pointed at one of the referents (*proximal* or *distal*). The top row displays pictures where distance between referents was manipulated on the sagittal axis. The bottom row displays pictures where referents are oriented laterally. The position of the participant, who is the addressee (A) of the utterance, is marked below the images.

Participants were first shown an introductory picture displaying either the *sagittal* or the *lateral* scenario. Then, they were shown a second picture (same scenario) where the speaker was pointing at one of the two referents. The picture on screen was paired with an auditory stimulus consisting of a proximal or a distal demonstrative form.

Using this paradigm, Peeters and colleagues (2015) found N400 effects when *distal* demonstratives were paired with pictures where the referent of the pointing gesture was located *within* shared space, as well as when *proximal* demonstratives were paired with pictures where the referent of the pointing gesture were located *outside* shared space. No effects of distance were observed. The authors interpreted these results as evidence in favor of a *sociocentric* account of demonstrative use (originally suggested in Hanks, 1990), rather than an *egocentric* one.

Arguments for a social approach to demonstrative reference (Peeters & Özyürek, 2016) have also been provided by fieldwork data. Enfield (2003) analyzed demonstrative production by Lao speakers during natural interactions. Lao is a language with a dyadic demonstrative system. In his work, Enfield showed that distance-marking falls short of explaining patterns of demonstrative use. The contrast between proximal and distal forms seems to encode a wide range of semantic and pragmatic parameters, including object saliency against perceptual and pragmatic common ground, as well as perceptual availability of the referent to the addressee. Demonstratives explicitly encode addressee-oriented perceptual parameters also in Turkish, a three-term system where the use of the demonstrative *şu* is obligatory when the addressee's visual attention is not on the referent (Küntay & Özyürek, 2006).

Questioning purely speaker-centered accounts of spatial deixis, these studies establish a close connection between the social, joint attentional function of demonstrative use, and usage patterns of different demonstrative forms. Nevertheless, *sociocentric* accounts still rely on the assumption that patterns of demonstrative use can be explained on the basis of *one* reference frame, centered on the conversational dyad and roughly invariant across conversational situations.

The studies presented in Article 3 are guided by the alternative hypothesis that reference frames underlying demonstrative use can *vary* as a function of contextual demands. Signaling object affordances from the *addressee's* perspective might facilitate him/her in identifying the intended referent within his/her perceptual space. However, shifting to addressee-centered frames might not be necessary in non-interactive contexts, and it might not be optimal in specific interactive ones (e.g. retelling of events in first-person perspective). A flexible use of encoding strategies might therefore enable the speaker to signal referent location in the format that is most suited to the specific situation. These context-dependent adaptations in demonstrative use would be in line with previously observed partner-oriented adaptations in the use of linguistic (Campisi & Özyürek, 2013; Fusaroli et al., 2012;

Fusaroli & Tylén, 2016; Pickering & Garrod, 2004, 2006; Tylén, Weed, Wallentin, Roepstorff, & Frith, 2010) and non-linguistic behavior (Fusaroli, Bjørndahl, Roepstorff, & Tylén, 2016; Vesper et al., 2017; Vesper, van der Wel, Knoblich, & Sebanz, 2011; Vesper & Richardson, 2014) aimed at optimizing alignment on situation models, comprehension, and performance of joint tasks.

1.6 The present work

The three articles reported in this dissertation address some of the outstanding questions pointed out in this Section.

The first article reports a study investigating the neural correlates of spatial demonstratives using a naturalistic fast fMRI paradigm. The experiment focused on understanding the brain mechanisms supporting the integration between linguistic, perceptual and pragmatic processing necessary for demonstrative comprehension, and involved in language processing at large.

The second article zooms in on the question of which kind of information is encoded in the contrast between proximal and distal demonstrative forms. We investigated whether semantic features of the referent affecting their manual affordances influence demonstrative choice, testing whether the proximal/distal contrast lexicalizes a general functional distinction between low- and high-affordance referents rather than a purely spatial one. Finally, the third article reports two experiments where we investigated whether and how proximal/distal coding of space via demonstratives is modulated by the presence and role of an interlocutor in social interaction. The results of each study are briefly presented in the next section, and extensively reviewed in the overall discussion.

2. Article 1: Neural correlates of demonstratives

2.1 Background

Demonstrative expressions like “this one”, or “over here”, convey little information on the object or location they are meant to denote. Contrary to nouns or descriptions like “the cat”, or “under the tree”, the meaning of these expressions cannot be gathered without the aid of contextual cues. To pick out the intended referent, addressees rely on the combination of visual information (which objects are present and/or visible?), knowledge of the pragmatic context (which objects are relevant for the ongoing interaction?) and higher-level expectations (what might the speaker intend to refer to?). This synergy between language and extralinguistic cognition is crucial for, though not unique to, the comprehension of demonstratives. But which neural substrates support it?

2.2 Naturalistic fMRI

In this study, we addressed this question using naturalistic fMRI. The importance of naturalistic paradigms to secure ecological validity of fMRI results has been increasingly stressed in the literature (Hamilton & Huth, 2018; Hasson et al., 2018). In the case of demonstratives, however, this is not simply an advantageous choice, but rather a constraint set by the very nature of these expressions. The meaning of demonstrative expressions is, as previously mentioned, entirely determined by the context in which they occur. Investigating demonstratives comprehension within single-word or single-sentence contexts would be pointless: these expressions can only be meaningful in rich linguistic and perceptual settings, where the context provides sufficient cues to identify the intended referent.

2.3 Stimuli

We presented 28 participants with a specially crafted 25 minutes dialogue (in Danish) between a male and a female voice. The choice of dialogue is, once again, motivated by an intrinsic feature of demonstrative use. Demonstratives tend to occur with markedly higher frequency in spoken and dialogical settings, in line with their function as devices for joint attention management.

In the dialogue, frequent occurrences of spatial demonstratives were equally distributed across the two voices. Each voice uttered a total of 40 proximal demonstratives and 40 distal demonstratives.

In the story, the two characters meet somewhere in the underground. It is dark, and they have to explore the surroundings to locate each other as well as specific objects. This overall narrative afforded frequent occurrences of spatial expressions.

Since the meaning of demonstrative expressions such as “over here” depends the location of the interlocutors, the two voices were recorded on separate audio channels, so to simulate a three-dimensional auditory environment where each voice is assigned a distinct spatial origin.

The dialogue was recorded using text-to-speech synthesis interfaced via the Python library *pyttsx*. Speech synthesis via *pyttsx* carries significant advantages in terms of both control over acoustic features of the stimulus and ease of stimulus generation. The library provides automated word onset annotations that enabled us to refine the stimulus over repeated pilots without the need for time-consuming manual annotation work.

2.4 Acquisition sequence and response modelling

In this study, we were interested in detecting brain responses to specific words occurring within a speech stimulus with an average rate of more than 2 words per second. This made it necessary to adopt a high frequency sample rate, in order to avoid conflating responses to demonstratives with responses to other linguistic expressions co-occurring with them. Achieving a high sampling rate has

long been problematic in fMRI, where temporal resolution for whole-brain acquisition has been limited to 0.5-1 Hz. These constraints have been recently overcome via the use of parallel imaging techniques such as multiband-EPI or simultaneous multi-slice methods (Setsompop et al., 2012).

To achieve the necessary temporal resolution, we therefore used a fast multiband-EPI acquisition sequence, which enabled us to attain a repetition time (TR) of 388ms. In the analysis, we used FIR basis functions to model response to specific words of interest over 20 intervals of 500ms, i.e. spanning over 10 seconds after the word had occurred. The combination of the fast acquisition sequence with FIR modelling of the response at these intervals made it possible to capture signal changes at word-level resolution.

The use of FIR models to estimate event-related signal changes provides the additional advantage of being free from assumptions on the temporal characteristics of the signal, as opposed to convolution models, which only allow minimal deviations from the time course of the HRF (Figure 4). The importance of flexible modelling approaches has become manifest in the light of results of recent studies, which have detected high-frequency components in the BOLD signal during sustained fast stimulation (Lewis, Setsompop, Rosen, & Polimeni, 2016) and thereby challenged traditional assumptions on the time course of the HRF.

Figure 4. Time course of the canonical hemodynamic response function from (R. Henson & Friston, 2007). Convolution models based on the canonical HRF allow variation in the *amplitude* of the response, but only minimal variability in the *time course* of the response.

2.5 Hypotheses

We hypothesized that processing of demonstratives would recruit integration areas in the parietal lobes, reflecting the need to combine information from the perceptual, linguistic and pragmatic context in order to decode their meaning. More specifically, we expected involvement of the angular gyrus, a higher-order area responsible for complex information integration (Binder, Desai, Graves, & Conant, 2009; Hassabis & Maguire, 2009; Seghier, 2013), and the supramarginal gyrus (SMG), an interface between the auditory cortex and the dorsal stream (Scott & Johnsrude, 2003). The left SMG and AG have been previously implicated in the processing of linguistic phrases describing spatial relations (H. Damasio et al., 2001; Kemmerer, 1999, 2006; Noordzij et al., 2008).

Moreover, we expected activation in medial regions of the superior posterior parietal cortex such as the *precuneus*, involved in retrieving and maintaining spatial representations in both visuospatial and linguistic tasks (Wallentin et al., 2006; Wallentin, Weed, et al., 2008).

Finally, as demonstratives trigger attentional shifts towards the intended referent, we expected demonstratives to modulate activity in frontal regions implicated in attentional orienting, such as the frontal eye fields (Wallentin et al., 2011; Wallentin, Roepstorff, et al., 2008).

2.6 Analyses and results

Data were preprocessed using standard SPM routines. During preprocessing, images were unwarped using gradient echo-based field maps, so to correct for geometrical distortions due to field inhomogeneities.

To identify areas of the brain which responded to the occurrence of spatial demonstratives, we fitted GLM models to the EPI time series. The first-level models included regressors coding for the occurrence of spatial demonstratives in either audio channel, as well as regressors coding for the occurrence of wh-words and pronouns, which were also inserted in the text in a controlled fashion. Additionally, the models included nuisance regressors from realignment parameters, as well as RETROICOR models of pulse-oximetry and respiration data (Glover, Li, & Ress, 2000; Lund, Madsen, Sidaros, Luo, & Nichols, 2006). For each first-level model, we specified T-contrasts testing for: a) the average effect of proximal and distal demonstratives at each of the 20 FIR time bins after stimulus onset; b) differences between proximal and distal demonstratives at each time point. Contrast images were entered into a second-level ANOVA (including non-sphericity correction). Covariates accounting for subject-specific effects were also included in second-level models. Group-level inference was drawn using F-contrasts testing for voxels where response significantly deviated from 0 at least over a subset of time bins in the FIR model. For all significant clusters detected in the analyses, inspection of the actual contrast estimates revealed response patterns matching the expected time course of hemodynamic responses.

When testing for average effects of proximal and distal demonstratives, we only included

voxels in the analysis where response was on average *positive* across the 20 FIR time bins after stimulus onset using a positive T-contrast image as a mask. Results were thresholded at $p < .05$ (FWE-corrected) and using a spatial extent threshold of 30 voxels.

The results showed that demonstratives recruit a largely bilateral network of fronto-parietal dorsal areas. In line with our hypotheses, we detected increased activation in posterior parietal areas, including the supramarginal gyrus, the angular gyrus, and the precuneus. Moreover, demonstratives recruited frontal regions (bilateral MFG and the right FEF) implicated in attentional orienting and changes in reference frames.

Figure 5. Statistical map of areas significantly responding to spatial demonstratives. Increased activation was detected bilaterally in the inferior parietal cortices (AG and SMG), in medial superior parietal areas (precuneus) and in the MFG, as well as in the right FEF.

We did not detect spatially distinct neural substrates for proximal and distal demonstratives. However, we detected a marginal difference between proximal and distal demonstratives in the amplitude of the response across all areas responding to demonstratives, with distal demonstratives eliciting larger responses.

2.7 The “where” stream and spatial language

Regions displaying increased activation for demonstratives are located along the dorsal visuospatial

stream (the "where" stream, Goodale & Milner, 1992; Mishkin, Ungerleider, & Macko, 1983), involved in processing object location, as opposed to the ventral "what" stream, involved in object recognition.

The role of the dorsal system in language processing, however, is not specific to spatial demonstratives. Landau and Jackendoff (1993, 2013) have hypothesized a general involvement of the dorsal "where" stream in spatial language, as opposed to the functional specialization of the ventro-temporal "what" stream for object semantics. Their hypothesis, however, was based on purely theoretical grounds, and although multiple studies have found evidence for dorsal involvement in spatial language processing, a direct comparison of "where" and "what" in language has never been performed directly.

In additional analyses, we tested the hypothesis of a general involvement of the dorsal visuospatial stream in spatial language using multivariate similarity analysis techniques.

By design, the stimulus text contained a controlled number of wh-words (*what*, *where* and *who*), priming the processing of spatial information (*where*), as opposed to information concerning the identity of objects and entities (*what*), or individuals (*who*). To detect whether shared brain circuits underlie the processing of demonstratives and other spatial expressions, we computed whole-brain similarity (Pearson's correlation) between GLM parameter maps for demonstratives and for each wh-word, hypothesizing higher similarity between demonstratives and *where* than between demonstratives and *what* or *who*. The rationale was that, if these hypotheses were confirmed, this would suggest that demonstratives and spatial language might rely on overlapping networks of resources. These networks could then be detected via local similarity analyses.

The similarity computations yielded 28 (subjects) x 6 (demonstrative/wh-word combinations) x 20 (time points) similarity values (see illustration of the procedure in Figure 6 and Equation 1).

Figure 6. Extraction of correlation values for the similarity analysis. For each subject (s), and for each of the 20 time points (t , 0 – 10 seconds after stimulus onset, at 500ms intervals), we computed correlation between the beta maps for demonstratives and for wh-words (as in Equation 1). This yielded one similarity value per subject, time point and combination of demonstrative and wh-word, i.e. 28 (subjects) x 20 (time points) x 6 (combinations) similarity values. For each wh-word, similarity values were averaged across proximal and distal demonstratives.

$$Corr_{HereWhere,s,t} = \frac{\sum_{v=1}^{voxels} (BetaHere_{v,s,t} - \overline{BetaHere}_{s,t}) \times \sum_{v=1}^{voxels} (BetaWhere_{v,s,t} - \overline{BetaWhere}_{s,t})}{\sqrt{\sum_{v=1}^{voxels} (BetaHere_{v,s,t} - \overline{BetaHere}_{s,t})^2} \times \sqrt{\sum_{v=1}^{voxels} (BetaWhere_{v,s,t} - \overline{BetaWhere}_{s,t})^2}}$$

Equation 1. Computation of whole-brain Pearson's correlation for *here* and *where* for each subject (s) and time point (t) across voxels (v). $BetaHere$ and $BetaWhere$ denote parameter maps for *here* and *where* from first-level GLMs for subject s at a specific time point t .

For each participant and demonstrative/wh-word combination, we thus obtained a time series consisting of 20 similarity values. We then computed the AUC of these time series for each subject. Subsequently, we compared AUC values (quantifying whole-brain similarity between demonstratives and each wh-word across the whole time series) across wh-words using mixed-effects linear regression. As hypothesized, we found that similarity between demonstratives and *where* was

significantly higher than similarity with *what* and *who* (see Figure 7).

Figure 7. Average whole-brain correlations between demonstratives and wh-words over time (500ms bins, over 10 seconds after stimulus onset). Bars indicate averages across subjects at each time point. The overlaid curve smooths the time series via local regression. Error bars stand for standard error across subjects. The AUC of correlation time series for *where* is overall higher than for *what* and *who*.

This result hinted at the existence of overlapping circuits for demonstratives and *where*, which might be generally involved in processing spatial language. To identify the contribution of local circuits, we analyzed regional similarity patterns, computing correlations between parameter maps for demonstratives and wh-words in 60 ROIs extracted from the AAL2 atlas (Rolls, Joliot, & Tzourio-Mazoyer, 2015; Tzourio-Mazoyer et al., 2002).

The resulting patterns show that higher similarity between demonstratives and *where* in the whole-brain analysis was likely driven by areas located in the frontal and posterior (superior) parietal lobes (Figure 8), along dorsal visuospatial processing pathways. We interpret this as suggestive of a general involvement of the dorsal “where” stream in the processing of spatial language, providing empirical

support to Landau and Jackendoff's (1993, 2013) hypothesis.

Figure 8. Local similarity between demonstratives and wh-words over 10 seconds post stimulus onset in 60 ROIs from the AAL2 atlas. Regions are sorted by ascending similarity between demonstratives and *where*. ROIs displaying highest similarity are located along dorsal fronto-parietal visuospatial processing pathways.

2.8 Main implications

Our results show that processing of demonstrative expressions engages a (mostly) bilateral network of dorsal fronto-parietal areas involved in information integration, attention and visuospatial processing. The intertwining between perceptual, pragmatic and linguistic representations required to process demonstrative expressions hinges upon the recruitment of a distributed network of

extralinguistic areas. As we will elaborate more extensively in the discussion, reliance on a distributed and non-segregated architecture is likely not unique to spatial demonstratives. A certain degree of integration between the processing of linguistic content and contextual cues is in fact necessary in language comprehension at large.

3. Article 2: Semantics and the proximal/distal contrast

3.1 Background

To identify the referent of a demonstrative expression, addressees can rely on cues conveyed by speakers' choices for specific demonstrative forms. Intuitively, the referent of an expression containing a proximal demonstrative (e.g. "these sunglasses") is likely to be located somewhere in the vicinity of the speaker or the addressee, rather than somewhere remote or out of sight. But what type of information does the contrast between proximal and distal demonstratives encode, exactly? Is the proximal/distal contrast solely concerned with distance, or do other factors, such as the semantics of the referent, play a role?

This article addresses these questions. Building upon insights from previous literature, we tested whether *size*, *harmfulness* and *animacy* of an object influence the choice of the demonstrative form used to reference it. These are all prominent semantic dimensions that shape an object's affordances for interaction.

3.2 Methods

To investigate semantic influences on demonstrative use, we conducted two cross-linguistic studies using a novel experimental paradigm, the Demonstrative Choice Task (DCT). In the experiment, participants were presented with nouns denoting concrete objects differing in size (big vs. small), harmfulness (harmless vs. harmful) and animacy (animate vs. inanimate). No further linguistic or visual context was provided. Participants were asked to pair these words with either a proximal or a distal demonstrative on the basis of their first and immediate preference. Participants were presented with 40 words in total, 32 experimental words, and 8 fillers denoting abstract concepts. Words were displayed one at a time.

The experiment was distributed online using the survey platform Qualtrics. In Experiment 1, we

collected data from speakers of Danish, English and Italian, three languages with a two-term (proximal vs. distal) demonstrative system. In Experiment 2, we replicated Experiment 1 using a new word stimulus set, with data from Danish and Italian speakers only.

3.3 Word stimuli

For Experiment 1, words were selected from a semantic database (Sudre et al., 2012) including 1000 concrete nouns rated on a 1-5 Likert scale along 218 semantic dimensions. We used the dimension “Is it bigger than a loaf of bread?” as a proxy for size, as it best mirrored the functional distinction between objects whose size *does* vs. *does not* allow for manual grasp. Words scoring lower than 3 on this dimension were coded as *small*, while words scoring 3 or higher were coded as *big*. The dimension “Is it dangerous?” was chosen as a proxy for harmfulness. Objects scoring less than 3 were coded as *harmless*, while objects scoring 3 or higher were coded as *harmful*. The dimension “Is it an animal?” was used as a proxy for animacy. Words scoring less than 3 were coded as *inanimate*, whereas objects scoring more than 3 were coded as *animate*. Table 1 displays the full stimulus set for Experiment 1 in the three languages.

Animate

	Big	Small
Harmful	Bull, shark, hyena, snake Toro, squalo, iena, serpente Tyr, haj, hyæne, slange	Bee, flea, spider, rat Ape, pulce, ragno, ratto Bi, loppe, edderkop, rotte
Harmless	Camel, goose, lamb, penguin Cammello, oca, agnello, pinguino Kamel, gås, lam, pingvin	Cricket, kitten, robin, shrimp Grillo, gattino, pettirosso, gamberetto Fårekylling, killing, rødhals, reje

Inanimate

	Big	Small
Harmful	Bomb, jail, rocket, rifle Bomba, prigionero, razzo, fucile Bombe, fængsel, missil, riffel	Burner, dagger, needle, thorn Bruciatore, pugnale, ago, spina Blus, dolk, nål, torn,
Harmless	Bench, couch, cradle, tent	Coin, comb, cookie, soap

	Panca, divano, culla, tenda Bænk, sofa, vugge, telt	Moneta, pettine, biscotto, sapone Mønt, kam, småkage, sæbe
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Table 1. List of stimulus words for Experiment 1

For Experiment 2, we initially selected experimental words on a qualitative basis. To validate our subjective coding of words with respect to the three semantic dimensions of interest, we trained SVR models which predicted scores for size, harmfulness and animacy from GloVe vectors for words included in the Sudre et al. (2012) database (Pennington, Socher, & Manning, 2014). The model was then used to predict semantic scores for the new words selected for Experiment 2. Model predictions displayed high overlap with manual coding. Table 2 provides the full stimulus set for Experiment 2.

Animate

	Big	Small
Harmful	Tigre, cobra, coccodrillo, cinghiale Tiger, kobra, krokodille, vildsvin (<i>Tiger, cobra, crocodile, boar</i>)	Zanzara, medusa, tarantola, zecca Myg, giftgople, fugeledderkop, skovflåt (<i>Mosquito, jellyfish, tarantula, tick</i>)
Harmless	Giraffa, cavallo, delfino, cerbiatto Giraf, hest, delfin, rådyr (<i>Giraffe, horse, dolphin, fawn</i>)	Coniglio, farfalla, scoiattolo, passero Kanin, sommerfugl, eger, spurv (<i>Rabbit, butterfly, squirrel, sparrow</i>)

Inanimate

	Big	Small
Harmful	Meteorite, valanga, vulcano, bombardiere Meteor, lavine, vulkan, bombefly (<i>Meteorite, avalanche, volcano, bomber</i>)	Mina, veleno, proiettile, coltello Landmine, gift, patron, kniv (<i>Mine, poison, bullet, knife</i>)
Harmless	Scuola, quercia, contrabbasso, cupola Skole, egetræ, kontrabas, kuppel (<i>School, oak, double-bass, dome</i>)	Tazza, scarpa, cucchiaino, mela Krus, sko, ske, æble (<i>Mug, shoe, spoon, apple</i>)

Table 2. List of Italian and Danish stimulus words for Experiment 2 (English translation below)

3.4 Analysis and results

Data were analyzed using mixed-effects logistic regression implemented in RStudio via *lme4* (Bates,

Mächler, Bolker, & Walker, 2014). The models included categorical regressors for Size, Animacy and Harmfulness (and the full interaction structure) as predictors, and random intercepts for each participant. The demonstrative chosen for each word was the binary outcome variable.

In line with our predictions, we found main effects of Size and Harmfulness on participants' choices for demonstrative forms. Participants used more proximal demonstratives for small vs. big objects, and for harmless vs. harmful objects. Moreover, Animacy modulated the effect of both Harmfulness and Size. The influence of Size and Harmfulness on demonstrative choice was weaker for animate beings than for inanimate objects. Figure 9 displays the results for Experiment 1.

Figure 9. Results from Experiment 1. We found significant main effects of Size and Harmfulness, as well as interactions between Animacy and Size and Animacy and Harmfulness.

All effects were replicated in Experiment 2 (Figure 10).

Figure 10. Results from Experiment 2. As in Experiment 1, we found significant main effects of Size and Harmfulness, as well as interactions between Animacy and Size and Animacy and Harmfulness.

The main effects of Size and Harmfulness support the hypothesis that the choice of proximal vs. distal demonstrative forms is influenced by semantic features of the referent reflecting the extent to which it offers affordances for manual interaction. The interaction between Animacy and the two functional features Size and Harmfulness is in line with sensory-functional explanations of the animate/inanimate distinction. If demonstrative use is shaped by functional features of objects, then the fact that patterns of demonstrative use are *less* strongly influenced by functional dimensions in the case of animate beings is likely due to the lower prominence of such dimensions in representations of animals compared to inanimate objects.

3.5 Additional analyses

The results presented so far are compatible with the hypothesis that the functional *status* of the referent (low- vs. high-affordance) drives demonstrative choice. However, these analyses do not

directly test whether the effects of size, harmfulness and animacy are driven by a common latent effect of manipulability. To provide direct evidence that this is the case, we complemented the planned analyses with post-hoc analyses testing for the effect of explicit manipulability scores. We asked an independent sample of Danish speakers to provide 1-5 ratings for each stimulus word in Experiment 2 in relation to the following questions: a) “Could you move it with your hands?”; b) “Is it something you would *consider* moving with your hands?”; c) “Is it something that would *let* you move it with your hands?”.

For each word, we extracted a summary manipulability score by summing cross-participant average scores for each of the three questions, and included these scores as an additional regressor in the models used for the planned analyses. Manipulability scores explained away most of the variance previously accounted for by Harmfulness and Size, although a residual effect of Harmfulness could still be observed (Figure 11).

Figure 11. Relation between manipulability scores and proportion of proximal demonstratives.

Additionally, comparison between models including the manipulability regressor and models *not* including it showed that adding manipulability increased the amount of variance explained. This suggests that further semantic dimensions contributing to shaping object affordances, but not modelled in the present experiment, might systematically modulate demonstrative choice.

3.6 Conclusions and implications

Our findings suggest that the proximal/distal contrast in demonstrative systems encodes information on functional properties of the referent, lexicalizing a distinction between high- and low-affordance objects. When speakers choose a specific demonstrative form, they cue the addressee to the intended referent by signaling its availability for manual interaction.

These results provide strong evidence for a grounding of demonstrative reference in interaction, which sparks new fundamental questions. Does a referencing strategy based on signaling action affordances concretely result in benefits in the execution of actions (e.g. speed, smoothness), compared to other strategies (e.g. coding for distance, using descriptions, nouns...)? How do speakers account for the fact that, in social contexts, object availability for interaction can vary across interlocutors, according to their position in space? Do any semantic features other than the three tested in these experiments influence demonstrative forms? Some of these questions were addressed in Article 3 and in follow-up studies, while others remain open to future investigation.

3.7 Follow-up: exploring the full semantic spectrum

Manipulability is, however, not the only parameter influencing the extent to which a referent lends itself to interaction. Dimensions such as its attentional status, its saliency, its desirability are other factors that might affect its readiness for action and, thereby, demonstrative use. A more comprehensive characterization of the role of semantics in demonstrative use is the focus of a large-

scale follow-up study, where we collected DCT data from 2200 English speakers on 535 words coded along 65 perceptually- and psychologically-motivated semantic dimensions (Binder et al., 2016). A list of the 65 semantic features and their correlation patterns is displayed in Figure 12.

Figure 12. Pairwise correlations between semantic features from the Binder et al. (2016) dataset.

The analysis of the data is still in progress. Preliminary analyses, however, confirm the patterns observed in Article 2 while also highlighting a number of additional features that might systematically influence demonstrative choice.

Figure 13 displays semantic features surviving zero-shrinkage in a regularized regression analysis with LASSO penalty. LASSO penalty optimizes prediction performance and interpretability of high-

dimensional regression models via feature selection. Feature selection is achieved by setting a regularization parameter on the sum of model coefficients which shrinks some parameter estimates while forcing others to zero. The features displayed in Figure 13 are the semantic features that are most likely to explain variance in choices of demonstrative forms in the task.

Figure 13. Features surviving zero-shrinkage in LASSO regression on the large-scale version of the DCT. These are the semantic dimensions from the Binder et al. set which are likely to play a role in demonstrative choice.

These non-zero features are, however, not fully independent from each other. Correlation patterns indicate that they can be further clustered into hyper-dimensions such as valence, saliency/attentional status, animacy/motion, perceptual properties (size), and proximity. Some of these clusters (size, valence) reflect the effects detected in Article 2, while others (attentional saliency, movement) point at other dimensions which might also be relevant when defining whether objects lend themselves to interaction (Figure 14).

Figure 14. Correlation between semantic features influencing demonstrative use in the DCT task. A number of clusters can be detected, indicating object saliency/attentional status (Attention, Loud, Low), valence (Happy, Pleasant, Unpleasant, Fearful, Human), size (Large, Landmark, Scene), animacy/motion (Human, Face, Biomotion, Fast, Motion, Path, Lowerlimb, Slow), and proximity (Self, Near, Needs).

In terms of performance, the model achieves an $R^2 = .61$, computed on the basis of Pearson's correlations between the *observed* proportion of proximal demonstratives for each word in the test set and the predicted proportion (Figure 15).

As pointed out above, however, analyses for this dataset are still in progress. First, we are aiming at achieving a more robust estimation of relevant predictors in the LASSO model by assessing stability in parameter estimates for each semantic feature over repeated iterations of the estimation procedure. Moreover, we are looking into the possibility of combining regularized regression with dimensionality reduction techniques which would allow to orthogonalize predictors while still preserving interpretability.

4. Article 3: Social modulations of demonstrative use

4.1 Background

Results from Article 2 show that the contrast between proximal and distal demonstratives codes for a distinction between low- and high-affordances objects. However, in contexts of social interaction, the extent to which an object lends itself to interaction varies across individuals (as a function of their position in space) as well as across tasks (as a function of the relevance of the referent for the ongoing action).

How are these context- and viewpoint-dependent modulations of the functional status of a referent reflected in demonstrative use? Do speakers always code objects as *proximal* or *distal* from their own perspective, or do they account for the presence of an addressee, adapting their use of demonstratives to his/her viewpoint? And if the latter, is this in some way conditional on the nature of the task?

These questions were addressed in Article 3. Over two experiments, we tested whether the presence of an addressee and engagement in tasks involving collaborative interaction modulated speakers' use of demonstratives, triggering a transition to partner-centered encoding strategies.

4.2 Experiment 1

4.2.1 Methods

In the two experiments reported in this article speakers' production of demonstratives was probed using a novel interactive paradigm. Participants stood by the inferior edge of a 40'' screen, placed horizontally on a table in front of them. As in the memory game paradigm (Figure 2), the experiment was framed as a memory task in order to keep participants unaware that demonstrative production was the behavior of interest.

At each trial, participants were presented with two targets appearing on screen for a short interval.

Their task was to memorize the location of the targets so to be able to pinpoint them after the targets had disappeared. Participants were then asked to indicate both target locations using a combination of manual pointing and a proximal and a distal demonstrative.

The position of the targets varied both on the sagittal and on the lateral axis, so to allow detection of potential lateralized biases in proximal space and effects of experimental manipulations on the left/right axis. In previous experiments, distance had only been manipulated on the sagittal axis.

In Experiment 1, participants performed the task over three conditions. In the *baseline* condition, they performed the task alone. In the *complementary* conditions, a confederate stood by their left. The confederate's task was to name the type of object that had lit up (e.g. *triangle*, *square*) after the participant had pointed at the target location. In this condition, the participant and the confederate's task were mutually independent. In the *collaborative* condition, the confederate's and the participant's task were related. The confederate was instructed to close his/her eyes while the targets appeared on screen, and to open them after hearing a click sound. Thus, the confederate did not have perceptual access to the location of the target. His/her task was to report the position of the two targets on a touch screen device relying on the information conveyed by the participant's pointing. Figure 17 provides an illustration of the setup and tasks over the three conditions.

Figure 17. Setup for Experiment 1.

We expected engagement in a joint task, but not mere co-presence of another individual, to modulate participant's use of the demonstratives, triggering a shift of proximal space towards the partner.

4.2.2 Analysis and results

Data were analyzed using mixed-effects logistic regression implemented in RStudio via *lme4* (Bates et al., 2014). At each trial, one of the two targets (henceforth: T1) was randomly logged as *target of interest*, and the demonstrative chosen to indicate this target was used as outcome variable. Relative distances between the x and y coordinates of the two targets were used as predictors, together with a categorical predictor coding for *condition*. Relative distance on the x-axis (RelativeX) was computed by subtracting the x coordinate of T1 from that of the other target (henceforth: T2). RelativeX thus took positive values if T1 was further to the participant's right than T2. Distance on the y-axis (RelativeY) was computed by subtracting the y coordinate of T1 from that of T2. This regressor took positive values if T1 was further away from the participant than T2 on the sagittal axis.

Figure 18. Example of the computation of relative distances between T1 and T2 on the sagittal (RelativeY) and lateral axis (RelativeX). RelativeX was computed by subtracting the x coordinate of T2 from the x coordinate of T1. Since the x coordinate of T1 is larger, in this example RelativeX takes positive value. RelativeY is computed by subtracting the y coordinate of T2 from the y

coordinate of T1. Since the y coordinate of T1 is smaller, *RelativeY* takes a positive value. The position of the participant relative to the screen is marked with “P”.

As expected, we detected an effect of *RelativeY*, reflecting increased probability of observing proximal demonstratives as distance between target referent and speaker on the sagittal axis increased, and an effect of *RelativeX*, reflecting increased probability of observing proximal demonstratives for targets located towards the participant’s right. Right-lateralized biases were expected on the basis of the tight link between demonstratives and manual action (Article 2).

Figure 19. Proportion of proximal demonstratives used to denote T1 as a function of its distance from the competing target (T2) on the *sagittal* (left) and *lateral* (right) axis across all conditions. As T1 moves further away from the participant on the sagittal axis, that is as the value of *RelativeY* increases, the probability of participants coding it as *proximal* decreases. As T1 moves further to the participant’s right, that is as the value of *RelativeX* increases, the probability of participants coding it as *proximal* increases, which speaks in favor of a right-lateralized bias for proximal space.

The effect of *RelativeX* was modulated by condition, an interaction that reflects a left-ward shift in proximal space in the *collaborative* condition, i.e. a shift in proximal space towards the partner. Changes in proximal/distal coding of locations across conditions are illustrated in Figure 20 and 21.

Figure 20. Proportion of trials in which T1 is coded as *proximal* as a function of distance of T1 from T2 on the sagittal (*RelativeY*) and lateral (*RelativeX*,) axis. Larger *RelativeY* values indicate that T1 is further away from T2 (and from the participant) on the sagittal axis. Larger *RelativeX* values indicate that T1 is further to the right of T2. The center of the plot represents the position of T2, providing a reference for the interpretation of relative distance values on the x and y axis.

The heatmaps clearly display the effect of *RelativeY* across all conditions. The right-lateralized bias on the x axis detected in the statistical analysis is particularly salient in the baseline and complementary condition, whereas proximal space is shifted towards the left, that is towards the partner.

Figure 21. Difference in proportion of proximal demonstratives between the collaborative and complementary condition. Positive values (red) indicate higher proportion of proximal demonstratives in the collaborative condition, while negative values denote higher proportion of proximal demonstratives in the complementary condition. In the collaborative condition, participants code targets located towards their right as distal more often than in the complementary condition. Conversely, participants have a stronger tendency to code as *proximal* those targets that are located towards the left side of the screen, an index of representations of proximal space shifting towards the interaction partner.

4.3 Experiment 2

4.3.1 Methods

Experiment 2 relied on the same experimental setup, but the interactive component of the collaborative condition was enhanced by introducing role-switching at every trial. Here, participants were recruited in pairs. They performed the task in a *complementary* and a *collaborative* condition, taking turns in performing the demonstrative and the naming task.

At each trial, a 7x7 gray grid of shapes was initially displayed on screen against a black background. Then, two figures changed color for a short interval, becoming either *red* or *green*. Each participant was instructed to respond to one of the two colors by pointing at the target locations and verbally indicating them using a proximal and a distal demonstrative after the targets had disappeared. The task of the other participant was to name the type of shapes that had lit up.

In the complementary condition, both participants had perceptual access to the change in color of the

two target shapes, and thereby to all information required to perform their own task. In the *collaborative* condition, participants wore glasses with either *red* or *green* lenses. The participant who was instructed to respond to red targets wore green glasses, and vice versa. This prevented participants from seeing the targets lighting up in trials where they did *not* have to perform the demonstrative task, but the naming one. Participants performing the naming task thus depended on their partner's pointing to know which shapes they were to name.

Figure 22. Setup for Experiment 2

4.3.2 Analyses and results

As in the previous experiment, engagement in a collaborative interaction triggered a shift of proximal space towards the partner, i.e. a left-ward shift for the participant standing by the lower edge of the screen, and a right-ward shift for the other participant (see Figure 23).

Figure 23. Proportion of trials in which T1 is coded as *proximal* as a function of relative distance of T1 from T2 on the sagittal and lateral axis. Targets with higher values of *RelativeX* correspond to T1 being located more towards the right of the screen, whereas higher values of *RelativeY* correspond to T1 being located further towards the top of the screen. In the complementary condition, the probability of coding a referent as *proximal* highly depends on its distance to the competing referent on the participant's sagittal axis. In the collaborative condition, participants tend to label as *proximal* those locations which lie closer to their partner, i.e. towards their own left (P1), or right (P2).

Interestingly, the shift in proximal space towards the partner was markedly more pronounced than in Experiment 1. Participants transitioned from an egocentric to a partner-centered coding strategy. Supplementary analyses revealed that participants' coding of space in the collaborative condition was indeed more similar to their partner's (egocentric) coding of space in the complementary condition, than their own (egocentric) behavior in the complementary condition and the partner's in the collaborative condition (Figure 24).

Figure 24. Density distributions displaying similarity between participants' behavior in the collaborative condition and: a) their partner's behavior in the complementary condition; b) their partner's behavior in the collaborative condition; c) their own behavior in the complementary condition. Similarity was highest between participant's behavior in the collaborative condition and the partner's behavior in the complementary condition, thus suggesting that participants shift to a partner-centered proximal/distal coding of space rather than minimally modulating an egocentric encoding strategy or converging towards a shared “in-between” reference frame.

4.4 Conclusions and main implications

Over two experiments, we observed that, in tasks involving collaborative interaction, contrastive use of proximal vs. distal demonstrative forms encodes object proximity from the addressee's perspective, as opposed to speaker-centered encoding strategies deployed in non-interactive settings. These results have two overarching implications, central to understanding the key function of demonstratives in human social interaction.

First, they provide evidence that usage criteria for proximal vs. distal forms vary across social

contexts and tasks, questioning the assumption, shared by egocentric and sociocentric (Peeters & Özyürek, 2016) approaches, that a context-independent reference frame underlies the whole of demonstrative use.

Second, these flexible adaptations might be interpreted as optimization strategies aimed at facilitating referent identification, hinting, in turn, at an *instrumental* role of demonstrative use in action execution. By coding referents as proximal or distal from the addressee's perspective, speakers provide cues to object location in a format that matches their partner's sensorimotor representations. Though these hypotheses remain to be tested empirically, this encoding strategy might reduce the load of spatial transformations required to map linguistic expressions onto the intended referent, thus smoothing action execution and optimizing task performance.

5. General discussion and future directions

5.1 Main results and significance

The three studies presented in this dissertation investigate the neural and cognitive correlates of spatial demonstratives, with a focus on the processing mechanisms underlying their use as well as their function in action and social interaction.

In the first study, we focused on elucidating the neural infrastructure supporting the processing of demonstrative expressions. Due to their deictic nature, identifying the referent of demonstratives hinges on integrating linguistic information with perceptual and pragmatic cues. As our results suggest, this is enabled by the direct recruitment of a distributed, bilateral network of dorsal visuospatial resources. Since a certain degree of context-dependency is implicit in the vast majority of linguistic expressions, the cognitive mechanisms and distributed architectures supporting demonstrative reference are likely to be paradigmatic of language processing at large.

In the second study, we focused on clarifying which semantic parameters are encoded in the contrast between proximal and distal demonstrative forms. We showed that the proximal/distal contrast lexicalizes a functional distinction between high- and low-affordance referents.

In the third study, we investigated how the implementation of the proximal/distal contrast is modulated by engagement in social interaction. We observed that, in collaborative contexts, speakers design their use of demonstratives *for* the addressee, by coding for referent proximity from his/her perspective. This arguably facilitates the addressee's task of identifying the intended referent.

These results lead to two fundamental implications. On the one hand, they highlight the tight interdependency between language, perception and attention characterizing demonstrative use. The meaning of demonstratives is contingent on perceptual processing, but, conversely, these expressions function as tools to *modulate* perceptual representations and attention, guiding our access to the physical world.

On the other hand, demonstratives are designed for action and social interaction. They signal information on functional affordances of the referent, and they do so in the coordinate system that best suits the interlocutor's needs in the ongoing action. This makes them *instrumental* to a successful unfolding of the social practices they are embedded in.

Crucially, the implications of these findings are not only of importance for a deeper understanding of demonstrative reference. Demonstratives magnify some properties which apply to language as a whole, such its propensity to function as a tool for the allocation of attention (Givón, 1984; Halliday & Matthiessen, 2004; Stroustrup & Wallentin, 2018; Talmy, 2007) and for social coordination (Tylén et al., 2010). Knowledge of their cognitive underpinnings is therefore more generally key to a deeper understanding of the relationship between language and core aspects of our cognitive system.

5.2 Semantics, deixis and naturalistic fMRI

In Article 1, we showed that processing of spatial demonstratives recruits a distributed network of areas implicated in visuospatial processing, attention and information integration. These results were in line with our expectations, and their interpretation is straightforward when considering the deictic nature of spatial demonstratives. As demonstratives do not provide specific semantic information on the intended referent, decoding their meaning relies on the combination of linguistic processing and representation of the perceptual and spatial context.

As highlighted above, however, the reliance on perceptual and contextual knowledge in language understanding is not unique to demonstratives, but rather pervasive in language use. Outside context, linguistic expressions are often underspecified with regards to both their semantic and pragmatic implications. Language processing *at large* is therefore likely to require co-opting of distributed, non-segregated networks of extralinguistic areas.

Generalizing these hypotheses to language as a whole requires further research, and it relies crucially

on the use of naturalistic paradigms. Over the last decades, a wealth of neuroimaging research has been dedicated to identifying the neural infrastructure supporting semantic processing, with a major split between *localist* views (Hodges, Patterson, Oxbury, & Funnell, 1992; Patterson, Nestor, & Rogers, 2007; Ralph, Jefferies, Patterson, & Rogers, 2017), and *distributed* views (Barsalou, Simmons, Barbey, & Wilson, 2003; Binder & Desai, 2011; Binder, Desai, Graves, & Conant, 2009; Binder, Westbury, McKiernan, Possing, & Medler, 2005; Fernandino et al., 2015; Pulvermüller, 2005).

However, literature on word semantics has been largely relying on experimental paradigms where words are presented in isolation or within single sentences (Desai, Choi, Lai, & Henderson, 2016; Hamilton & Huth, 2018; Yarkoni, Speer, & Zacks, 2008). Here, the absence of full-scale linguistic and perceptual context prevents from evaluating the extent to which extralinguistic processing is involved in comprehension. Moreover, single-word and single-sentence paradigms fail in reproducing basic characteristics of language comprehension in the wild (Hamilton & Huth, 2018). This poses major external validity issues which might lie at the root of the long-held belief of a localized, specialized and left-lateralized language processing system (de Heer, Huth, Griffiths, Gallant, & Theunissen, 2017). As observed in our study, experiments using naturalistic paradigms display, in fact, patterns of response to linguistic stimuli that are markedly different from those detected in single-sentence and single-word studies in terms of extent of contributing cortical areas, lateralization profile, and degree of engagement of higher-order regions (Bottenhorn et al., 2018; de Heer et al., 2017; Frank & Willems, 2017; Hamilton & Huth, 2018; Huth, de Heer, Griffiths, Theunissen, & Gallant, 2016; Huth, Nishimoto, Vu, & Gallant, 2012; Jain & Huth, 2018).

The use of simplified stimuli in language research has been mostly motivated by technical limitations. Acquisition sequences for whole-brain EPI images have long been constrained to a temporal resolution in the order of seconds. This resolution is probably insufficient to investigate the neural

correlates of word-level semantics within naturalistic speech input. Moreover, assumptions on the sluggish time course of the BOLD signal (Logothetis, Pauls, Augath, Trinath, & Oeltermann, 2001) have discouraged researchers from investigating responses to sub-sentence linguistic units. These limitations and concerns, however, are progressively being overcome thanks to significant advances in acquisition protocols made possible by simultaneous multi-slice methods (Setsompop et al., 2012) and to novel insights on the presence of higher-frequency components in the BOLD signal (Lewis et al., 2016). Naturalistic paradigms are therefore gaining ground, and arguments in favour of their necessity for language research have been extensively provided in recent perspective papers (Hamilton & Huth, 2018; Hasson et al., 2018).

Along the lines of this paradigm shift, our ambition was also to provide a methodological contribution to the field. Combining automatic stimulus generation techniques, fast acquisition sequences and naturalistic stimuli with some degree of experimental control, we aimed at validating a paradigm which allows to investigate word-level meaning in ecologically valid contexts and with relatively low investment in terms of computational and annotation costs.

5.3 A methodological note

The use of naturalistic stimuli opens new methodological perspectives for the neurobiology of language, but it does not come without its problems. The increase in ecological validity comes at the expense of experimental control, which calls for awareness of the potential shortcomings in using GLM analyses as inference tools. A brief review of these limitations is necessary for a critical evaluation of the methodologies used in the present experiment.

GLMs provide a conceptually solid, widely accepted and simple heuristics to explore the neural correlates of specific lexical items. However, in natural speech, linguistic features pertaining to different levels of processing (phonological characteristics, word frequency, syntactic position, and

semantic context) are often highly correlated. To provide a concrete example, words with a similar semantics (e.g. “cat” and “dog”) often tend occur in the same syntactic position. This intertwining of syntax and semantics is to some degree unavoidable in natural languages, and full orthogonality is therefore hard to achieve. As a consequence, GLM analyses are subject to an increased risk of conflating the effect of multiple collinear features under the same regressors. Awareness of such risks should induce extra care in designing GLMs so to include possible confound regressors, and in acknowledging the potential limitations of inference drawn on the basis of these analyses (Yarkoni et al., 2008).

Two additional remarks are relevant for a critical consideration of our methodologies. First, results of GLM contrasts are highly dependent on the chosen baseline. In this experiment, inference on demonstratives was drawn on the basis of contrasts comparing activity triggered by demonstratives to a general language baseline. Although this should in principle be an unbiased (but controlled) baseline, it cannot be excluded that activation patterns for demonstratives would vary as a result of variation in the global characteristics (e.g. prominent semantic domain) of the stimulus. Note, however, that the baseline problem is far from unique to naturalistic paradigms (Stark & Squire, 2001).

Second, univariate analyses capture variation in the amplitude of the BOLD signal within single voxels, but they are not sensitive to structured variation in topographical patterns of activation across several voxels. These effects can only be detected via complementary analysis methods, which motivates the combination of univariate analyses with multivariate (e.g. similarity) techniques.

5.4 Demonstratives in the brain: outstanding questions

The results presented in Article 1 provide a first significant contribution towards an understanding of the neural correlates of spatial deixis, but a number of outstanding questions call for further

investigation. First, as shown in Article 2, the proximal/distal distinction carries information on functional features of the referent, hinting at a close link between demonstratives and action. Evidence for an overlap between the neural underpinnings of language processing and action has been extensively provided in previous literature (Pulvermüller, 2005; Willems & Hagoort, 2007; Willems, Özyürek, & Hagoort, 2006). Nevertheless, in our experiment we do not detect explicit involvement of brain areas encoding functional representations of objects or space in demonstrative processing. A potential explanation for the lack of results in this direction is that functional features of the referent might not be necessary for the comprehension of demonstrative expressions in this experimental context, where no visual input is presented. Scanning mental representation of the scene on the basis of distance cues provided by demonstrative forms might be sufficient to identify the intended referent. In settings where the participant is either *directly* involved in the conversational exchange, or where real objects are presented in physical space, demonstrative processing might rely to a significantly higher degree on an explicit representation of affordances and reachability.

Similarly, we do not find evidence in favor of distinct spatial substrates for *proximal* and *distal* demonstratives. As hypothesized above, in absence of a visual or physical stimulus, perceptual scanning of the imagined scene on the basis of distance cues might be enough to pick out the referent of both proximal and distal demonstrative forms. An alternative explanation might be the lack a clear-cut distinction between neural substrates encoding representations of reachable and non-reachable space. Although a wealth of work has been devoted to this endeavor (see, for example, Andersen, Andersen, Hwang, & Hauschild, 2014; Astafiev et al., 2003; Batista, Buneo, Snyder, & Andersen, 1999; Connolly, Andersen, & Goodale, 2003), no agreement has been reached in the literature concerning whether and how this distinction is hard-coded in the brain.

On the other hand, we detected a difference between proximal and distal demonstratives in the *amplitude* of the response across a number of visuospatial and attentional areas. Since this effect was

only detected in exploratory contrasts using a liberal cluster threshold, its reliability is to be confirmed. If replicated, however, this result would hint at a difference in cognitive demands posed by proximal and distal demonstratives. While expressions like “here” limit the search space for the intended referent to the vicinity of the speaker (or the dyad), expressions like “there” can denote any location which is *not* in the proximity of the speaker, requiring more costly inference and/or extensive search. This hypothesis lends itself to be put to test using simple behavioral paradigms, e.g. comparing reaction times in comprehension or visual search tasks when referents are indicated via proximal vs. distal demonstrative expressions.

5.5 Grounding demonstratives in action

Inference drawn on the basis of perceptual information, multimodal cues and pragmatic context is necessary for understanding deictic expressions, but reference resolution is not entirely dependent on it. The use of specific demonstrative forms provides the addressee with important additional cues to the intended referent.

In Article 2 we investigated which semantic information is encoded in the proximal/distal contrast, and we observed that, as expected, the contrast lexicalizes a distinction between low- and high-affordance referents. When asked to pair a spatial demonstrative with a noun referring to a concrete entity, participants consistently used a higher proportion of proximal demonstratives for small objects than for big ones, and for harmless objects than for harmful ones. These effects were more pronounced for inanimate objects than for animate beings, in line with predictions from sensory-functional explanations of the animate-inanimate distinction (Warrington & Shallice, 1984).

These results carry a number of implications that are key to understanding the cognitive underpinnings of spatial demonstratives and their function in language use. To begin with, this study is the first to highlight the role of semantic features in the choice of specific demonstrative forms,

thus questioning purely spatial and distance-based accounts of the proximal/distal distinction. A comprehensive description of the relationship between demonstratives and semantics, and a clarification of the relative influence of spatial factors and semantic features in shaping demonstrative choice are the natural follow-ups of this work.

Crucially, findings from this study also suggest that demonstrative use relies on action-oriented representations of objects, rather than purely perceptual parameters. This clear example of lexicalization of functional features makes demonstratives a strong case in favor of the hypothesis of language being grounded into action representation (Barsalou et al., 2003; Pecher & Zwaan, 2005).

The question of *why* demonstratives encode such features, however, might be compatible with different explanations. On the one hand, demonstrative use is an intrinsically multimodal act, of which pointing gestures are integral components (Cooperrider, 2016). The choice between proximal and distal demonstrative forms might therefore be tied to biomechanical constraints and kinematic characteristics of the co-occurring gesture, as suggested by the right-lateralized bias in proximal space detected in Article 3. Alternatively, it could be hypothesized that referring to relevant objects by signaling their availability for manual interaction is simply the optimal strategy for situations *actually* involving action execution, since cues to the intended referent are provided directly in an action-oriented format. Finally, one could speculate that functional representations of space might simply be the default format for human spatial encoding. Providing cues to the intended referent in functional coordinates might therefore be the cognitively less costly strategy, which minimizes the need for spatial transformations and thereby facilitates referent identification.

As an additional remark, it is interesting to note that the effects of object affordances on demonstrative use translate into a more general effect of *valence* when demonstratives are paired with abstract words. Although words like “freedom” or “disappointment” are very infrequently coupled with demonstratives in naturalistic language use, comparisons between the positive- and negative-valence

fillers used in our experiments show remarkably consistent patterns. As displayed in Figure 25, Danish and Italian participants from Experiment 1 systematically used a higher proportion of proximal demonstratives for positive than for negative words, and a similar behavior is observed for English participants (with the exception of one word, “rise”).

Figure 25. Proportion of demonstratives used for positive- and negative-valence fillers in Experiment 1 across the three languages. Dots represent individual words. Participants tend to use more proximal demonstratives for positive-valence words than for negative-valence words. Average differences between words with positive and negative valence are less pronounced in English, due to the deviant pattern observed for one of the words.

The same pattern is observed for Experiment 2, as shown in Figure 26.

Figure 26. Proportion of demonstratives used for positive- and negative-valence fillers in Experiment 2. The pattern is similar to that observed in Experiment 1, with more proximal demonstratives for positive-valence words.

5.6 A tool for interaction

In contexts where multiple individuals are present, the extent to which objects are available for interaction can differ across interlocutors and tasks. An object can be easy to reach for one agent but not for another, it might be relevant or irrelevant for the unfolding of the interaction, and so on.

In Article 3, we showed that these social and task-specific factors modulating functional affordances of referents *also* play a role in demonstrative use. When using demonstratives in social contexts, speakers can shift between signaling referent proximity from their *own* perspective to coding for it from their *interlocutor's* perspective if convenient for the ongoing action.

These findings suggest that, although affordances for interaction constitute the invariant “semantic” core of the proximal/distal contrast, this contrast is implemented in a flexible way. Demonstrative use is *not* grounded on a single reference frame and does not respond to static usage criteria (as assumed by both egocentric and sociocentric accounts). The way demonstratives carve space into proximal

and distal regions varies across contexts.

Crucially, these addressee-oriented adaptations are *conditional* on the characteristics of the task. Demonstrative use is adapted to the perspective of the interlocutor only in certain contexts. This could lead one to hypothesize that these adaptations only take place in situations where a perspective shift is *advantageous* for the ongoing interaction, i.e. in contexts where signaling object affordances from the partner's point of view facilitates reference resolution and/or action execution. Providing a cue to object location in a format which matches the addressee's default frame of reference might facilitate the identification of the intended object, possibly resulting in advantages for movement performance (as observed in Bonfiglioli et al., 2009).

Results from Article 3, however, also raise a number of new interesting questions. In our experiments, we do not observe a convergence towards a shared sociocentric frame, as predicted by social accounts of demonstrative reference (Peeters et al., 2015; Peeters & Özyürek, 2016). Over subsequent turns, participants oscillate between reference frames centered on each of the two interlocutors (the current addressee). A shared, intermediate reference frame might, however, be advantageous for efficient action in other contexts, e.g. cases where both participants have to act *jointly* in reference space. Our experimental paradigm can be easily adapted to test these and similar hypotheses, exploring a wider range of social settings and tasks, potentially involving larger participant groups, and even manipulating additional factors such as the location of referents with respect to the interlocutors' attentional focus (e.g. using cueing paradigms).

5.7 Spatial language and perception

The idea of a flexible mapping between demonstrative use and functional representations of objects carries important implications with regards to the debate on the relationship between perceptual and linguistic representations of space.

As highlighted in the introduction, some approaches have argued in favor an isomorphism between non-linguistic representations of personal space and linguistic coding of space via demonstratives (Coventry et al., 2014). Others (Kemmerer, 1999; 2006) have rather highlighted the discrepancies, showing how the proximal/distal distinction in language functions as a purely contrastive, scale-free encoding tool.

Highlighting the role of semantic features and social factors in demonstrative use, our results present some major objections to isomorphic accounts. First, results from Article 2 underline that the functional contrast encoded by the distinction between proximal and distal demonstratives is not a purely *spatial* one, but it encompasses *both* space and semantics. Second, results from Article 3 show that the mapping between perceptual and linguistic representations of space observed in non-interactive settings does not always hold in social contexts, where participants can adapt their linguistic coding strategy to the position of the addressee. In these cases, the linguistic distinction between proximal and distal locations might or might *not* bear any resemblance to the speaker's perceptual representations of near and far space, depending on the characteristics of the ongoing task.

5.8 Semantic mapping using the DCT

Alongside the theoretical implications of our results, we regard the *methodological* aspects of our work as foundational for future research on demonstratives (and beyond). In this respect, potential developments of the DCT deserve a special mention.

While apparently confronting participants with random choices, the Demonstrative Choice Task generates very consistent patterns of linguistic behavior (Figure 27).

Figure 27a. Distribution of cross-group reliability values in demonstrative choices for the DCT. Over 1000 iterations, we divided the dataset for Experiment 1 in two groups, each containing data for half of the participants. For each word, we then computed the proportion of times it was labeled with a proximal demonstrative in each of the two groups, thus obtaining two (one per group) vectors of proportions for each of the languages. Squared Pearson's correlation between the two vectors were computed for each language and at each iteration. The figure displays the distribution of the resulting R^2 values over iterations, showing high consistency in participants' behavior.

Figure 27b. Distribution of cross-group reliability values for Experiment 2. As in Experiment 1, participants' behavior is highly consistent.

This remarkable overall consistency speaks in favor of the high reliability of the DCT. At the same time, it is interesting to note that the data still display some residual variability between stimulus words in the consistency of participants' behavior. Some words (mostly strong negative-valence words, as displayed in Figure 28) tend to be systematically associated to certain demonstrative forms, while other words elicit more variable behavior.

Figure 28a. Cross-group variability in demonstrative use for each experimental word in Experiment 1. Values on the y-axis denote differences between proportions of proximal demonstratives used for each word across the two groups in which the dataset was randomly split over 1000 iterations.

Figure 28b. Cross-group variability in demonstrative use for each experimental word included in Experiment 2.

This residual inter-subject variability might not be *unsystematic* in nature. Personality traits are, for example, good candidate sources for *systematic* variation in demonstrative use, given their possible influence on attitudes towards interaction with specific objects. To provide a concrete example, it could be hypothesized that individuals with a high score on the personality trait *openness to experience* (see Judge, Higgins, Thoresen, & Barrick, 1999) might be more willing to interact with unknown, “exotic” objects than more conservative personality types. Individuals with depressive traits might be psychologically closer to negatively charged words than individuals scoring low on depression scales. And highly extraverted individuals might be generally keener on interacting with social stimuli than introverts.

Differences in dispositions towards objects as a function of their semantic characteristics (familiarity, valence, social connotations...) are likely to surface in patterns of linguistic behavior in the DCT. Conversely, this implies that the DCT might potentially be used as a tool to *predict* personality on the basis of individual semantic signatures in linguistic behavior, with potential applications, for

example, as complementary personality tests or diagnostic tools (e.g. depression scales). In these contexts, the DCT would bring the advantage of *not* relying as much on introspection and subjective assessment, providing a more objective and conceptually simple measure for the phenomenon of interest. These hypotheses and potential applications are the focus of a follow-up study (in progress), where we are exploring the possibility of mapping personality profiles from demonstrative use on large-sample DCT datasets complemented with personality and depression questionnaires.

6. Conclusion

In this dissertation, I reviewed three articles addressing the neurocognitive foundations of spatial demonstratives and exploring their role in social interaction. In Article 1, we showed that demonstratives recruit extralinguistic brain areas implicated in visuospatial processing and attentional orienting. In demonstrative reference, language, attention and visuospatial representations are tightly intertwined. Perception and attention contribute to processing demonstrative expressions, while being in turn modulated by demonstrative use. In Article 2 and 3, we turned to investigating the cognitive underpinnings of the proximal/distal demonstrative contrast. We observed that proximal/distal coding of referents via demonstratives is grounded in a *functional* representation of the referent. The use of specific forms signals to the addressee the referent's availability for manual interaction. However, this low- vs. high-affordance contrast is implemented *flexibly* across contexts. Speakers can signal affordances either from their own or from the addressee's perspective, depending on the characteristics of the ongoing task.

Taken together, these results highlight the significance of spatial demonstratives for human cognition and social interaction, while also providing insights on more general aspects of the relationship between key aspects of cognition and language use.

In this respect, the overarching contribution of this work is two-fold. On one hand, our studies provide concrete exemplifications of how demonstratives can be used as a searchlight into core organizational and functional principles of human cognition. On the methodological side, our experiments lay the foundation for further work on the topic. Many outstanding questions and novel hypotheses remain unexplored, which could be effectively addressed with minimal adaptations of the experimental paradigms developed in this work.

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Article 1

Language beyond the language system: dorsal visuospatial pathways support processing of demonstratives and spatial language during naturalistic fast fMRI

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Abstract

Spatial demonstratives are powerful linguistic tools used to establish joint attention. Identifying the meaning of semantically underspecified expressions like “this one” hinges on the integration of linguistic and visual cues, attentional orienting and pragmatic inference. This synergy between language and extralinguistic cognition is pivotal to language comprehension in general, but especially prominent in demonstratives.

In this study, we aimed to elucidate which neural architectures enable this intertwining between language and extralinguistic cognition using a naturalistic fMRI paradigm. In our experiment, 28 participants listened to a specially crafted dialogical narrative with a controlled number of spatial demonstratives. A fast multiband-EPI acquisition sequence ($TR = 388\text{ms}$) combined with finite impulse response (FIR) modelling of the hemodynamic response was used to capture signal changes at word-level resolution.

We found that spatial demonstratives bilaterally engage a network of parietal areas, including the supramarginal gyrus, the angular gyrus, and precuneus, implicated in information integration and visuospatial processing. Moreover, demonstratives recruit frontal regions, including the right FEF, implicated in attentional orienting and reference frames shifts. Finally, using multivariate similarity analyses, we provide evidence for a general involvement of the dorsal (“where”) stream in the processing of spatial expressions, as opposed to ventral pathways encoding object semantics.

Overall, our results suggest that language processing relies on a distributed architecture, recruiting neural resources for perception, attention, and extra-linguistic aspects of cognition in a dynamic and context-dependent fashion.

Keywords: spatial demonstratives, naturalistic fMRI, dorsal stream, spatial language, spatial cognition

1. Introduction

1.1 Demonstratives: an interface between language, attention, and spatial cognition

The two utterances “I would like to buy the yellow cake” and “This one” can mean the same thing, depending on the circumstances. The latter is often used in situations where knowledge about the intended interaction (e.g. a buying frame) can be taken for granted, and the speaker simply wishes to point the hearer’s attention to the relevant object. Both sentences, however, use linguistic cues to coordinate interlocutors’ focus of attention to particular aspects of the environment. This ostensive function is a cornerstone of language, that supports collaboration and other forms of collective engagement with the physical world (Tomasello et al., 2005; Tylén et al., 2010).

Word types vary, as exemplified above, in the amount of semantic and extralinguistic (e.g. visuospatial) information needed for their comprehension. So-called *content* words, a category which includes most nouns, verbs, and adjectives, are expressions that denote objects (“cake”), qualities (“yellow”), or actions (“to buy”), by explicitly naming them. These expressions provide the semantic core of an utterance, as they have rich and view-point independent meaning (Diessel, 2006). Little extralinguistic information is needed to disambiguate the intended referent in the environment.

Other types of linguistic utterances, on the other hand, point to specific referents in the physical or discursive environment in specific situations, as seen from a specific viewpoint, without providing explicit semantic information about them. An example of this is spatial demonstratives, i.e. words like *this* and *that* in English. Demonstratives are *deictic* expressions (S. C. Levinson, 1983b): when presented in isolation, they can denote virtually *any* referent. Interpreting what “this one” means hinges on perceptual processing (e.g. how far away from the speaker are potential referents located?), attentional orienting on the basis of gaze cues and pointing gestures (Cooperrider, 2016; García et al., 2017; Stevens & Zhang, 2013), and pragmatic inference (what could the speaker be intending to refer

to?). Demonstratives are therefore a paradigmatic example of how linking language to the physical world requires the integration of linguistic forms with extra-linguistic perceptual and cognitive processing.

Demonstratives are foundational to language on a number of levels. They are linguistic universals (Diessel, 2014), they are milestones in language acquisition (E. V. Clark & Sengul, 1978), they are among the most frequent words in the lexicon (Leech & Rayson, 2014), and they play a crucial role in the evolution of grammar (Diessel, 2013). In spite of their importance in language, no neuroimaging studies investigating the neural processing of demonstratives exist, probably due to the methodological challenges posed by studying these words. As the meaning of demonstratives is dependent on the context, investigating their neural underpinnings hinges on simulating a rich linguistic and physical environment within the constraints intrinsic to neuroimaging experiments.

In this study, we constructed a novel naturalistic paradigm where we simulated such rich contexts, with the aim of elucidating which neural architectures enable the interaction between linguistic, perceptual, and attentional processes in language comprehension.

1.2 Usage patterns for demonstratives reflect functional encoding of space

The tight interdependencies between demonstrative reference and fundamental aspects of attention, perception, and spatial representations are explicitly reflected in usage patterns of different demonstrative forms.

The vast majority of natural languages encodes at least a binary distinction between a so-called *proximal* demonstrative, such as *this*, and a *distal* demonstrative form, such as *that* in English (Diessel, 1999). Experimental evidence has shown that this distinction does not encode purely metric distance between the speaker and the referent. In a series of experiments based on the *memory game* paradigm, Coventry and colleagues have shown that the contrast between proximal and distal

demonstratives maps onto the functional distinction between *peripersonal* and *extrapersonal* space, that is, between space within and outside reach (Caldano & Coventry, in press; Coventry et al., 2014, 2008; Gudde et al., 2016). In these experiments, participants were presented with shapes placed at one of 12 potential distances along a table. After a (variable) number of trials, participants were presented again with one of the shapes, and asked to indicate at which location it had previously been placed by pointing at the intended location while producing phrases consisting of a demonstrative adjective, a color adjective and a noun (e.g. “this blue square”). Referents placed *within* reach were more likely to be indicated using proximal demonstratives, while objects *outside* reach were more likely to elicit distal demonstratives.

However, when multiple competing referents are present, their relative distance also matters when speakers choose between proximal and distal demonstratives. Bonfiglioli and colleagues conducted an experiment (Bonfiglioli et al., 2009) where participants were primed with either a proximal or a distal demonstrative forms before performing reach movements towards objects positioned at either of two possible distances *within* their peripersonal space. Semantic interference effects on movement initiation were detected (in terms of slower reaction times) when participants had to reach for the *closer* target location after being primed with a *distal* demonstrative, and when they reached for the *farther* location after being primed with a *proximal* demonstrative. The proximal/distal contrast thus also codes for relative distance between potential referents and the speaker even when *both* referents are within her reach.

Previous studies have furthermore detected lateralized biases towards the pointing hand. Speakers are more likely to use *proximal* demonstratives for referents located towards their right when pointing with their right hand, which has been interpreted as evidence in favor of a connection between demonstratives and affordances for manual action (Rocca, Wallentin, Vesper, & Tylén, 2018). A strong link between demonstratives and manual action has also been observed at a purely

semantic level. When participants are asked to choose between a proximal and a distal demonstrative in the absence of any explicit spatial context, they consistently choose proximal demonstratives for objects that more easily afford manual grasp, such as small vs. big objects, and harmless vs. harmful referents (Rocca, Tylén, & Wallentin, 2019).

Additionally, demonstrative use is significantly modulated by social factors, such as the presence, position, and role of an interlocutor in the ongoing interaction. On the basis of the results from an EEG/ERPs study, Peeters and colleagues have argued that the use of proximal vs. distal demonstrative forms is influenced by whether the referent is located within vs. outside the region of space shared between two interlocutors (Peeters et al., 2015). Other studies have found that speakers tend to adapt their use of demonstratives to the position of the addressee in the context of social interaction. During collaborative interactions, proximal space tends to shift towards the addressee (Rocca et al., 2018). Speakers tend to code locations as proximal or distal depending on their distance from the *addressee*, rather than from themselves, in interactions involving turn-taking (Rocca, Wallentin, Vesper, & Tylén, 2019).

In summary, behavioral evidence suggests that the use of demonstrative forms is influenced by extralinguistic perceptual, functional and social representations of space. This leads us to hypothesize that similar extralinguistic representations might be necessary on the addressee's side, in order to process the cues provided by the use of proximal vs. distal forms.

1.3 A dorsal pathway for semantics?

Previous literature on spatial language has suggested that processing spatial expressions shares resources with non-linguistic spatial encoding. A network of dorso-parietal brain regions supports both visuospatial perception and linguistic reference to the perceived space (Wallentin et al., 2006; Wallentin, Weed, et al., 2008), while shifting spatial frames of references engage the system for

shifting visual attention, including the frontal eye fields (Corbetta et al., 1998; Wallentin et al., 2011; Wallentin, Roepstorff, et al., 2008). Additionally, integration areas in the inferior part of the parietal lobe, namely the left supramarginal gyrus and the angular gyri, have been implicated in processing of spatial closed class items, such as prepositions (H. Damasio et al., 2001; Kemmerer, 1999, 2006; Noordzij et al., 2008). The SMG is part of the temporoparietal junction, which interfaces the auditory cortex with parietal and frontal circuits (Scott & Johnsrude, 2003). The angular gyrus, located in the IPL, has been implicated in complex information integration and knowledge retrieval (Binder et al., 2009) and in scene construction (Hassabis & Maguire, 2009), both central in processing linguistic spatial relations.

Interestingly, posterior-superior parietal areas and frontal regions identified in previous studies on spatial language all belong to the dorsal visuo-spatial stream (Mishkin et al., 1983). This suggests that, globally, language processing might be organized along a ventral-dorsal divide between semantics and (spatial) relations parallel to that between object identification and locations in vision (Landau & Jackendoff, 1993, 2013). Naming objects and talking about their locations differ widely in the type of information encoded in linguistic forms. Object descriptions draw on abstract representations of spatial features, prioritizing viewpoint-independent attributes such as shape and surface relevant to categorization. Spatial relations, on the other hand, are conveyed by very coarse geometrical detail, mostly drawing on functional properties such as relative distance, containment, and contact. This provides sufficient cues for allocating attention to the relevant part of space or time in order to access more detailed information.

The hypothesis of a ventral/dorsal what/where divide in language is supported by evidence from semantic analyses of linguistic expressions and the studies mentioned above, but whether such a divide is rooted on a functional segregation at the neural level has never *directly* been tested empirically. In our study, we aimed not only to elucidate the neural architecture underlying the

processing of spatial demonstratives, but also at directly testing the hypothesis of the existence of a dorsal “where” stream for the processing of linguistic spatial relations, largely overlapping with the visuospatial dorsal stream.

Such results would make a compelling empirical case in favor of a ventral-dorsal segregation in language processing, and, more generally, underline the what/where distinction being a fundamental organizational principle for information processing in the human brain.

1.4 Present study: experimental paradigm

In this experiment, we presented participants with a specially crafted, scripted dialogue featuring two voices (a male and a female). The decision to use dialogue was motivated by the fact that, as demonstratives are prominently used to establish joint attention, they tend to occur in dialogic contexts, rather than in monologues or written discourse (i.e. *that* is 5.5 times more frequent in spoken language than in written, and *this* is 1.2 times more frequent, see Leech & Rayson, 2014). The choice of spoken dialogue therefore added further ecological validity to our investigation.

In the dialogue, two characters try to find each other in the darkness, a setting which naturally affords occurrences of spatial expressions. Demonstratives can be used *exophorically*, i.e. to refer to objects in the perceptual environment, or *endophorically*, that is, in an intralinguistic fashion, to denote parts of discourse (Diessel, 1999). This study focuses on the *exophoric* use. Several demonstratives were inserted in the text, with a balanced number of proximal (*here*) and distal (*there*) demonstratives, equally distributed across voices. By recording the two voices onto two separate audio channels, we simulated a minimal 3D-like auditory environment where participants experienced one character as being located to their left and the other to their right. Demonstratives provide indications on the position of objects (or locations) relative to the position of the speaker and conversational dyad (Coventry et al., 2014, 2008; Gudde et al., 2016; Peeters et al., 2015). It is

therefore crucial that the two speakers in the dialogue are assigned specific and distinct spatial origins.

Moreover, this manipulation enabled us to tease apart the effect of different demonstrative forms (here vs. there) from the effects of the location they denote in auditory space (left, right), especially with regards to proximal demonstratives. The location denoted by proximal demonstratives is tied to the position of the speaker and interacts with the spatial source of the speech input (while the scope of distal demonstratives is broader).

Our paradigm relied on a fast acquisition sequence ($TR = 388\text{ms}$), which, combined with finite impulse response (FIR) modelling of the hemodynamic response, allows us to optimally capture neural response at word-level resolution within naturalistic paradigms even when response patterns deviate from the time course of the canonical hemodynamic response function. Deviations from the canonical response model might indeed be expected on the basis of recent results showing that, under sustained stimulation (of which naturalistic speech is an instance), the hemodynamic response is faster than assumed by the canonical HRF (Lewis et al., 2016).

1.5 Hypotheses

In our analysis, we tested the following hypotheses:

First, we investigated which brain areas respond to the occurrence of spatial demonstratives, averaging across proximal and distal demonstrative forms. We hypothesized that processing spatial demonstratives would engage a) areas interfacing the speech input with visuospatial processing in the parietal lobes, such as the supramarginal gyrus (Scott & Johnsrude, 2003); b) higher-order integration areas in the posterior parietal cortex such as the angular gyrus, previously implicated in tasks requiring complex information integration (Binder et al., 2009; Hassabis & Maguire, 2009) and therefore likely crucial for spatial demonstratives, where comprehension hinges on integrating the categorical distance cues with the visuospatial, linguistic and pragmatic context. The left SMG and

AG have been previously implicated in the processing of spatial prepositions (H. Damasio et al., 2001; Kemmerer, 1999, 2006; Noordzij et al., 2008). Moreover, we expected demonstratives to engage c) medial parts of the superior posterior parietal cortex, previously implicated in constructing and maintaining spatial representations for both language and vision (Wallentin et al., 2006; Wallentin, Weed, et al., 2008), and d) frontal regions within the dorsal parieto-frontal attentional network effecting the attentional shifts triggered by spatial demonstratives (Corbetta et al., 1998; Wallentin et al., 2011; Wallentin, Roepstorff, et al., 2008).

Second, we compared proximal and distal demonstratives, exploring differences in the neural correlates of the two forms. Behavioral evidence on demonstratives suggests a mapping between demonstrative forms and the distinction between peripersonal and extrapersonal space. Differences between proximal and distal forms might therefore be encoded in the superior parietal lobule (SPL) and superior parieto-occipital cortex (SPOC), previously implicated in spatial encoding for manual reach (Andersen et al., 2014; Connolly et al., 2003; Gallivan, Cavina-Pratesi, & Culham, 2009; Grivaz, Blanke, & Serino, 2017).

Additionally, we analyzed interactions between demonstrative form and ear of presentation. In line with preferences for contralateral locations observed in the frontoparietal attentional stream (Halligan, Fink, Marshall, & Vallar, 2003), we tested whether areas responding to demonstratives displayed higher sensitivity to proximal forms in the contralateral ear and distal forms in the ipsilateral ear, i.e. to cases where demonstratives likely code for locations in the contralateral spatial hemifield.

Third, we tested whether, more generally, neural processing of spatial relations (as expressed in language) relies on a dorsal *where* processing stream, as opposed to a ventral *what* stream for object semantics. To test this hypothesis, we compared response to spatial demonstratives with response with the wh-words *where*, *what*, and *who*. These words prime the processing of spatial information,

object identity, and personal identity respectively, and therefore function as proxies to the divide between semantic content and spatial relations in language. Neural representations for these words were compared to representations underlying demonstratives using a novel similarity-based method, under the hypothesis of higher topographical similarity between demonstratives and *where* at the whole-brain level. Zooming in on an anatomical partitioning of brain areas, we expected this pattern to be mostly driven by higher topographical similarity in areas belonging to the dorsal processing stream. If this hypothesis held true, this would suggest that resources supporting language processing strongly overlap with resources for visuo-spatial processing, inheriting fundamental organizational principles (dorsal vs. ventral) shared across multiple domains of human cognition.

Besides testing these hypotheses, we ensured that our acquisition sequence yielded high-quality images by regressing the data against low-level acoustic features (sound envelopes from both audio channels), expecting to replicate results from previous literature (Jäncke, Wüstenberg, Schulze, & Heinze, 2002; Schönwiesner, Krumbholz, Rübsamen, Fink, & von Cramon, 2006; Stefanatos, Joe, Aguirre, Detre, & Wetmore, 2008) on spatial activation patterns in the auditory cortices for monaural stimulation. We expected both auditory cortices to respond to both envelopes for the left and right auditory channels, with larger and more widespread response in the contralateral auditory cortex. Additionally, exploiting the combination of high sampling rate (~2.58Hz) with flexible FIR models, we explored temporal BOLD response patterns in auditory cortices under sustained speech stimulation.

2. Methods

2.1 Participants

Twenty-nine participants with normal hearing and anatomically normal brains took part in the study.

Data from one participant were discarded from the analysis, due to the presence of artifacts in the EPI images. Therefore, data from 28 participants (Female = 12, Age median = 24, Range = 19-36) were included in the analyses. Participants were recruited on a voluntary basis from the participant pool of the Center for Functionally Integrative Neuroscience at Aarhus University. All participants were right-handed and reported having Danish as their first language. Gender was not deemed relevant (Wallentin, 2009, 2018). The study received approval from the research ethics committee of Region Midtjylland, Denmark, and participants gave informed written consent in accordance with local ethical requirements. Participants received monetary compensation for their participation in accordance with local policies on participant payment.

2.2 Acquisition details

Functional images were acquired on a 3-T Siemens Magnetom Tim Trio MR system equipped with a 32-channels head coil at Aarhus University Hospital, Denmark. For each participant, 3670 volumes, each containing 54 T2*-weighted slices, were acquired using a multiband-EPI sequence, with repetition time (TR) = 388ms, echo time (TE) = 27.6ms, flip angle: 36°, voxel size = 2.5mm isotropic, slice-acceleration factor = 9 (Setsompop et al., 2012), but no in-plane acceleration.

At the end of each session, a gradient echo-based field map was acquired, based on subtraction of the phase images from a dual echo acquisition, with the following parameters: repetition time (TR) = 1020ms, echo time (TE) = 10ms and 12.46ms, flip angle = 90°, voxel size = 3mm isotropic, field of view = 192 x 192 mm. These field maps were then used to unwarp geometrical distortions due to field inhomogeneities using the FieldMap toolbox and the Unwarp module in SPM12.

Pulse-oximetry and respiration were recorded during the whole experiment using scanner hardware, and used for denoising purposes. Modelling cardiac and respiration data in GLM analyses has proven effective in accounting for serial correlations in the noise structure of EPI time series,

especially in the context of acquisition sequences with sub-second temporal resolution (Bollmann, Puckett, Cunningham, & Barth, 2018; Lund et al., 2006; Purdon & Weisskoff, 1998; Sahib et al., 2016).

2.3 Stimuli

Participants listened to a spoken dialogue (in Danish) with a total duration of 23 minutes and 40 seconds through headphones. No visual stimuli were displayed during the experiment. Participants were instructed to keep their eyes open through the experiment.

In the dialogue, two fictive characters are heard, one speaking through the left channel of the headphones and the other speaking through the right. The two characters find themselves in a dark and unfamiliar environment. The dialogue unfolds with constantly alternating focus on narrative and spatial information. Over the course of the interaction, the two characters try to figure out where they are, what the surrounding environment looks like, who their interlocutor is, as well as how and why they ended up in the darkness. This setting, where characters are constantly engaged in exploring and describing a spatial scene, makes room for several motivated occurrences of spatial demonstratives. Moreover, it provides a suitable context for questions, and therefore wh-words, to occur naturally and with high frequency.

These characteristics enabled us to create a naturalistic speech stimulus while retaining control of the frequency of occurrence of words of interest, as well as on their position and spacing in the text.

The full text of the dialogue in Danish and in an English translation is available at osf.io/j9fm5/. Overall, the dialogue included 80 occurrences of each demonstrative form (*proximal* = *her*, *distal* = *der*), equally distributed across the two voices (and therefore auditory hemifields). Inter-stimulus intervals for each demonstrative type were not fixed but semi-controlled, with a mean ISI of

17.78s for proximal demonstratives and a mean ISI of 17.43s for distal demonstratives. Forty instances of the words *what* (*hvad*), *where* (*hvor*), and *who* (*hvem*) were embedded in the text, balanced across the two voices. The mean ISI was 31.39s for *what*, 35.76s for *where*, and 33.7s for *who*.

The dialogue unfolds over 340 lines (170 per character). The two characters speak a total of 1585 words and 1470 words.

One hundred instances of singular first- and second- person pronouns (*I* and *you*) also occurred in the text, equally distributed across voices. The results of this latter manipulation will be reported elsewhere.

2.4 Speech synthesis

The dialogue was recorded using two synthesized Danish voices (a male and a female). We interfaced an NSSpeechSynthesizer instance on macOS Sierra (Version 10.12.2) via the *pyttsx* library. The script set each voice to read aloud specific parts of the dialogue at a pace of 130 words per minute. The sound output was played and recorded on the internal audio system using SoundflowerBed (v 2.0.0) and saved as waveform stereo file with a sampling rate of 44.1kHz. We embedded AppleScript commands interacting with QuickTime Player (v 10.4) in the Python script, in order to automatize recording and time-lock the audio file to the onset of the sound stimulus.

Using text-to-speech synthesis offered a number of advantages over using recordings of natural voices. The engine interface in *pyttsx* allowed us to implement a callback function providing exact time stamps for the onset of each word in the dialogue. This overcomes the disadvantages of manual coding of audio files both in terms of precision and time requirements. Moreover, speech synthesis enabled an optimal combination of control and flexibility in stimulus generation. The output was tightly controlled in terms of pace and pronunciation, and the audio signal was not affected by

any source of noise. Overall, the automatization of stimulus generation using Python-based speech synthesis enabled us to flexibly refine our stimulus over different steps of the piloting process, optimizing time demands over repeated iterations of processing and annotation stages.

The dialogue was recorded onto a two-channel stereo track, with each voice presented monaurally. Manipulating the spatial source of voices afforded simulation of a minimal 3D spatial context, with each character being experienced as located either to the left or to the right of the participant.

The dialogue was presented through MR-compatible OptoACTIVE headphones (OptoAcoustics Ltd.). The side of presentation of each voice was counterbalanced across participants.

2.5 Online behavioural task

During the experiment, participants performed a simple on-line behavioural task, to ensure that they remained actively engaged throughout the experiment and to avoid data loss due to participants falling asleep. Thirty breaks lasting 5 seconds were embedded in the dialogue. Fifteen out of thirty breaks were interrupted by a pure tone of 500ms duration. Participants were instructed to respond to the occurrence of pure tones by pressing a button on the response box.

Tones always occurred during silent breaks, and their onset followed the start of the break with a perceptible lag. Participants were informed that tones would only occur during the silent breaks, so to make sure that they could entirely focus on the comprehension of the dialogue without expecting sudden disruptions of its flow. Participants were split into two groups. Groups differed in the subset of breaks during which pure tones were presented in order to decorrelate perceptual and motor effects from the linguistic stimuli across participants. PsychoPy2 (Peirce, 2007) was used for stimulus delivery and response collection.

Twenty-six (26) out of 28 participants responded to all tones embedded in the dialogue, while

the remaining 2 participants responded to 14 out of 15 tones. Performance levels for all participants were therefore deemed sufficient for inclusion in the analysis.

2.6 Post-experiment behavioural tasks

Participants performed two additional post-experiment tasks outside the scanner. Before entering the scanner, participants were informed that, at the end of the experiment, they would be asked to draw the scene where the dialogue took place, and answer some comprehension questions on the content of the dialogue. While responding to tones ensured general engagement during the unfolding of the experiment, the post-experiment tasks motivated participants to pay close attention to the content of the dialogue and tested their actual comprehension of the text.

The drawing task was meant to prime participants to focus on spatial expressions, while still keeping them naïve to our interest in spatial demonstratives. Drawings were entirely unconstrained in terms of degree of detail, number of elements represented, and their configuration. No behavioural metrics were extracted from this task.

The questionnaire tested engagement in the comprehension of the dialogue, and it was meant to provide a behavioural criterion for inclusion in the fMRI analysis. Participants answered 20 comprehension questions tapping onto narrative aspects of the stimulus story, e.g. information on characters and events mentioned during the dialogue. All participants performed significantly above chance (mean performance = 88.2% correct responses) and were therefore included in the fMRI analysis.

After the comprehension questionnaire, participants were administered a short questionnaire tapping onto their experience of the dialogue. All participants reported being able to hear the two voices clearly and to understand the dialogue without major effort. They were explicitly asked to comment on whether and how the use of synthesized voices affected their experience of the dialogue.

Some participants reported having noticed a few oddities in the pronunciation, but all specified that this did not have an impact on their comprehension of and focus on the content. No participants reported tones being disruptive of their engagement in the comprehension of the dialogue.

2.7 Data pre-processing

2.7.1 EPI images and anatomical images

Data were preprocessed using SPM12. T1-weighted images, T2*-weighted EPI images and field maps were first converted from DICOM to NIFTI format. EPI images were then realigned to the first image in the time series via rigid body spatial transformations. Realignment parameters for each subject were stored and used in the GLM analyses to account for residual movement-related variance.

Using the FieldMap toolbox, subject-specific voxel displacement maps were computed from the presubtracted phase image and the magnitude image with shorter echo time ($TE = 10\text{ms}$). EPI images were then unwarped using the resulting voxel displacement maps to correct for geometric distortions caused by field inhomogeneities. Subject-specific anatomical images were co-registered to the mean unwarped functional image, then segmented into 6 tissue maps. A 4mm FWHM smoothing filter was applied to the images prior to estimation of a forward deformation field, used to normalize the unwarped EPI images and T1-weighted images to MNI space.

2.7.2 Physiological data

Pulse-oximetry and respiration data were processed using Matlab PhysIO Toolbox (Kasper et al., 2017) and modelled using the RETROICOR algorithm (Chang, Cunningham, & Glover, 2009; Glover et al., 2000) with 3rd order and 4th order expansion for cardiac and respiratory terms, and 1st order expansion for their interaction. The 6 movement regressors estimated during realignment of EPI images were included in the RETROICOR model, and all regressors were orthogonalized.

2.8 Hemodynamic response modelling

In all GLM analyses reported in the Results section, hemodynamic response was modelled using finite impulse response (FIR) basis sets including 20 basis functions with 20 contiguous 500ms time bins modelling hemodynamic response from 0 to 10 seconds after stimulus onset.

FIR basis sets model the average peristimulus signal over each time bin via linear deconvolution of impulse response (R. N. A. Henson, 2003). Carrying minimal assumptions on the response, FIR models allow for local variation in its shape and amplitude, and can capture event-related signal changes with temporal patterns that deviate from the canonical HRF. Coupled with fast acquisition protocols, FIR models thus enable detection of high-frequency modulations present in the BOLD signal under sustained fast-paced stimulation (Lewis et al., 2016). This makes these models suitable for naturalistic experiments on word semantics, where the speech rate of the stimulus tends to exceed one hundred words per minute, and responses to individual lexical units are likely expressed by high-frequency modulations over a sustained response.

2.9 GLM analyses

2.9.1 Model structure and statistical inference

In all GLM analyses reported in the Results section, first-level models included regressors coding for the occurrence of each event of interest (differing across analyses), and a shared set of regressors accounting for non-speech events occurring in the experiment (silent breaks, pure tones, button presses). All components of individual RETROICOR models for physiological data and the 6 realignment parameters were added as covariates to account for residual movement-related variance and physiological noise.

For all analyses, T-contrasts testing for the effects of interest were computed on the first level,

and contrast images at each time bin were entered into a second-level ANOVA with non-sphericity correction. The second-level model included 28 contrast images (one per subject) for each time bin, as well as covariates accounting for subject-specific effects.

Group-level inference was based on F-contrasts testing for the significance of first-level estimates at any time bin. The results of these contrasts were masked so to include only those voxels which are also significant in T-contrasts testing for an average positive effect across the 10 seconds post-stimulus interval. This allowed us to limit inference to those regions where signal increased as a response to events of interest, as well as to exclude those regions where F-tests might capture unreliable effects driven by estimates in one (or few) time bins. Such masking was not applied when directly testing for differences between regressors, thus allowing for effects with both positive and negative directionality.

In all analyses, inference was drawn at the voxel level using a significance threshold of $p < .05$ (FWE-corrected) and an additional spatial extent threshold of 30 voxels.

2.9.2 Sound envelope

In order to ensure that the fast acquisition sequence yielded high-quality EPI images, we performed a first whole-brain analysis targeting responses to low-level acoustic features (sound levels) of the stimulus, expecting significant effects in the auditory cortices, with larger and more widespread response in the contralateral auditory cortex (Jäncke et al., 2002; Schönwiesner et al., 2006; Stefanatos et al., 2008). In this analysis, sound envelopes for the left and the right channels were used as regressors of interest in the first-level models.

2.9.3 Spatial demonstratives

In the GLM analyses testing for regions responding to the occurrence of spatial

demonstratives, four sets of FIR regressors were included at the first-level, modelling the onsets of *proximal* and *distal* demonstratives in the *left* and the *right* auditory channel. The model thus included one set of FIR predictors coding for *all* occurrences of *proximal demonstratives* in the *left* auditory channel, one set coding for *all* occurrences of *distal demonstratives* in the *right* auditory channel, one set coding for *all* occurrences of *proximal demonstratives* in the *right* auditory channel, one set coding for *all* occurrences of *distal demonstratives* in the *right* auditory channel. As all non-speech events in the experiment (nuisance regressors, silent breaks, tones, button presses) were also modelled, what was left unmodelled was thus a general language baseline. Analyses testing for an average effect of demonstratives thus compare demonstratives to this general language baseline.

2.9.4 Wh-words

To extract parameter maps for wh-words for multivariate similarity analyses, we fitted a comprehensive model including regressors for all words systematically manipulated in the experiment. This model included two sets of FIR regressors coding for all occurrences of proximal and distal demonstratives (*here* and *there*, regardless of side of presentation), three sets coding for all occurrences of wh-words (*what*, *where*, *who*) and regressors coding for occurrences of personal pronouns. First-level parameter estimates for each demonstrative and wh-word were used as input to compute correlations used in the multivariate similarity analysis.

2.10 Multivariate similarity analyses

First-level FIR models yielded, for each regressor and for each participant, one parameter map for each post-stimulus time bin. From the cumulative model including regressors for all experimentally controlled words, we extracted parameter maps for the two demonstrative forms (*proximal* and *distal*), and for the wh-words *where*, *what* and *who*, at each time point. This yielded 28 (subjects) x

20 (time points) x 5 (words) parameter maps.

For each subject and at each of the 20 time points, we computed Pearson's correlations between parameter maps for demonstrative forms and wh-words. Correlations between whole-brain parameter maps for each pair of words quantified global topographical similarity in response to such words at each time point. This yielded one correlation value for each of the 28 subjects, at each of the 20 time points, for each of the 6 combinations between a demonstrative and a wh-word.

As expanded upon in the Results section, three summary metrics (area under the curve, mean correlation, and maximum correlation) were extracted for each correlation time series. These measures were used as outcome variables in linear mixed-effects regression models comparing whole-brain topographical similarity between representations of demonstratives and representations of each wh-word. Zooming in on similarity patterns at a more local level, we also computed Pearson's correlations for each word pair, each subject, and each time point on 60 brain regions extracted from the AAL atlas (Rolls, Joliot, & Tzourio-Mazoyer, 2015; Tzourio-Mazoyer et al., 2002; see also Appendix A for more details). A descriptive overview of local topographical similarity patterns is provided in the Results section.

2.11 Data and Code Availability Statement

Materials and code for the present experiment are publicly available on the Open Science Framework (osf.io/j9fm5/). The repository includes the full text of the stimulus dialogue in Danish and a full English translation, the audio files used as stimuli (in Danish), a 5 minutes audio sample in English, Python scripts used for stimulus creation and delivery, processed fMRI data and analysis scripts for both whole-brain and ROI-based similarity analysis, English translations of the post-experiment questionnaires, data and analysis script for the post-experiment comprehension questionnaires, data and analysis scripts for the online behavioural task. The repository also includes a description of each

item in its wiki. Raw MR data are not fully anonymized and have therefore not been made publicly available.

All the group-level statistical maps (both thresholded and unthresholded) are publicly available on NeuroVault, at the ID: <https://identifiers.org/neurovault.collection:5717>.

Analysis scripts are available on GitHub at: [rbroc/demonstrativesfMRI](https://github.com/rbroc/demonstrativesfMRI). GLM models for first-level analyses and second-level results can be shared upon request.

3. Results

3.1 Univariate analyses

3.1.1 Sound envelopes

Variation in sound levels in the left channel significantly modulated activity in the right auditory cortex, with peak in the primary auditory cortex and extending along the superior temporal gyrus, MNI: [52, -18, 6], $F_{20,513} = 30.07$, cluster extent = 1220 voxels, and in the left auditory cortex, peak MNI coordinates: [-66, -24, 0], $F_{20,513} = 15.65$, cluster extent = 124 voxels.

Additional clusters in the precentral and postcentral gyri also responded to modulations in the left sound envelope. We detected significant clusters in the right precentral gyrus, peak MNI: [54, -8, 50], $F_{20,513} = 14.77$, cluster extent = 43 voxels, and left precentral gyrus, peak MNI: [-54, -14, 50], $F_{20,513} = 8.02$ and cluster extent = 46 voxels. Significant clusters were also detected in the right postcentral gyrus, peak MNI: [22, -38, 74], $F_{20,513} = 12.20$, cluster extent = 52 voxels, and left postcentral gyrus, peak MNI: [-58, -26, 46], $F_{20,513} = 8.00$, cluster extent = 31 voxels.

Figure 1. Regions responding to variation in sound levels in the left audio channel, $p(\text{FWE}) < .05$, cluster threshold = 30 voxels. Colors code for F-values ($df = 20, 513$) from second-level contrasts.

Figure 2 displays the time course of contrast estimates at each contiguous 500ms time bin after stimulus onset. The time course of the response is similar across hemisphere, with peak between 3 and 4 seconds, but the intensity of the response was higher in the contralateral auditory cortex.

Figure 2. Time course of the response to variation in sound levels in the left channel at peak voxels in the left auditory cortex (left panel), and right auditory cortex (right panel). Error bars indicate between-participant standard errors. The overlaid curve smooths the average time series using local regression.

Sound levels in the right channel significantly modulated response in the left auditory cortex, with peak in A1 at MNI coordinates $[-52, -28, 10]$, $F_{20,513} = 44.27$, cluster extent = 1722 voxels, and in the right auditory cortex, peak MNI: $[64, -12, 8]$, $F_{20,513} = 23.69$, cluster extent = 898 voxels.

Beyond auditory cortices, we detected clusters with peaks in the left precentral gyrus, peak MNI coordinates $[-52, -10, 48]$, $F_{20,513} = 24.94$, cluster extent = 250 voxels, in the right precentral gyrus, peak MNI coordinates $[56, 2, 44]$, $F_{20,513} = 14.62$, cluster extent = 120 voxels, and in the left postcentral gyrus, peak MNI coordinates $[-56, -26, 50]$, $F_{20,513} = 9.92$, cluster extent = 42 voxels.

Figure 3. Regions responding to modulations in sound levels in the right channel. Significant clusters were detected in the left and right auditory cortices, as well as in the precentral gyri bilaterally and in the left postcentral gyrus. Colors code for F-values ($df = 20, 513$) from second-level contrasts.

As observed for the left sound envelope, response was larger in the contralateral auditory cortex. Contrast estimates show that response peaks around 3-4 seconds in the left auditory cortex, while response might peak later in the right auditory cortex.

Figure 4. Time course of the response to variation in sound levels in the right channel, for peak voxels in the left auditory cortex (left panel), and right auditory cortex (right panel). Error bars indicate between-participant standard errors. The overlaid curve smooths the average time series using local regression.

A direct comparison of response to the left and right sound envelope showed that the left auditory cortex displayed a stronger response to variation in sound levels in the right channel. The contrast detects a cluster with peak in the left primary auditory cortex, MNI: [54, -28, 10], $F_{20,513} = 26.42$, cluster extent = 986 voxels. No preference for either the contralateral or the ipsilateral auditory hemifield was observed for the right auditory cortex.

Overall, the observed lateralization patterns, with bilateral responses marked by a contralateral advantage, are in line with our prediction. Moreover, our results suggest that, in the context of monaural stimulation, the magnitude of response to auditory stimuli in the right hemifield is stronger, which is consistent with the right-lateralized advantages in auditory processing largely attested in the literature (Hugdahl & Westerhausen, 2016; Kimura, 1967). These results are discussed in more detail in Appendix B.

Figure 5. Direct contrast between left and right sound envelope. The left auditory cortex responds more strongly to sound variations in the right channel than in the left channel. No asymmetry is observed in the right auditory cortex.

3.1.2 Demonstratives

3.1.2.1 Average effect of demonstratives (proximal and distal)

The occurrence of demonstratives across both sides of presentations significantly modulated activity in a bilateral network involving inferior parietal, frontal and parieto-occipital regions.

In the inferior part of the parietal lobes, we detected a cluster with peak in the posterior part of the left angular gyrus, MNI: [-38, -80, 36], $F_{20,513} = 29.68$, cluster extent = 362 voxels, and a cluster with peak in the right angular gyrus, MNI: [40, -74, 42], $F_{20,513} = 23.40$, cluster extent = 439 voxels, both extending towards the middle occipital cortex. We also detected significant activation in the left supramarginal gyrus, peak MNI coordinates [-42, -50, 58], $F_{20,513} = 12.00$, cluster extent = 67 voxels.

Demonstratives also modulate activity in the left precuneus, peak MNI coordinates [-2, -78, 42], $F_{20,513} = 11.77$, cluster extent = 131 voxels, and in the right precuneus, peak MNI coordinates [10, -76, 42], $F_{20,513} = 9.71$, cluster extent = 34 voxels.

The anterior part of the middle frontal gyrus also responds to the occurrence of demonstratives, with a significant cluster in the left hemisphere, peak MNI coordinates [-38, 52, 14], $F_{20,513} = 8.20$, cluster extent = 50, and in the right hemisphere, peak MNI coordinates [42, 52, 16], $F_{20,513} = 8.20$, cluster extent = 50.

$F_{20,513} = 10.42$, cluster extent = 75 voxels.

Additionally, effects of demonstrative processing were also observed in the right frontal eye field, peak MNI coordinates [32, 6, 64], $F_{20,513} = 28.04$, cluster extent = 46 voxels.

Figure 6. Brain regions responding to spatial demonstratives (both proximal and distal) across left and right channel. The analysis displays significant clusters in the inferior parietal cortices, in the medial superior parietal cortices, as well as in the middle frontal gyri, and right frontal eye field.

The time course of the response in parietal clusters is displayed in Figure 7. Response follows a slower time course than the auditory cortices, with peaks around 6 seconds after stimulus onset.

Figure 7. Time course of the response in peak voxels in the left angular gyrus (top left), right angular gyrus (top right), left precuneus (bottom left), right precuneus (bottom right). Error bars indicate between-participant standard errors. The overlaid curve smooths the average time series using local regression.

3.1.2.2 Proximal vs. distal demonstratives

All the regions detected in the previous analysis were used as an inclusive mask for a direct comparison of distal and proximal demonstratives, aimed at highlighting differences between neural underpinnings of different demonstrative forms.

A direct comparison of proximal and distal demonstratives did not detect any significant cluster at a threshold of $p < 0.05$, and a cluster threshold of 30 voxels.

As a post-hoc test, we lowered the cluster threshold to 5 voxels to explore whether differences

between proximal and distal demonstratives might be encoded in smaller neuronal subpopulations within the regions of interest.

The analysis displayed higher activation for distal demonstratives in clusters with peaks in the left angular gyrus, MNI: [-42, -78, 34], $F_{20,513} = 7.84$, cluster extent = 13 voxels, right angular gyrus, MNI: [40, -74, 42], $F_{20,513} = 6.26$, cluster extent = 13 voxels, right frontal eye fields, (MNI: [38, 6, 60], $F_{20,513} = 10.45$, cluster extent = 12 voxels), and right middle frontal gyrus (MNI: [42, 52, 16], $F_{20,513} = 8.34$, cluster extent = 8 voxels).

These patterns might indicate that responses to proximal and distal demonstrative differ in intensity (with larger response for distal demonstratives) rather than in neural substrates. However, given the lenient threshold used for this exploratory contrast, the small effect size, and since linguistic context for proximal and distal demonstrative forms was not controlled for in the text, these results provide a pointer for future studies, rather than direct evidence for the nature of semantic representation supporting different demonstrative forms.

3.1.2.3 Whole-brain time course of response to demonstratives

Summarizing spatial and temporal features of neural response to demonstrative expressions, Figure 8 and Figure 9 display whole-brain parameter maps for proximal and distal demonstratives over contiguous 500ms time bins after word onset.

Figure 8. Parameter maps (averaged across participants) for *proximal* demonstratives over 10 seconds after stimulus onset, at 500ms intervals.

Figure 9. Parameter maps (averaged across participants) for *distal* demonstratives over 10 seconds after stimulus onset, at 500ms intervals.

Distal demonstratives exhibited more widespread and larger (although not significantly larger) responses than proximal demonstratives in all regions identified in the analysis. While the auditory cortices displayed an early and fast response, response in inferior parietal and medial occipital cortex peaks later in the case of proximal and distal demonstratives, with more sustained activation for distal demonstratives. Response in the frontal clusters showed higher-frequency fluctuations, with an early response for proximal demonstratives and multiple waves of activation for distal demonstratives.

3.1.2.4 Interaction between demonstrative type and sound source

To identify whether any regions respond to the specific spatial location denoted by demonstratives, rather than to specific demonstrative forms, we tested for interactions between demonstrative form (proximal vs. distal) and sound source (left vs. right). As in the contrast between proximal and distal demonstratives, we constrained the analysis to those voxels that significantly responded to the occurrence of spatial demonstratives.

The rationale behind the test is that, if any areas respond more strongly to locations to the left of the participant, they would exhibit a positive response to both: a) occurrences of proximal demonstratives in the left channel; b) occurrences of distal demonstratives in the right channel, i.e. to instances of *here* or *this* uttered by the character located to the left of the participant, and instances of *there* or *that* uttered by the character located to the right of the participants. The opposite patterns would be observed for regions preferentially responding to locations in the right hemifield.

This contrast detected no significant voxels at a significance threshold of $p(\text{FWE-corrected}) < .05$ and a spatial extent threshold of 30 voxels, nor any clusters were detected when lowering the cluster threshold to 5 voxels.

3.1.3 Wh-words

The occurrence of *where* in the text significantly modulated activity in clusters with peaks in the left angular gyrus, MNI: [-52, -62, 38], $F_{20,513} = 21.90$, cluster extent = 93 voxels, and in the right angular gyrus, MNI: [44, -68, 42], $F_{20,513} = 10.60$, cluster extent = 37 voxels. These clusters largely overlap with the inferior parietal clusters responding to the occurrence of spatial demonstratives. No clusters were detected when testing for effects of *what* and *who*.

3.2 Multivariate similarity analysis

3.2.1 Whole-brain similarity between demonstratives and wh-words

Figure 10 displays between-participant averages of whole-brain topographical similarity (whole-brain correlations) between demonstratives and wh-word at each time point after stimulus onset.

Figure 10. Whole-brain correlations between demonstratives and wh-words over time (500ms bins, over 10 seconds after stimulus onset). Bars denote averages across subjects and demonstrative type at each time point. The overlaid curve smooths the average time series using local regression. Error bars indicate standard error across participants. Correlations are on average higher for *where*, and their time course suggests similar BOLD response patterns for *where* and spatial demonstratives.

We extracted three summary metrics for the correlation time series. For each participant and each demonstrative/wh-word pair, we computed the area under the curve (AUC) defined by the correlation time series, as well as mean and maximum correlation over the 10 seconds span.

We used these measures to test for differences between wh-words in their overall

topographical similarity with demonstratives using mixed-effects linear regressions. We fitted three models with the same fixed and random effects structure, and with AUC, mean correlation and maximum correlation as continuous outcome variables. In all models, the fixed effects structure included a categorical regressor coding for wh-word with *where* as reference level, while the random effects structure included an intercept for each subject and a random slope for the effect of wh-word.

In all models, similarity was higher for *where* compared to both *what* and *who*. AUC values were significantly lower for *what* compared to *where*, $\beta = -0.16$, $se = 0.06$, $t(68.11) = -2.5$, $p < .05$, and for *who* compared to *where*, $\beta = -0.21$, $se = 0.07$, $t(27.41) = -3.07$, $p < .01$. Post-hoc contrasts displayed no significant difference between *what* and *who*. Analogous patterns were observed using mean and maximum correlation as outcome variables (see Appendix C).

3.2.2 Local similarity patterns

To zoom in on local topographical similarities and identify whether specific regions are driving the global similarity pattern observed above, we computed Pearson's correlations between demonstratives and wh-words for 60 brain regions extracted from the AAL2 atlas, covering all regions within the frontal, temporal, parietal and occipital lobes. This yielded 28 (subjects) x 20 (time points) x 6 (word combinations) x 60 (regions of interest) similarity values. Here, correlation values represent topographical similarity between words within each of the regions.

Figure 11 provides an overview of correlations between neural representations of demonstratives and wh-words at each time point and for each brain region.

Figure 11. Local topographical similarity between demonstratives and wh-words over 10 seconds post stimulus onset in 60 brain regions extracted from the AAL2 atlas. Regions on the y-axis are sorted by ascending AUC for similarity between demonstratives and *where*.

The patterns in the figure suggest that correlations were lower for *what* and *who* compared to *where* across most regions, indicating that differences in topographical similarity at the whole-brain level reflect a widespread tendency rather than being uniquely driven by a small subset of regions.

Within this overall pattern, however, regions exhibit gradient variability. A group of frontal and parietal regions, located at the top of the graph (see Figure 11), displays markedly higher similarity with *where*, as well as a time course suggestive of analogous BOLD response patterns for demonstratives and *where*. These regions, bilaterally distributed and extending beyond the language network, largely overlap with the dorsal processing stream responsible for non-linguistic spatial

perception, and they might constitute a network of neural resources for spatial cognition shared across the linguistic and non-linguistic domain.

Figure 12. Correlation between demonstratives and *where* by region of interest over time. Colours code for average correlation values across subjects. Areas along the dorsal stream exhibit higher correlation values, with similarity evolving at a time course plausible for hemodynamic response, suggesting that the dorsal stream might constitute a network of resources for spatial processing shared across the linguistic and non-linguistic domain.

4. Discussion

Spatial demonstratives are powerful linguistic tools used to manipulate and share attention, and rely heavily on the synergy between language, perception, and spatial cognition. In this experiment, we

investigated how this intertwining of linguistic and extra-linguistic cognition is implemented in the brain. This interplay is pivotal to language comprehension in general, but especially prominent in demonstratives. As predicted, we observed that spatial demonstratives engage a network of frontoparietal areas previously implicated in the construction, maintenance, and navigation of visuospatial representations. Additional analyses suggested that dorsal visuospatial pathways might be generally implicated in the processing of linguistic spatial expressions.

4.1 Integrating input, space and context in the posterior parietal cortex

Consistent with our predictions, demonstratives elicited bilateral responses in the supramarginal gyri, the posterior part of the angular gyrus, extending towards the middle occipital gyrus, as well as in medial superior parietal clusters with peaks in the precuneus. Crucially, all these regions are part of dorso-parietal visuospatial pathways not specific to linguistic processing (Kravitz, Saleem, Baker, & Mishkin, 2011).

The supramarginal gyrus is part of the temporo-parietal junction, responsible for interfacing the auditory cortex with parietal and frontal systems (Scott & Johnsrude, 2003). It is anatomically connected to the angular gyrus (Lee et al., 2007), a heteromodal association area (Bonner, Peelle, Cook, & Grossman, 2013; A. R. Damasio, 1989; Rademacher, Galaburda, Kennedy, Filipek, & Caviness Jr, 1992) implicated in a variety of processes requiring the integration of (task-relevant) information into coherent wholes (Seghier, 2013).

Integrating novel incoming information with previously constructed spatial and semantic contexts is crucial for spatial demonstratives. To decode the intended location, the coarse distance cues encoded by the semantics of specific forms (*here* = *near* vs. *there* = *far*) need to be integrated with knowledge on the position of the speaker within the previously constructed spatial scene, as well as with context-driven expectations on the intended referent. In this process, the angular gyri are

supported by co-activated parietal clusters. Representations of spatial scenes are maintained in working memory and updated by the precuneus, which is directly connected to the angular gyrus via the occipitofrontal fascicle (Makris et al., 2007) and has previously been implicated in spatial working memory for both vision and language (Wallentin, Weed, et al., 2008; Zaehle et al., 2007).

4.2 Attentional orienting towards intended location: frontal clusters

Demonstratives bear a close link to attentional reorienting, as they are used to directly trigger attentional shifts towards relevant locations. Congruent with this, we found increased activation in the anterior part of the middle frontal gyrus bilaterally (BA10 and BA46) and in the right frontal eye fields. These areas belong to attentional networks responsible for controlling visually and memory-guided saccades also in absence of overt attentional reorienting (Corbetta et al., 1998; Fox, Corbetta, Snyder, Vincent, & Raichle, 2006). The frontal eye fields have previously been implicated in shifts in reference frames for the processing of linguistic spatial relations (Wallentin, 2012), a process relevant in decoding the referent of spatial demonstratives. Spatial demonstratives provide distance cues on the location of the intended referent relative to the speaker (or the dyad), thus requiring a transition from a default egocentric encoding of the scene to an allocentric frame with the speaker's position as centre. However, significant activation in the frontal eye fields was only found in the right hemisphere, an asymmetry which does not directly resonate with previous studies and calls for further investigation. Other complementary factors might explain the effect of demonstratives on the FEF. FEF activation might also be triggered by participants performing actual eye movements in response to demonstratives. While this interpretation is compatible with the function of the frontal eye fields, it cannot be tested empirically in this context as no eye-tracking data were collected during the experiment.

4.3 No spatial segregation between proximal and distal forms

Contrary to our predictions, we did not find any evidence for spatially distinct substrates supporting processing of proximal and distal demonstratives, contrary to the hypothesis that areas coding for object reachability would be differentially recruited by the two demonstrative forms. This lack of spatial segregation might be explained by different factors. While reachability might be driving speakers' choices in production, explicit encoding of reachability might not be necessary for comprehension. Scanning the visual scene on the basis of allocentric distance indications (near vs. far from the speaker), as well as the aid of context-driven expectations, might be sufficient to identify the intended referent.

A further explanation for the lack of segregation between demonstrative forms might be the absence of a clear-cut partition between neural resources coding for reachable and non-reachable locations. Solid evidence for such segregation has been found in non-human primates (Batista et al., 1999; Cohen & Andersen, 2002; Colby & Goldberg, 1999). In humans, behavioural patterns from visuo-tactile integration tasks are coherent with the existence of a similar architecture (di Pellegrino & Ládavas, 2015; Ládavas, 2002), and in line with neuropsychological evidence for double dissociations between peripersonal and extrapersonal neglect (Halligan et al., 2003; Halligan & Marshall, 1991; Ten Brink, Biesbroek, Oort, Visser-Meily, & Nijboer, 2019; Vuilleumier, Valenza, Mayer, Reverdin, & Landis, 1998). However, coherent evidence for a hard-wired segregation is yet to be found. A number of studies have attempted to identify areas exclusively associated to manual reach (Connolly et al., 2003; Gallivan et al., 2009), but object reachability is often confounded with purely visual parameters, such as distance from the subject and position of the target relative to the centre of fixation.

Nonetheless, we detected magnitude differences in response to proximal and distal forms in all areas responding to demonstratives. This finding might be explained by distal forms imposing

heavier processing demands. Proximal expressions denote a location which is roughly equivalent to the position of the speaker. Shifting attentional focus towards the speaker might be enough to decode the intended referent. On the other hand, distal demonstratives provide more underspecified cues, compatible with any location which is *not* in the proximity of the speaker. In this case, reference resolution might require a more extensive search, and more heavily rely on the integration between spatial context and top-down expectations. Further experiments are needed to directly test this hypothesis.

Finally, we found no interactions between demonstrative forms and side of presentation, thus not supporting the hypothesis of areas of interest displaying preferences for the contralateral hemispace. Variability in the spatial configuration of the imagined scene across participants and the spatial underspecification of locations denoted by demonstrative forms (especially distal forms) in absence of an external visual stimulus might explain the lack of such an effect.

4.4 Spatial language and the dorsal stream

In our analysis, we showed that global topographical similarity between demonstratives and wh-words priming processing of spatial (*where*) content is higher than similarity with non-spatial (*what* and *who*) wh-words. This pattern is driven by frontal and parietal areas belonging to the dorsal stream and related pathways. We interpret this as suggestive of a functional role for dorsal (*where* or *how*, see Goodale & Milner, 1992) pathway(s) in the processing of linguistic expressions describing spatial relations, as opposed to ventral structures (the *what* stream) supporting semantic and conceptual processing.

The involvement (and functional segregation) of the *where* and *what* pathways in language comprehension has previously been hypothesized on a theoretical basis (Landau & Jackendoff, 1993, 2013), and has been indirectly supported by empirical evidence on the overlap between neural

substrates for linguistic and visual spatial processing (Wallentin, Weed, et al., 2008). However, our study is the first to provide direct evidence of a general involvement of the dorsal stream in spatial language, and it paves the way for further research.

The dorsal stream might not be recruited exclusively by spatial expressions, but rather exhibit a preference for words heavily relying on contextual integration. Moreover, some studies have suggested a tripartite organization of the dorsal stream into pathways encoding spatial information for manual action (parieto-premotor pathways), attentional orienting (parietal-prefrontal pathway), and spatial navigation (parieto-medial-temporal pathway) (Kravitz et al., 2011). This tripartite distinction might also be reflected in a further functional specialization of dorsal pathways for different types of linguistic spatial reference frames (e.g. allocentric or landmark-based vs. egocentric reference, categorical vs. coordinate-based encoding).

Finally, direct involvement of the dorsal stream in spatial language might bear a crucial indication on the nature of the neurobiological substrates of language processing in line with distributed accounts (Barsalou et al., 2003; Desai et al., 2016; Fernandino et al., 2015; Huth et al., 2012; Pulvermüller, 2005). Rather than relying on a specialized circuitry, language processing seems to engage a flexible and non-segregated architecture, where neural structures supporting perceptual, attentional and higher-level cognitive tasks are dynamically recruited and mutually interfaced in a context-dependent fashion.

5. Conclusions

We conducted a naturalistic fast fMRI experiment to investigate the neural correlates of spatial demonstratives. Our findings suggest that processing spatial demonstratives recruits dorsal parieto-frontal areas previously implicated in extra-linguistic visuospatial cognition and attentional orienting. Additionally, we provide evidence that dorsal “where” pathways might be generally

involved in the processing of linguistic spatial expressions, as opposed to ventral pathways encoding object semantics. More generally, these results suggest that language processing might rely on a distributed and non-segregated architecture, recruiting neural resources for attention, perception and extra-linguistic aspects of cognition in a dynamic and context-dependent fashion.

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Appendix A

The 60 regions of interest included in the similarity analysis correspond to all sub-regions of the frontal, temporal, parietal and occipital lobes in AAL2 (see Table 2 in Rolls et al., 2015). The opercular, triangular and orbital part of the inferior frontal gyrus were collapsed into a single region of interest. Homologue regions in left and right hemisphere were kept as separate ROIs.

Appendix B

In addition to the analyses targeting the neural correlates of spatial demonstratives, we reported further analyses aimed at ensuring the quality of the images yielded by our acquisition sequence and exploring lateralization patterns for auditory response to the speech stimulus.

We fitted sound envelopes from the left and right auditory channel to the EPI time series expecting to detect robust effects of the low-level profile of the signal in the auditory cortices.

As predicted, auditory cortices responded bilaterally to monaural input, but, for both ears, response in the contralateral hemisphere was larger than response in the ipsilateral, which is consistent with previous studies (Hirano et al., 1997; Jäncke et al., 2002; Schönwiesner et al., 2006; Stefanatos et al., 2008; Suzuki et al., 2002).

Interestingly, when directly comparing the effects of the left and the right envelope, we observed asymmetries across the two hemispheres. Response in the left auditory cortex was significantly larger for input from the contralateral ear than from the ipsilateral. However, no such difference was observed for the right auditory cortex, where the magnitude of the response was comparable across ears. A similar lateralization pattern has been previously reported for non-speech stimuli (Schönwiesner et al., 2006), and it might be compatible with different interpretations. Input from the right ear seems to elicit larger and more widespread response in both auditory cortices. This levels out responses to right and left ear in the right hemisphere, while preserving an advantage for the right ear in the left auditory cortex. Larger overall responsiveness to right-ear input might explain the widely-attested behavioural advantage for right-ear input observed in dichotic listening (Hugdahl & Westerhausen, 2016; Kimura, 1967). Functional specialization of right and left auditory cortices for fine spectral and temporal features respectively might also be compatible with our results (Zatorre, Belin, & Penhune, 2002). The analytic envelope of the sound preserves spectral modulations of the signal while filtering out its fine temporal structure. Specialization for spectral features might

therefore explain why the magnitude of response to sound envelopes in the right AC remains constant regardless of spatial origin of the sound.

Finally, the temporal profile of contrast estimates from the FIR analysis showed that response in the primary AC peaked between 3 and 4 seconds after stimulus onset, earlier than reported in previous literature (Hall et al., 2000). This pattern is compatible with previous studies showing faster response in primary sensory areas for sustained and rapidly varying input (Lewis et al., 2016). Further analyses are needed to achieve a reliable characterization of time course of the signal under naturalistic conditions.

Appendix C

Supplementary analyses on whole-brain similarity between demonstratives and wh-words using mean and maximum correlation as outcome variables displayed results analogous to those obtained using AUC as outcome. Mean correlations were significantly lower for *what* compared to *where*, $\beta = -0.02$, $se = 0.007$, $t(69.74) = -2.43$, $p < .05$, and for *who* compared to *where*, $\beta = -0.02$, $se = 0.007$, $t(27.27) = -3.11$, $p < .01$. The same effects were detected using maximum correlation as outcome, with significantly lower correlations for *what* than for *where*, $\beta = -0.02$, $se = 0.008$, $t(36.22) = -2.77$, $p < .01$, and for *who* than for *where*, $\beta = -0.03$, $se = 0.009$, $t(31) = -3.54$, $p < .01$. Post-hoc contrasts displayed no significant difference for *what* and *who* on any of the outcome measures.

Article 2

RESEARCH ARTICLE

This shoe, that tiger: Semantic properties reflecting manual affordances of the referent modulate demonstrative use

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Abstract

Demonstrative reference is central to human communication. But what influences our choice of demonstrative forms such as “this” and “that” in discourse? Previous literature has mapped the use of such “proximal” and “distal” demonstratives onto spatial properties of referents, such as their distance from the speaker. We investigated whether object semantics, and specifically functional properties of referents, also influence speakers’ choices of either demonstrative form. Over two experiments, we presented English, Danish and Italian speakers with words denoting animate and inanimate objects, differing in size and harmfulness, and asked them to match them with a proximal or a distal demonstrative. Objects that offer more affordances for manipulation (smaller and harmless) elicited significantly more proximal demonstratives. These effects were stronger for inanimate referents, in line with the predictions of sensory-functional views on object semantics. These results suggest that demonstrative use may be partly grounded on manual affordances, and hints at the possibility of using demonstratives as a proxy to investigate the organization of semantic knowledge.

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Introduction

Spatial demonstratives: Function and deictic nature

Spatial demonstratives are referencing expressions present in all languages [1]. They are among the first items to be acquired in early development [1–6]. Moreover, demonstrative determiners (e.g. *this*, *that* in English) and adverbials (*here*, *there*) are by far the most prominent items in the lexicon of children between 1 and 2 years of age, with *that* being the most frequent words for this age group in the CHILDES database [7]. Alongside their role in language development, demonstratives are also among the most frequent words in adults’ lexicon [8]. While not explicitly encoding any specific information about the referent, words like *this* and *that* are used to establish a joint focus of attention on concrete objects in the physical space (*exophoric* usage), or on items in discourse space (*endophoric* usage) [1, 9–12]. The ability to

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coordinate attention on a referent is a central building block of human social interaction and enables mutual engagement in shared practices [13]. This pivotal function in communication grants demonstratives a special status among the variety of referencing tools languages are endowed with.

Interestingly, both production and comprehension of spatial demonstratives hinge upon the perceptual context of the utterance and the multimodal communicative signals they co-occur with. When used to denote entities in the physical environment, demonstratives are usually coupled with a pointing gesture which enables disambiguation of the intended referents among competing objects [14–17]. Given their tight link with visuo-motor communicative signals and their role in supporting fundamental cognitive processes, such as managing joint attention, it has been hypothesized that demonstratives might be primordial elements in the emergence of language [7]. Indeed, differently from all other function words, the deictic roots of demonstratives cannot be traced back to any content words, which provides evidence in favor of demonstratives having emerged very early in language evolution [7].

Crucially, spatial demonstratives are deictic expressions, i.e. lexical items that differ from other referencing expressions (such as nouns) in that they do not unambiguously denote the intended object, but rather provide *instructions* on how to locate it among various competing referents. Without any contextual information, the meaning of words such as *this* or *that* is opaque: knowledge of some elements of the context of utterance is therefore required in order to single out what they are meant to refer to. In the case of spatial demonstratives, such knowledge can either consist of information on the perceptual context of the utterance (e.g. position of speaker, addressee and/or other objects), or on discourse context (e.g. common ground between interlocutors) [18].

Demonstratives do not carry univocal information on the intended referent, but demonstrative systems across all languages have multiple lexical forms, which encode some deictic contrast facilitating reference resolution [1]. All languages encode at least one distinction between so-called proximal and distal demonstratives, either by explicit lexical forms, such as in the contrast between *this* and *that* in English, or via reinforcing elements, such as in the contrast between the Danish expressions “den *her*” and “den *der*” [1]. Some languages have more complex systems with additional deictic distinctions. In the simplest, dyadic case, the use of either a proximal or a distal form is likely to convey information about the distance of the position of the referent within the search space (e.g. close or far from the speaker). Complex systems including three or more distinct demonstrative forms either lexicalize more fine-grained information on the distance of the referent relative to the speaker (e.g. medial distances), or the location of the referent relative to the addressee, or may even explicitly encode perceptual features of the referent such as its visibility [4].

This or that: Distance-based or functional contrast?

It is thus widely accepted that the distance between the referent and the speaker and/or the addressee is a crucial factor when it comes to describing the usage criteria of proximal and distal demonstrative forms (but see [19–21] for complementary perspectives). However, the detailed usage profile of the proximal/distal contrast is still a subject of debate, receiving more and more attention in experimental literature.

In a series of experiments, Coventry and colleagues [22–23] have uncovered a mapping between the proximal/distal contrast and the functional organization of space into peripersonal and extrapersonal space, that is, into space within and outside manual reach. Results are consistent across several studies targeting a number of genetically heterogeneous languages. Interestingly, the mapping between referent location and demonstratives seems to be sensitive

to the same dynamic adjustments that can modify the boundaries between extrapersonal and peripersonal space. The use of tools, ownership of the referent, and familiarity seem to affect the scope of the proximal deictic space [22–24].

In a reaching task involving hand movements, Bonfiglioli and colleagues [25] have further explored the relationship between functional organization of space and demonstrative reference using semantic priming. In the study, participants were primed with either a proximal or a distal demonstrative, and then asked to reach for objects placed at two possible distances within the participant's reach. By looking at reaction times in the initiation of reaching movements, they observed semantic interference effects when the demonstrative used for priming and the object's location were incongruent. This suggests that the contrastive nature of demonstrative systems is sensitive to relative distances between competing referents even within peripersonal space. Additionally, in a recent study [26], we have shown that, when presented with competing referents in a two-dimensional plane extending away from the participant, he/she displays a lateralized bias for proximal demonstratives in favor of the pointing hand. This asymmetry in the organization of space in spatial deixis suggests that the frame of reference for distance-based demonstrative contrasts might be centered on the dominant hand, rather than on the head or the locus of foveal fixation.

Taken together, this corpus of experimental evidence converges on showing that the use of demonstratives could be grounded in representations of objects in terms of their functional properties, including the extent to which they allow manual interaction. In this respect, distance from the speaker is only one of the relevant factors. As we will explore in the next section, a range of semantic features can shape the functional profile of a referent, and therefore possibly modulate lexical preferences for different demonstrative forms.

Spoons, rockets and other dangerous things: Object semantics and demonstrative use

In spite of a growing interest in the variety of factors that can modulate preferences for proximal or distal demonstratives (e.g. object *token* properties such as familiarity, visibility and ownership [23]), previous studies have largely considered semantic features of the referent (i.e. related to object *type*) as irrelevant to the usage profile of spatial demonstratives.

As outlined above, however, there is increasing evidence suggesting that the distinction between proximal and distal demonstratives maps onto differences in the extent to which referents afford grasp and/or manipulation. Arguably, such affordances do not only depend on whether an object is located within reach, but also on its physical properties, such as object size, and on more abstract properties, such as its harmfulness, or its familiarity.

Therefore, if the assumption that demonstrative use is sensitive to gradient manual affordances holds true, it can be expected that a preference for proximal demonstratives would be observed for referents whose semantic features result in greater affordances for manipulation, regardless of their position in space.

As mentioned, lower-level properties such as size are intuitively some of the core dimensions in shaping an object's functional profile. The ability to manipulate an object obviously depends on the object being small enough to be graspable by a human hand. If demonstrative use is indeed tied to manual affordances, then smaller objects should be more likely to be referred to via a proximal demonstrative than bigger objects, as smaller objects tend to afford manipulation more easily than bigger ones.

Alongside lower-level properties, additional cognitive dimensions are also directly relevant to manual affordances. It has been pointed out that the functional organization of space into peripersonal and extrapersonal space responds not only to the need for representing action

possibilities, but also to defensive purposes [27]. Indeed, it has been found that object valence can interact with perceptual judgements of reachability [28–29]. Moreover, harmfulness can modulate space and object perception in peripersonal space. Peripersonal space tends to shrink for defensive purposes when harmful or undesirable objects are present, and it has been argued that common neural resources might be responsible for modulating spatial attention in peripersonal space, monitoring harmful events, and selecting and coordinating defensive behavior [30–34]. Furthermore, reachability judgements tend to be influenced by the on-line relationship between the object and the subject. The extension of peripersonal space is reduced more substantially when harmful objects are oriented towards the subject compared to when oriented away, regardless of the perceived degree of harmfulness [35]. As demonstrative use is grounded in a dynamic functional organization of space oriented to manual grasp [22–24, 26], it is reasonable to expect that the degree of harmfulness of a referent could modulate the usage profile of spatial demonstratives. More specifically, if these hypotheses hold true, stimuli perceived as dangerous should be more likely to trigger the use of a distal demonstrative than harmless referents.

The animate-inanimate distinction: A sensory-functional prediction

In addition to properties such as size and harmfulness, existing literature suggests that the distinction between animate and inanimate objects could be another relevant window into the relation between semantics and demonstrative contrasts.

The distinction between animals and artefacts has gained considerable attention in the scientific literature, as it seems to be one of the main dimensions along which human semantic knowledge is organized. Since the 1980s, several neuropsychological studies have shown that semantic knowledge of animate and inanimate objects can be selectively impaired as a consequence of focal brain lesions [36–38]. However, the exact profile of such dissociations and the underlying causes are far from uncontroversial.

In a *domain-specific* interpretation, the dissociation in cognitive deficits reported in the literature is claimed to reflect an evolved modular organization of semantic knowledge with domain-specific systems, supported by separate neurobiological mechanisms [39].

On the other hand, sensory-functional theories (SFT) hypothesize that the observed dissociations in semantic knowledge for living and non-living things can be explained in terms of lower-level sensory and functional properties of objects [38, 40–43]. Sensory-functional theories explain the observed dissociations in terms of the relative importance of sensory and functional properties in the representation of living and non-living things. While sensory features are relatively more important in discriminating between living things, functional properties of objects are attributed more importance in discriminating between different types of artefacts. The observed animate/inanimate dissociation in semantic knowledge is thus explained by a distinction between sensory processing (damage to which primarily results in impaired knowledge for animate beings) and functional representations, where lesions disproportionately impair semantic knowledge for tools and artefacts [38]. More recent formulations of the sensory-functional approach to semantic knowledge have reframed the distinction between animate and inanimate beings in terms of differences in the ratio between sensory and functional features relevant to the representation of category tokens [44]. This ratio is claimed to be larger for animate beings compared to artefacts, as functional features tend to be more prominent in the representation of and discrimination between inanimate objects, while sensory features are equally relevant for the representation of both categories.

Sensory-functional approaches to semantic knowledge have interesting implications with regards to the relationship between object semantics and spatial demonstratives. First, the

distinction between animate and inanimate things can itself be thought of as a distinction between objects affording manual interaction to a smaller or greater extent respectively. Intuitively, inanimate objects are often more readily represented in terms of their possibility for manipulation, compared to animate beings. A reasonable hypothesis thus is that a higher proportion of proximal demonstrative would be observed for inanimate referents, compared to animate referents. However, sensory-functional theories additionally posit that representations of inanimate objects are more sensitive to variability along functional dimensions of the feature space than representations of animate objects. If this hypothesis holds true, then differences in functional features, such as size and harmfulness, should determine larger differences in the proportion of proximal vs distal demonstratives between tokens of the inanimate category, compared to those observed between animate beings. In more concrete terms, the possibility for interaction with animals is less determined by their size and harmfulness than inanimate objects (small, harmless animals also tend to run away. . .). Crucially, testing such predictions in an experimental fashion would not only contribute to elucidating the usage profile of spatial demonstratives, but also provide insights on core questions of the debate on the organization of human semantic knowledge.

The present study

In the present study, we employed a simple elicitation paradigm in order to investigate whether semantic properties of objects, i.e. differences in affordance for manual interaction, systematically influence speakers' preferences for proximal or distal demonstrative forms.

We tested speakers of English, Danish and Italian over two experiments. These three languages all have dyadic demonstrative systems, that is, they explicitly encode a simple binary contrast between so-called *proximal* and *distal* demonstrative forms. The choice of a cross-linguistic sample was motivated by the aim of countering language specific phenomena, rather than by expectations for cross-linguistic differences in patterns of demonstrative use.

The experiments were distributed in the form of a multiple-choice online survey. Participants were presented with concrete nouns and asked to pair the words with either a proximal or a distal demonstrative, based on their first and most immediate preference. No further linguistic or perceptual context was provided. This was meant to rule out possible confounds due to contextual or co-textual effects, so that observed systematic preferences could only be driven by properties intrinsic to the stimulus words.

Stimulus words differed along three main semantic dimensions denoting either: 1) animate or inanimate referents; 2) big or small referents; 3) harmful or harmless referents.

Levels of these three semantic dimensions involve a common distinction in the degree to which referents afford manipulation. Small referents are likely to offer more manual affordances than big referents. The same holds for harmless compared to harmful referents, and for inanimate compared to animate referents.

Consequently, we expected a preference for proximal demonstratives: 1) for nouns denoting small referents compared to big referents; 2) for nouns denoting harmless referents, compared to harmful referents; 3) for nouns denoting inanimate referents compared to animate referents. We expected to observe these effects as main effects of each of the variables of interest.

Moreover, in line with the sensory-functional view on semantic knowledge, we predicted that the effect of harmfulness and size would be stronger for inanimate objects, compared to animate beings. We therefore expected to observe two-way interactions between animacy and harmfulness, and between animacy and size. We expected our predictions to hold across the three languages tested in the experiment.

The aim of the study was two-fold. On the one hand, we aimed at contributing to elucidate the usage profile of the proximal/distal demonstrative contrast. On the other hand, we aimed at exploring the possibility of using demonstratives to probe the organization of human semantic knowledge.

As mentioned, the study is articulated into two experiments. The first study tested speakers of all three languages (Experiment 1). We then replicated it in Italian and Danish (Experiment 2) using the same design and procedure, but with a different stimulus set.

Data and code are available on the Open Science Framework at osf.io/gnh5s.

Experiment 1

Methods

Participants. In Experiment 1, we collected data from 131 English speakers (96 native), 102 Danish speakers (101 native), and 131 Italian speakers (126 native).

Participants were recruited online. The survey was advertised via social media and institutional web platforms. No information on the purpose of the experiment was provided in advance. Participants took part in the experiment voluntarily, and they did not receive monetary compensation for their participation.

At the beginning of the study, participants were provided with instructions and a detailed consent form, and they consented to the conditions of participation by proceeding to the first experimental trial. At the end of the experiment, participants were asked to provide information on their gender and age. Moreover, they were asked to specify whether they were native speaker of the language of the survey. If this was not the case, they were further asked to specify their native language. In the English version of the experiment, those who stated having English as their native language were asked to specify which variety of English they spoke, choosing between American English, British English, or other. Due to the limitations of our convenience sampling method, this information was not included in the analysis.

Participants were further asked to specify whether they knew the meaning of all the words presented in the survey. If not, they were asked to tick the words they did not know, and the corresponding data points were then excluded from the analysis. Only data from participants who completed the survey were included in the analysis.

As two participants from the English dataset reported not to know the meaning of eight out of thirty-two experimental words, we excluded them from the analysis. All other participants reported to know the meaning of the vast majority of words (median: 40 out of 40 words, range: 36–40), thus no further data were discarded. Both L1 and L2 speakers were included in the analysis.

The study received ethical approval from the Ethical Committee of the Cognition and Behaviour Lab at Aarhus University, Denmark.

Platform. The experiment was hosted by the online platform *Qualtrics Experience Management Platform* (Qualtrics, Provo, UT, USA). Access to the platform was provided by the School of Business and Social Sciences (BSS) at Aarhus University.

Task and procedure. Participants in both experiments were presented with 40 individual words. Participants had to match each word with either a proximal or a distal demonstrative, that is, *this* or *that* in English, *den/det her* or *den/det der* in Danish, and *questo/a* or *quello/a* in Italian. Target words were displayed one at a time at the top of the screen together with the two possible demonstrative forms positioned on two separate lines below the word. Participants chose between the two demonstrative forms by ticking the box corresponding to the preferred demonstrative form. They were asked to make their choice based on their first and immediate preference. No further context nor any extra information was displayed on screen.

After having made their choice, participants could proceed to the next word. It was not possible to go back to previous trials once the response was given. A response was required in order to proceed to the next trial. The order of presentation of nouns was randomized across participants. The order in which the two demonstratives were displayed on screen was randomized across trials and participants.

Stimuli. All the words were singular nouns. Out of 40 nouns, 32 were experimental words, and 8 were fillers. All the words used for Experiment 1 are reported in Table 1 (in English). The full stimulus list in all three languages is reported in the Supporting Information (S1 Table).

Experimental words always referred to concrete objects. *Animacy* (animate/inanimate), *Size* (big/small) and *Harmfulness* (harmful/harmless) of the referent were the binary variables of interest, yielding 2x2x2 combinations per language. Participants were presented with four words from each possible combination, which resulted in a within-subject repeated measures design. Fillers denoted abstract entities.

Target words were chosen from a semantic knowledge database (in English) including 1000 concrete nouns rated along 218 semantic dimensions on an integer scale from 1 to 5 [45].

For the purpose of the study, words were selected according to their ratings on the dimensions “Is it an animal?”, corresponding to the variable *Animacy* in our experimental design, “Is it bigger than a loaf of bread?”, corresponding to the variable *Size*, and “Is it dangerous?”, corresponding to the variable *Harmfulness*. Different dimensions were available which could be relevant for the variable *Size* relying on comparisons in size between the target objects and different referent objects. Among them, however, we chose the dimension that best mirrored a distinction between objects whose size allows manual grasp and objects whose size does not.

All nouns labelled as non-animate in our experiment were rated less than 3 along the *Animacy* dimension, while animate referents were rated 3 or more. Nouns labelled as small referents were rated less than 3 on the *Size* dimension, while big referents were rated 3 or more. Nouns denoting dangerous referents were rated 3 or more on the *Harmfulness* dimension, while harmless referents were rated less than 3. All words were translated into Italian and Danish by native speakers of the two languages (the paper’s first and last authors). Danish translations of a subset of the words present in the database had been previously used and validated in the context of a neuroimaging study on word processing [46].

Demonstrative expressions. In English, participants could choose to match the noun with either “this” or “that”.

In Danish, demonstratives in their adjectival use were created by combining the articles “den” or “det” (roughly equivalent to “it” in English) with the demonstrative adverbs “her” (“here”, in English) or “der” (“there”, in English). As Danish has two grammatical genders,

Table 1. Stimulus words for Experiment 1, English.

Animate		
	<i>Big</i>	<i>Small</i>
<i>Harmful</i>	Bull, shark, hyena, snake	Bee, flea, spider, rat
<i>Harmless</i>	Camel, goose, lamb, penguin	Cricket, kitten, robin, shrimp
Inanimate		
	<i>Big</i>	<i>Small</i>
<i>Harmful</i>	Bomb, jail, rocket, rifle	Burner, dagger, needle, thorn
<i>Harmless</i>	Bench, couch, cradle, tent	Coin, comb, cookie, soap
Fillers		
Deal, dawn, hurry, loss, quarrel, rise, rest, stress		

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demonstratives were matched to the grammatical gender of the noun. For nouns in common gender, participants could choose between “den her” and “den der”, while for nouns in neutral gender, “det her” and “det der” were presented as possible options.

Italian also has two grammatical genders, and demonstratives in their adjectival use have to be matched for the gender of the noun. For nouns starting with a consonant sound, “questo” and “quello” / “quel” are respectively the proximal and distal masculine forms, while “questa” and “quella” are the feminine forms. The masculine demonstrative “quel” is used for all nouns except those starting with semi-consonantic sounds (*i*, *y* and *j*), with sibilants (*s* and *z*), and with other consonant clusters (*gn*, *sc*, *pn* and *ps*), where “quello” is the correct form. For nouns starting with a vowel, the final vowel of both feminine and masculine demonstratives “questo” / “questa” and “quello” / “quella” is elided, yielding the forms “quest” and “quell” respectively. For example, when the feminine demonstratives “questa” and “quella” are to be coupled with the feminine noun “anatra” (duck), the resulting form would be “quest’anatra” or “quell’anatra”. For Italian, we decided to uniformly present the forms “questo” / “quello” for masculine words and “quello” / “quella” for feminine words regardless of the first letter of the noun. We decided to do so in order to obtain uniformity of methods across languages, and because we anticipated that, given the presentation format, presenting the elided forms “quest” and “quell” not followed by a noun would have appeared strange to a proficient speaker, even though such forms would have been the grammatically correct ones.

Word frequency. In order to control for potential confounds due to effects of word frequency, we compared frequency of experimental words across levels of each of the experimental factors. For English, we extracted word frequencies from the British National Corpus [8]. For Italian and Danish, we extracted word frequencies from the respective corpora in the Ten-Ten Corpus Family [47] from 2017. Details on the distribution of word frequencies for Experiment 1 are provided as Supporting Information (S1 Fig).

Linear regressions with animacy, harmfulness and size and their interactions as fixed effects and word frequency as outcome variable revealed no significant differences ($p > .05$) across levels of the experimental variables in any of the three languages.

Analysis. Animacy, harmfulness and size were used as binary independent variables.

For the independent variable *animacy*, nouns were coded as either *inanimate* or *animate*. *Inanimate* was set as reference level. For the independent variable *Size*, nouns were coded as either *small* or *big*. *Small* was set as reference level. For the independent variable *Harmfulness*, nouns were coded as either *harmless* or *harmful*. *Harmless* was set as the reference level. For the independent variable *Language*, Danish was set as reference level.

The outcome variable coded for the demonstrative chosen at each trial. Responses were coded as either *distal* or *proximal*. *Distal* was set as reference level, while *proximal* was coded as success outcome. All instances of “this” in English, “den/det her” in Danish, and “questo” / “questa” in Italian were coded as *proximal* demonstratives, while all instances of “that” in English, of “den/det der” in Danish, and “quello” / “quella” in Italian were re-coded as *distal* demonstratives.

Data visualization and analysis was performed using RStudio, version 1.1.383 (RStudio Team 2016).

Data were analyzed using mixed-effects logistic regression implemented via the function *glmer* from the package *lme4* [48]. Parameters for the logistic regression model were estimated using maximum likelihood estimation with Laplace approximation, and inferences were drawn via likelihood ratio tests. R^2 estimates reported in the analysis and discussion are computed using the function *r2* from the R package *sjstats* [49].

Data from all languages were analyzed in a single logistic regression model. The fixed effects structure included all the three variables of interest, a categorical predictor coding for

language, and the full interaction structure. The random effects structure included a random intercept for participants.

Results

Fig 1 provides an overview of the data from Experiment 1.

The analysis revealed an overall preference for distal demonstratives, in line with corpus frequency data for each of the three languages, $\beta = -1.75$, $se = 0.16$, $z = -10.98$, $p < .001$.

There was a significant main effect of language, indicating that the proportion of distal demonstratives was overall larger in Danish compared to English, $\beta = 0.43$, $se = 0.20$, $z = 2.13$, $p < .05$, and compared to Italian, $\beta = 1.65$, $se = 0.2$, $z = 8.41$, $p < .001$. The model revealed a significant main effect of harmfulness, $\beta = 0.74$, $se = 0.18$, $z = 4.1$, $p < .001$, and a significant main effect of size, $\beta = 0.56$, $se = 0.18$, $z = 3.07$, $p < .01$, both in the predicted direction. Additionally, there was a main effect of animacy, $\beta = 0.52$, $se = 0.18$, $z = 2.82$, $p < .01$, as well as significant interactions between animacy and harmfulness, $\beta = 0.91$, $se = 0.24$, $z = 3.76$, $p < .001$, and animacy and size, $\beta = 0.68$, $se = 0.24$, $z = 2.79$, $p < .01$, suggesting that the effects of harmfulness and size were more pronounced for inanimate objects than for animate beings.

The analysis also hinted at unpredicted cross-linguistic differences in the effects of the experimental variables. There was a significant interaction between language and animacy, showing that the effect of animacy was stronger in Italian compared to Danish, $\beta = -0.49$, $se = 0.22$, $z = -2.21$, $p < .05$. Moreover, the interaction between animacy and harmfulness was significantly stronger in Danish, compared to English, $\beta = -0.64$, $se = 0.31$, $z = -2.07$, $p < .05$, and Italian, $\beta = -0.98$, $se = 0.31$, $z = -3.21$, $p < .01$, as shown by the three-way interaction between animacy, harmfulness and language. A three-way interaction between animacy, size and language indicated that the interaction between animacy and size was marginally less pronounced in English, compared to Danish, $\beta = -0.62$, $se = 0.31$, $z = -1.97$, $p < .05$.

The model also displayed an unpredicted three-way interaction between animacy, size, and harmfulness, $\beta = -0.81$, $se = 0.33$, $z = -2.46$, $p < .05$, as well as a four-way interaction between

Fig 1. Proportion of proximal demonstratives across languages, Experiment 1. Small, inanimate and harmless nouns tend to be denoted with a proximal demonstrative across languages. The effects of size and harmfulness tend to be stronger for inanimate, compared to animate referents.

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animacy, size, harmfulness and language, when comparing Danish to Italian, $\beta = 1.09$, $se = 0.43$, $z = 2.56$, $p < .05$. The model has a marginal R^2 of 0.126, and a conditional R^2 of 0.265.

A summary of the estimated fixed effects coefficients is reported in Table 2.

Interim discussion

Data from the three languages all converge on showing a strong, significant main effect of harmfulness and size in the direction predicted in the introduction. The proportion of proximal demonstratives over distal demonstratives was consistently higher in the case of harmless referents compared to harmful referents, and in the case of smaller referents compared to big referents. This is in line with our hypothesis that the proximal/distal demonstrative contrast encodes a gradient distinction in the extent to which objects lend themselves to manual interaction.

A main effect of animacy was also detected, but the strength of such effect seemed to vary across languages. Additionally, the model provided strong evidence in favor of the predicted interaction between animacy and size and between animacy and harmfulness, though such interactions were significantly more robust in Danish compared to English and Italian. Taken together, the results lend support to all our predictions suggesting several, motivated semantic dimensions influence speakers' choice of demonstratives.

Table 2. Fixed effects for Experiment 1.

	Beta	SE	z	95% CI lower	95% CI upper	Odds Ratio	p
(Intercept)	-1,75	0,16	-10,98	-2,06	-1,44	0,17	< .001***
Animate	0,52	0,18	2,82	0,17	0,87	1,68	< .01 **
Size	0,56	0,18	3,07	0,21	0,91	1,75	< .01 **
Harm	0,74	0,18	4,1	0,39	1,09	2,1	< .001***
Lang (EN vs. DK)	0,43	0,2	2,13	0,04	0,82	1,54	< .05 *
Lang (IT vs. DK)	1,66	0,2	8,42	1,27	2,05	5,26	< .001***
Animate x Size	0,68	0,24	2,79	0,21	1,15	1,97	< .01 **
Animate x Harm	0,91	0,24	3,76	0,44	1,38	2,48	< .001***
Size x Harm	-0,11	0,24	-0,44	-0,58	0,36	0,9	n.s.
Animate x Lang (EN vs. DK)	-0,002	0,23	-0,01	-0,45	0,45	1	n.s.
Animate x Lang (IT vs. DK)	-0,5	0,23	-2,21	-0,95	-0,05	0,61	< .05 *
Size x Lang (EN vs. DK)	0,12	0,23	0,53	-0,33	0,57	1,13	n.s.
Size x Lang (IT vs. DK)	-0,26	0,22	-1,14	-0,69	0,17	0,77	n.s.
Harm x Lang (EN vs. DK)	0,22	0,23	0,95	-0,23	0,67	1,25	n.s.
Harm x Lang (IT vs. DK)	-0,28	0,22	-1,28	-0,71	0,15	0,76	n.s.
Animate x Size x Harm	-0,81	0,33	-2,46	-1,46	-0,16	0,44	< .05 *
Animate x Size x Lang (EN vs. DK)	-0,62	0,31	-1,97	-1,23	-0,01	0,54	< .05 *
Animate x Size x Lang (IT vs. DK)	-0,43	0,31	-1,41	-1,04	0,18	0,65	n.s.
Animate x Harm x Lang (EN vs. DK)	-0,64	0,31	-2,07	-1,25	-0,03	0,53	< .05 *
Animate x Harm x Lang (IT vs. DK)	-0,98	0,31	-3,21	-1,59	-0,37	0,38	< .01 **
Size x Harm x Lang (EN vs. DK)	-0,41	0,31	-1,33	-1,02	0,2	0,66	n.s.
Size x Harm x Lang (IT vs. DK)	0,3	0,31	0,97	-0,31	0,91	1,35	n.s.
Animate x Size x Harm x Lang (EN vs. DK)	0,76	0,43	1,78	-0,08	1,6	2,14	n.s.
Animate x Size x Harm x Lang (IT vs. DK)	1,1	0,43	2,57	0,26	1,94	2,99	< .05 *

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The results from Experiment 1, however, leave a number of questions open to discussion.

First, we did not expect to observe strong cross-linguistic differences in the effects of interest. Based on these findings, it cannot be excluded that cross-linguistic discrepancies are due to actual differences in patterns of demonstrative use across the three languages of interest, but a number of alternative explanations are compatible with the observed patterns. Bigger sample sizes, which increase statistical power, might provide more robust insights on cross-linguistic differences in patterns of demonstrative use.

Secondly, as explained in section 2.1.5, the matching between the default distal demonstrative forms presented in the survey and stimulus words was sometimes not entirely correct from a grammatical point of view in the Italian version of the experiment. A separate analysis of the Italian data, reported in [S1 Appendix](#), showed that this affected participants' choices for proximal or distal demonstrative forms, with a significantly higher proportion of proximal demonstratives for cases in which the matching between stimulus word and distal demonstratives was experienced as strange. It can therefore not be ruled out that the differences between Danish and Italian data detected in the analysis could potentially be driven by such confound.

Furthermore, the unexpected three-way interaction between animacy, size and harmfulness is difficult to relate to predictions from the present study, or to expectations drawn from the literature. While it could be explained in terms of the psychological prominence of the harmfulness dimension, with the interaction between size and animacy being amplified in the case of harmful referents, such an effect still remains difficult to interpret and highlights the potential for false positives due to our complex model. Given the relatively low number of stimulus words, it also could not be excluded that such effect could be driven by particular words, more than by the manipulations in semantic features.

In order to test the reliability and replicability of the effects detected in experiment 1, we decided to collect data from a second set of stimulus words. In the second experiment, we aimed at bigger sample sizes in order to increase the statistical power of the analysis. The availability of a second dataset also enabled us to conduct a cumulative analysis of the two datasets. The availability of more stimulus words for the cumulative analysis provided the possibility of fitting a more complex and more conservative random effects structure, including intercepts for each stimulus word, in order to rule out the possibility of the observed effects being driven by specific stimulus words.

Experiment 2

Methods

Participants, task, design and procedure. In Experiment 2, we collected data from highly proficient Italian speakers and Danish speakers. In this experiment, 291 Italian speakers (280 native) and 225 Danish speakers (219 native) completed the survey. Recruitment and data collection followed the same procedure and conformed to the same criteria as Experiment 1.

The task, procedure and modality of stimulus presentation were analogous to Experiment 1. However, given the potential confounds present in the Italian dataset from Experiment 1, in Experiment 2 we only presented words which would not require vowel elision in Italian. Moreover, in the Italian version of the survey we presented “quel” as option for distal demonstratives when required, this time prioritizing grammatical correctness over uniformity of stimulus presentation.

Stimulus set. For Experiment 2, we initially selected 32 experimental words on a qualitative basis. The design was identical to experiment 1, with 2x2x2 combinations of levels of the three experimental factors per language. We selected four words per each combination in the design matrix. The English translations of all the nouns used in Experiment 2 are reported in

Table 3. The corresponding Danish and Italian words are reported as Supporting Information (S2 Table).

As in Experiment 1, none of the experimental words were consistently reported as unknown to participants (median = 40 words known across participants, range: 37–40), and all participants were included in the analysis.

In order to obtain quantitative scores on each of the three dimensions of interest, comparable to the scores for stimuli from Experiment 1 in Sudre and colleagues' [45] database, and in order to ensure that qualitative word selection was not severely biased, we derived semantic ratings for each of the words from word embeddings via Support Vector Regression.

Using the *svm()* function from the *e1071* library in RStudio [50], we trained three SVR models on the semantic dataset from Sudre and colleagues [45]. We extracted 300-dimensional GloVe vector representations [51] trained on Wikipedia and Gigaword for all words in the dataset (available for download here: <https://nlp.stanford.edu/projects/glove/>). All the 300 dimensions of the vectors were used as features to tune and train the SVR model. Scores for animacy, harmfulness and size were the variables to be predicted. We tuned model parameters for values of epsilon ranging from 0 to 1 (with 0.1 steps) and cost values ranging from 2^2 to 2^9 . The best performing model for each of the variables of interest was used to predict animacy, size and harmfulness scores for experimental words, once again using 300-dimensional vector representations as features. We performed a median split on the predicted ratings for each of the categories of interest, and we assessed the performance of the model in terms of the number of words ending up in the correct half of the value range.

To provide a concrete example, the models predicted scores for animacy on a scale from 1 to 5. All animate objects were expected to display values higher than the median. If any animate object displayed a value lower than the median, or any inanimate objects displayed a value higher than the median, this was subtracted from the models' performance. The model for animacy achieved 100% accuracy. The model for harmfulness achieved 81.25% accuracy. The model for size achieved 87.5% accuracy. Such performance scores can be considered as sufficient evidence for word selection being unbiased and reliably consistent with the criteria and metrics from experiment 1.

The predicted scores were later used for the parametric analysis of the data reported in S2 Appendix.

The ratings predicted by the SVR models are plotted in Fig 2

Word frequency. Details on the distribution of word frequencies for Experiment 2 are displayed in S2 Fig. As for Experiment 1, linear regressions for word frequencies did not display any significant differences between categories in any of the three languages ($p > .05$).

Analysis. We analyzed the data in a logistic mixed-effects regression model. As for Experiment 1, the fixed effects structure included binary predictors for Animacy, Harmfulness and

Table 3. Stimulus words for Experiment 2 (English translation).

Animate		
	<i>Big</i>	<i>Small</i>
<i>Harmful</i>	Tiger, cobra, crocodile, boar	Mosquito, jellyfish, tarantula, tick
<i>Harmless</i>	Giraffe, horse, dolphin, fawn	Rabbit, butterfly, squirrel, sparrow
Inanimate		
	<i>Big</i>	<i>Small</i>
<i>Harmful</i>	Meteorite, avalanche, volcano, bomber	Mine, poison, bullet, knife
<i>Harmless</i>	School, oak, double-bass, dome	Mug, shoe, spoon, apple
Fillers		
Change, defeat, disappearance, disappointment, peace, promotion, shame, surprise, shame		

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Fig 2. Scores for Animacy (2a), Harmfulness (2b) and Size (2c), predicted by SVR. Labelled items are words that do not conform to our qualitative binary classification.

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Size, a categorical predictor coding for Language, and the full interaction structure. The random effects structure included random intercepts for each participant. Danish was set as reference level for the categorical regressor coding for language.

Results

An overview of the data from Experiment 2 is provided in Fig 3.

The analysis displays an overall preference for distal demonstratives, $\beta = -1.91$, $se = 0.1$, $z = -18.24$, $p < .001$. There was a significant main effect of language, with a higher proportion of proximal demonstratives for Italian compared to Danish, $\beta = 0.79$, $se = 0.13$, $z = 5.97$, $p < .001$.

As in Experiment 1, there was a significant main effect of Harmfulness, $\beta = 0.31$, $se = 0.12$, $z = 2.55$, $p < .05$ in the predicted direction, as well as a main effect of Size, $\beta = 0.52$, $se = 0.12$, $z = 4.27$, $p < .001$. However, no main effect of Animacy was observed ($\beta = -0.04$, $se = 0.13$, $z = -0.31$, $p > .05$).

There was a significant interaction between Animacy and Harmfulness, $\beta = 1.17$, $se = 0.17$, $z = 6.77$, $p < .001$, as well as a significant interaction between Animacy and Size, $\beta = 0.6$, $se = 0.17$, $z = 3.56$, $p < .001$, suggesting that the difference in proportion of proximal

Fig 3. Overview of the data from Experiment 2. Small and harmless objects display a tendency to be denoted with a proximal demonstrative across languages. The effects of size, and harmfulness interact with animacy.

<https://doi.org/10.1371/journal.pone.0210333.g003>

Table 4. Fixed effects from statistical model for Experiment 2.

	Beta	SE	z	95% CI lower	95% CI upper	Odds Ratio	p
(Intercept)	-1,91	0,1	-18,24	-2,11	-1,71	0,15	< .001***
Animate	-0,04	0,13	-0,31	-0,29	0,21	0,96	n.s.
Size	0,52	0,12	4,27	0,28	0,76	1,68	< .001***
Harm	0,31	0,12	2,55	0,07	0,55	1,36	< .05 *
Lang	0,79	0,13	5,97	0,54	1,04	2,2	< .001***
Animate x Size	0,6	0,17	3,56	0,27	0,93	1,82	< .001***
Animate x Harm	1,17	0,17	6,77	0,84	1,5	3,22	< .001***
Size x Harm	0,02	0,17	0,1	-0,31	0,35	1,02	n.s.
Animate x Lang	-0,24	0,16	-1,5	-0,55	0,07	0,79	n.s.
Size x Lang	0,09	0,15	0,57	-0,2	0,38	1,09	n.s.
Harm x Lang	-0,09	0,15	-0,57	-0,38	0,2	0,91	n.s.
Animate x Size x Harm	0,38	0,23	1,64	-0,07	0,83	1,46	n.s.
Animate x Size x Lang	-0,73	0,21	-3,43	-1,14	-0,32	0,48	< .001***
Animate x Harm x Lang	0,06	0,22	0,27	-0,37	0,49	1,06	n.s.
Size x Harm x Lang	-0,03	0,21	-0,14	-0,44	0,38	0,97	n.s.
Animate x Size x Harm x Lang	-0,18	0,3	-0,62	-0,77	0,41	0,84	n.s.

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demonstratives between harmful and harmless referents was bigger for inanimate referents, compared to animate referents.

The interaction between Animacy, Size and Language was significant, $\beta = -0.73$, $se = 0.21$, $z = -3.43$, $p < .001$, indicating that there was a bigger difference in the effect of size across animate and inanimate beings in Danish, than in Italian. The model achieves a marginal R^2 of 0.138, and a conditional R^2 of 0.299.

A summary of the estimated fixed effects coefficients is reported in Table 4.

Interim discussion

The analysis of data from Experiment 2 confirmed the robustness of the main effects of harmfulness and size detected in Experiment 1, and it provided additional strong evidence in favor of the animate-inanimate distinction modulating the effects of size and harmfulness. This, again, is in line with our initial predictions. However, there was no significant main effect of animacy, contrary to what observed in the analysis of data from Experiment 1. The predicted effects of harmfulness and size and the interaction between these two factors and animacy are consistent across both languages, but some of the effects vary in strength across languages. This is also in line with the findings from Experiment 1.

Overall analysis

In order to further test the robustness of our results, and to provide a comprehensive picture of the results from the two studies, we conducted a cumulative analysis of both data from Experiment 1 and Experiment 2 in a mixed-effects logistic regression model. In this analysis, we fitted the same fixed effects structure used for the individual analyses of Experiment 1 and Experiment 2, but we refined the random effects structure by including intercepts for each individual stimulus word.

The fixed effects structure included categorical regressors for Animacy, Harmfulness, Size and Language, as well as the full interaction structure. The random effects structure included

not only one intercept for each participant, but also random intercepts for each individual word, nested within levels of each of the experimental variables.

These latter random effects ensured that the parameter estimates were pooled for specific effects of individual experimental words, thus ruling out the possibility that observed main effects or interactions would be driven only by specific items in the stimulus set, rather than being genuine effects of the experimental manipulation. Given the anomalies detected in the Italian dataset from Experiment 1, this dataset was excluded from the analysis.

Overall, the model included data from 327 Danish speakers (320 native), 291 Italian speakers (280 native), and 131 English speakers (96 native).

As in Experiment 1, Danish was set as reference level for the categorical regressor coding for the language of each experiment. The model revealed an overall preference for distal demonstratives, $\beta = -1.95$, $se = 0.17$, $z = -11.31$, $p < .001$. There was a significant main effect of language showing that such preference was stronger in Danish than in Italian, $\beta = 0.83$, $se = 0.13$, $z = 6.39$, $p < .001$, and in English, $\beta = 0.59$, $se = 0.19$, $z = 3.06$, $p < .01$.

There was a main effect of Harmfulness, $\beta = 0.58$, $se = 0.23$, $z = 2.5$, $p < .05$, and a main effect of Size, $\beta = 0.59$, $se = 0.23$, $z = 2.58$, $p < .01$. No main effect of animacy was observed ($\beta = 0.27$, $se = 0.23$, $z = 1.18$, $p > .05$). The interaction between animacy and harmfulness was significant, $\beta = 1.02$, $se = 0.32$, $z = 3.16$, $p < .01$, as well as the interaction between animacy and size, $\beta = 0.65$, $se = 0.32$, $z = 2.04$, $p < .05$.

The model revealed a couple of significant differences across languages. There was an interaction between animacy and language, with a smaller difference in distal/proximal demonstratives used for animate *versus* inanimate referents in Italian, compared to Danish, $\beta = -0.37$, $se = 0.16$, $z = -2.34$, $p < .05$. The interaction between animacy and size was significantly stronger in Danish, compared to English, $\beta = -0.64$, $se = 0.30$, $z = -2.13$, $p < .05$, and Italian, $\beta = -0.76$, $se = 0.21$, $z = -3.59$, $p < .001$. The interaction between animacy and harmfulness was significantly stronger in Danish compared to English, $\beta = -0.71$, $se = 0.3$, $z = -2.35$, $p < .05$. No other effects reached statistical significance. The overall model with refined random effects structure yields a marginal R^2 of 0.123 and a conditional R^2 of 0.319.

A summary of the estimated fixed effects coefficients is reported in [Table 5](#).

Post-hoc analyses

Harmfulness and size as parametric predictors

As a further control test, we analyzed the data using the scores on the harmfulness and size dimensions for each stimulus word as parametric predictors, and demonstrative as outcome variable. Animacy was included as categorical predictor, assuming a binary distinction between animals and inanimate beings. This step was meant to test claims on gradient sensitivity of demonstratives to the experimental variables, and to rule out the possibility that observed effects could be artefacts of the binary categorization of harmfulness and size.

The results of the parametric analysis confirmed all the effects observed in the binary analysis, and they are reported in [S2 Appendix](#).

Manipulability and experimental variables

The analyses reported in the previous sections elucidate how size, harmfulness and animacy influence demonstrative use. In our experiments, these three dimensions are claimed to be proxies of manipulability, under the hypothesis that manual affordances drive the choice of specific demonstrative forms.

Table 5. Fixed effects from statistical model for overall analysis.

	Beta	SE	z	95% CI lower	95% CI upper	Odds Ratio	p
(Intercept)	-1,96	0,17	-11,32	-2,29	-1,63	0,14	< .001***
Animate	0,27	0,23	1,18	-0,18	0,72	1,31	n.s.
Size	0,59	0,23	2,58	0,14	1,04	1,8	< .01**
Harm	0,58	0,23	2,5	0,13	1,03	1,79	< .05*
Lang (EN vs. DK)	0,59	0,19	3,06	0,22	0,96	1,8	< .01**
Lang (IT vs. DK)	0,83	0,13	6,39	0,58	1,08	2,29	< .001***
Animate x Size	0,65	0,32	2,04	0,02	1,28	1,92	< .05*
Animate x Harm	1,02	0,32	3,16	0,39	1,65	2,77	< .01**
Size x Harm	-0,11	0,32	-0,33	-0,74	0,52	0,9	n.s.
Animate x Lang (EN vs. DK)	0,07	0,23	0,3	-0,38	0,52	1,07	n.s.
Animate x Lang (IT vs. DK)	-0,37	0,16	-2,34	-0,68	-0,06	0,69	< .05*
Size x Lang (EN vs. DK)	0,12	0,22	0,54	-0,31	0,55	1,13	n.s.
Size x Lang (IT vs. DK)	-0,01	0,15	-0,04	-0,3	0,28	0,99	n.s.
Harm x Lang (EN vs. DK)	0,27	0,22	1,23	-0,16	0,7	1,31	n.s.
Harm x Lang (IT vs. DK)	-0,22	0,15	-1,44	-0,51	0,07	0,8	n.s.
Animate x Size x Harm	-0,17	0,45	-0,37	-1,05	0,71	0,84	n.s.
Animate x Size x Lang (EN vs. DK)	-0,64	0,3	-2,13	-1,23	-0,05	0,53	< .05*
Animate x Size x Lang (IT vs. DK)	-0,76	0,21	-3,61	-1,17	-0,35	0,47	< .001***
Animate x Harm x Lang (EN vs. DK)	-0,71	0,3	-2,35	-1,3	-0,12	0,49	< .05*
Animate x Harm x Lang (IT vs. DK)	0,2	0,21	0,92	-0,21	0,61	1,22	n.s.
Size x Harm x Lang (EN vs. DK)	-0,42	0,3	-1,4	-1,01	0,17	0,66	n.s.
Size x Harm x Lang (IT vs. DK)	0,08	0,21	0,39	-0,33	0,49	1,08	n.s.
Animate x Size x Harm x Lang (EN vs. DK)	0,65	0,41	1,56	-0,15	1,45	1,92	n.s.
Animate x Size x Harm x Lang (IT vs. DK)	-0,13	0,29	-0,46	-0,7	0,44	0,88	n.s.

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However, while our analyses decompose the effect of manipulability into finer-grained semantic components, the relationship between manipulability and the combination of our experimental variables is more complex than that of a complete overlap.

On the one hand, the three dimensions tested here do not entirely exhaust the range of semantic features contributing to shape an object's degree of manipulability. To provide a concrete example, shape also plays a role in determining the extent to which an object afford manipulation, a factor which is not accounted for by the combination of our experimental variables. Our models might therefore leave unexplained part of the variance in the data which can still be accounted for by manual affordances.

On the other hand, the three semantic dimensions tested in our experiments are likely to encode *more* semantic content than mere manipulability. This residual information might also have a consistent impact on demonstrative choices. For instance, the distinction between a harmless object and a harmful one does not only translate into a difference in how easy, or how desirable, it is to manually interact with the objects. A harmful and a harmless object also differ in how willing one might be to be exposed to them, or to establish physical proximity. Our analyses do not allow to fully assess to what extent the observed effects are driven by distinctions in manual affordances common to all three experimental variables, rather than by variable-specific (non-shared) semantic content encoded by each feature.

In order to further test our claim that observed effects are driven by manual affordances, we acquired explicit manipulability ratings *post hoc* for each of the words used in Experiment 2. These ratings were used for a two-fold purpose. First, we ensured that variation along the three

variables tested in our experiments does indeed reflect significant and consistent distinctions in the extent to which objects afford manipulation. Secondly, we added explicit manipulability scores as a parametric regressor to the model used for the analysis of the Danish data from Experiment 2. This allowed to disentangle the shared effect of manipulability from any potential effects of residual semantic information encoded by each individual semantic variable.

Manipulability ratings

We asked native speakers of Danish to rate each of the 32 experimental words from Experiment 2 for manipulability. For each word, participants provided three separate scores by answering the following questions: 1) Can you move it with your hands? (“Kan du flytte den med hænderne?”); 2) Is it something you would consider moving with your hands? (“Er det en ting, som du kunne finde på at flytte med hænderne?”); 3) Is it something that would let you move it with your hands? (“Er det noget, der ville lade sig flytte med hænderne?”). These three formulations present the rather abstract problem of how “manipulable” an object is from concrete perspectives, thus confronting participants with specific, explicit and easy-to-grasp problems. The three scores for each word were summed, in order to obtain a reliable and unbiased quantitative proxy to the overarching semantic property of interest.

The questionnaire was set up in Qualtrics, and advertised via social media and institutional web platforms. Before the beginning of the questionnaire, participants were presented with a consent form analogous to the one used for Experiment 1 and 2, and consented to its conditions by proceeding to the first trial. Participants were presented with words in randomized order, one word at a time, and asked to provide a rating on a Likert scale from 1 to 5 in response to each of the three questions. They scored each word by moving the cursor of a slider to an integer value between 1 and 5. We collected data from 67 participants. Fig 4 displays mean scores for each experimental word across the three questions, as well as the sum of all three scores for each word.

Experimental variables reflect manipulability ratings

In order to test whether different levels of size, animacy and harmfulness reliably reflect distinctions in the degree of manipulability of the referent, we fitted a mixed effects linear regression using binary predictors for size, harmfulness, and animacy, and their interactions, as fixed effects, and the sum of manipulability scores as outcome variable. The model included a random intercept for each participant.

The model displays a significant main effects of harmfulness, $\beta = 1.18$, $se = 0.27$, $t(2068.95) = 4.37$, $p < .001$, suggesting that objects coded as “harmful” score significantly lower on manipulability compared to harmless objects. The model also displays a significant main effect of size, $\beta = 4.49$, $se = 0.27$, $t(2068.95) = 16.64$, $p < .001$, suggesting that objects coded as “big” are rated as less manipulable than objects coded as “small”. Interestingly, we also found a significant *negative* effect of animacy, $\beta = -1.94$, $se = 0.27$, $t(2068.99) = -7.18$, $p < .001$. This effect indicates that manipulability ratings for inanimate objects are significantly *lower* than for animate objects, which might explain the inconsistent results concerning the effect of animacy on demonstrative use in Experiment 1 and Experiment 2.

However, animacy modulates the effects of harmfulness and size. The model displays a significant interaction between animacy and harmfulness, $\beta = 2.06$, $se = 0.38$, $t(2068.97) = 5.41$, $p < .001$, with differences in manipulability ratings between harmful and harmless objects being larger for inanimate objects compared to animate objects. Moreover, the interaction between animacy and size is significant, $\beta = 3.35$, $se = 0.38$, $t(2068.97) = 8.78$, $p < .001$. These two effects could be interpreted as further indirect evidence in favour of the sensory-functional hypothesis

Fig 4. Overview of manipulability scores per word. The figures display mean scores for each word on each of the three questions. Error bars reflect the standard error of the mean. Values in the bottom right panel correspond to the mean (across participants) of the sum of the three scores. Colors indicate the SVR-derived scores along the animacy, size, and harmfulness dimensions used in the parametric analysis.

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on the animate-inanimate distinction. Manipulability, a prototypical functional semantic feature, seems to be more distinctive of different types of inanimate objects than of types of animate objects.

Finally, the model displays a marginally significant interaction between harmfulness and size, $\beta = -0.98$, $se = 0.38$, $t(2068.94) = -2.57$, $p < .05$. A full summary of the model parameters and significance levels is provided in [S3 Table](#). The model achieves a marginal R^2 of 0.49, and a conditional R^2 of 0.55. The relationship between manipulability scores and the three experimental variables is summarized in [S4 Fig](#).

Manipulability scores and demonstrative use

In order to assess the extent to which the effects of size and harmfulness are driven by manipulability rather than by residual variable-specific semantic information, we added the sum of manipulability scores as a parametric regressor to the model used to analyze the data from Experiment 2.

In this analysis we first fitted the original model used for Experiment 2 to the Danish data. In line with the cumulative analysis, the model reveals main effects of Size, $\beta = 0.57$, $se = 0.13$,

$z = 4.35$, $p < .001$, and Harmfulness, $\beta = 0.36$, $se = 0.13$, $z = 2.72$, $p < .01$, as well as interactions between Animacy and Size, $\beta = 0.79$, $se = 0.18$, $z = 4.43$, $p < .001$, and Animacy and Harmfulness, $\beta = 1.16$, $se = 0.18$, $z = 6.4$, $p < .001$. The model achieves a marginal R^2 of 0.169 and a conditional R^2 of 0.39. We then compared the original model ($df = 9$, log-likelihood = -3656.5) to the extended one ($df = 10$, log-likelihood = -3645.1) using ANOVA. Adding the manipulability regressor significantly improved the model fit, $\chi^2(1) = 22.73$, log-likelihood difference = -11.4, $p < .001$. The explicit manipulability scores thus explain an additional part of the variance in the data. This suggests that, alongside the three dimensions tested in our experiments, additional functional features contributing to an object's manipulability play a role in demonstrative choice.

The extended model displays a significant effect of manipulability, $\beta = 0.07$, $se = 0.01$, $z = 4.78$, $p < .001$, indicating that, the more manipulable the referent, the higher the proportion of proximal demonstrative used to refer to it. There was no significant effect of Animacy, $\beta = 0.13$, $se = 0.14$, $z = 0.91$, $p > .05$, nor a significant effect of Size, $\beta = 0.27$, $se = 0.14$, $z = 1.85$, $p > .05$. The effect of Harmfulness was marginally significant, $\beta = 0.28$, $se = 0.13$, $z = 2.12$, $p < .05$.

The absence of a main effect of size and the reduced reliability of the effect of Harmfulness indicate that manipulability explains away the majority of the variance previously accounted for by these variables. This provides further support to the claim that the effects of Size and Harmfulness were indeed due to these variables encoding distinctions in manual affordances. However, while the effect of Size is entirely explained away by manipulability, the residual effect of Harmfulness suggests that additional semantic information encoded by this dimension might influence for demonstrative choice. It could be hypothesized that the valence component intrinsic to the harmful / harmless distinction independently modulates demonstrative choice, a claim that remains to be addressed in future experiments.

As in the previous model, there were significant interactions between Animacy and Harmfulness, $\beta = 1.02$, $se = 0.18$, $z = 5.56$, $p < .001$, as well as between Animacy and Size, $\beta = 0.57$, $se = 0.19$, $z = 3.1$, $p < .01$. In the extended model, marginal R^2 increases to 0.172 and conditional R^2 increases to 0.394.

A full summary of the estimated parameters and their significance levels for both models is provided in [S4 Table](#). The relationship between manipulability scores and the proportion of proximal demonstratives for each word is illustrated in [Fig 5](#).

Discussion

Beyond the distance-based account

In our experiment, we investigated whether different types of objects, which varied in the degree to which they afford for manual interaction, consistently elicit different patterns of demonstrative use, regardless of the spatial context of utterance. Following our predictions, our results showed that speakers were more likely to use proximal demonstratives for objects more readily affording manipulation. Harmfulness and size of the referent affected participants' choices of demonstrative forms across two experiments and three different languages, with participants being more likely to use proximal forms when presented with words denoting smaller compared to bigger referents, and harmless compared to harmful referents. As predicted, such effects were significantly stronger for inanimate referents, compared to animate beings.

However, contrary to our prediction, we only found evidence for a main effect of animacy in the first of two experiments. This might suggest that, contrary to our assumptions, the animate-inanimate distinction does not itself map onto a functional distinction between objects

Fig 5. Proportion of proximal demonstratives as a function of manipulability. The proportion of proximal demonstratives used by participants in relation to specific words increases as a function of manipulability. Here, manipulability is obtained as the average (across participants) of the sum of the three manipulability ratings.

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affording interaction to different extents, as suggested also by the analysis of post-hoc manipulability ratings. While animacy consistently influenced demonstrative use by modulating the effect of other functional dimensions, there is no conclusive evidence in favor of an independent preference for proximal demonstratives for inanimate objects, compared to animate beings.

Our results are consistent across the three languages tested in the experiment, which shows that the observed effects extend beyond patterns specific to a single language. We are nonetheless aware that the languages sampled in the current study are only representative of a restricted group within one language family, and we are not aiming at claiming cross-linguistic universality for such effects.

Manual affordances and object semantics

Our studies provide a range of novel contributions to studies on demonstrative reference, which so far have almost exclusively focused on mapping the proximal/distal contrast onto spatial properties of the referents.

As our results indicate, spatial factors are likely to only account for part of the causal mechanisms underlying the usage profile of demonstratives. Dyadic demonstrative contrasts do not only encode the position of the referent relative to the speaker or the dyad, but additionally rely on semantic representations involving several functional dimensions along an object's feature space. More specifically, functional properties of objects, i.e. the extent to which objects afford manual interaction, seem to be among the core factors shaping demonstrative use. However, while the link between demonstrative use and object semantics is a novel contribution to current research on spatial deixis, our results are also in continuity with existing literature. Indeed, although on a purely spatial basis, recent studies have converged on suggesting that the proximal/distal distinction is grounded in functional hand-centered representations of space and biomechanical affordances [23, 25–26]. In our experiments, we tested and expanded these hypotheses by targeting *non-spatial* dimensions that affect the extent to which a referent is available for manipulation. We focused on size and harmfulness as prototypical examples of functional properties that play a crucial role in defining an objects' readiness for manual grasp, as well as on animacy as a factor which is thought to be intrinsically linked to the functional profile of objects.

Although size and harmfulness both play a role in the functional profile of referents, they reflect different ways in which manual affordances are relevant to demonstrative use. In the case of size, the difference between small and big referents is entirely determined by the physical and perceptual properties of a referent, and by purely biomechanical affordances. On the other hand, the effect of harmfulness projects the distinction to a deeper cognitive level, as it is likely to involve richer action representations, and arguably emotional components. In this respect, the effect of harmfulness could be interpreted as a more complex effect also involving object valence, that is of the degree to which manipulating an object is desirable, rather than merely physically possible.

Demonstratives as a window onto semantic knowledge

Crucially, we also observed that preferences for proximal demonstratives for smaller over bigger objects, and for harmless over harmful objects were more pronounced for inanimate objects compared to animate objects.

This finding is in line with our predictions formulated along the line of a sensory-functional view on semantic knowledge. Sensory-functional theories are based on the claim that functional features are more prominent in semantic representations of inanimate objects compared to animate objects [38, 40–43]. As opposed to domain-specific, sensory-functional views explain the distinction between representations for inanimate and animate objects in terms of a difference in the degree to which functional and sensory features are involved in the representation of category tokens. Functional features are thought to be more prominent than sensory features in the representation of inanimate objects, while the relative importance of functional features is lower in the case of representations of animate beings. The core assumptions of sensory-functional theories were central to our predictions, and crucial to explain our main findings.

The central claims of the sensory-functional view on the animate-inanimate distinction are compatible with the observed effects of harmfulness and size. Though functional features are claimed to be more prominent in the case of inanimate objects, in a sensory-functional framework they are still thought to play a role in both the representation of animate beings and of inanimate objects. This leads to the prediction that within-category differences in harmfulness and size should affect patterns of demonstrative use both within animate beings and inanimate objects, which is reflected in the observed main effects of size and harmfulness.

A central tenet of sensory-functional theories is furthermore that functional features are more prominent for inanimate objects than for animate beings. This leads to the prediction that differences in affordance for grasp and manipulation should more heavily affect patterns of demonstrative use in the case of inanimate objects, than in that of animate beings. The interactions observed between animacy and harmfulness, and between animacy and size are in line with this hypothesis.

The congruency between our results and the sensory-functional hypothesis adds a further dimension to the significance of our results. As mentioned, the observed effects provide support to the idea that demonstrative reference is partly grounded in perceptual-motor affordances and biomechanical constraints. This is undoubtedly a crucial point in itself, as it brings to light the pivotal role of demonstratives as powerful interfaces between language, cognition and action. However, the observed relationship between demonstrative usage patterns and the animate-inanimate distinction contributes to the long-standing debate between domain-specific and modality-specific views on semantic knowledge by lending support to some of the predictions of sensory-functional approaches. While still not providing conclusive evidence, these results display the potential of using demonstratives to shed light onto core aspects in the organization of human semantic knowledge.

Future directions: A comprehensive semantic analysis

In the present study, we selected a controlled set of words that varied along three target dimensions. As illustrated in the methods section, the selection process was tightly controlled, and the results hold even when accounting for item-specific patterns via a conservative random effects structure, which provides robust evidence for replicability of our effects. Still some variability in patterns of demonstrative choice can be observed both across languages and within levels of the experimental variables.

For example, while the effects of interest hold robustly across languages, the analyses displayed some cross-linguistic variation in the strength of the two-way interactions. As previously mentioned, these fluctuations might reflect false negatives, differences in sample size, or actual discrepancies in patterns of demonstrative use or word semantics.

Additionally, as displayed in Fig 6A and Fig 6B, a few specific words elicited a markedly different use of demonstratives across languages. It could be hypothesized that this is due to differences in the semantic profile of these words across languages, reflecting cross-cultural variation in exposure to certain referents. To provide a concrete example, specific animals might be present in certain countries but not in others, and customs or social practices involving the use of specific objects can vary across cultures, which could affect both familiarity with a certain referent and its perceived valence.

On the other hand, the plots also display some language-independent variability in the proportion of proximal demonstratives for individual tokens *within* levels of the experimental variables, with some words consistently showing higher proportions of proximal demonstratives compared to other items of the same category.

While, on the one hand, such patterns might reflect random fluctuations in the usage of demonstratives, it cannot be excluded that they reflect systematic variations due to further semantic factors that have not been explored in the present study.

Indeed, while in our experiments we found support for particular central semantic dimensions modulating the use of demonstratives, they are probably not exhaustive. A larger word

Fig 6. Proportion of distal demonstratives for each stimulus word across languages for Experiment 1 (left) and Experiment 2 (right). On the x axis the proportion of distal demonstratives for each word in Danish. On the y axis the proportion of distal demonstratives for each stimulus word in English for Experiment 1 and in Italian for Experiment 2. The diagonal line indicates the linear fit between the two. Words located closer to the fitted line display a similar use of demonstratives across languages, while words located further away from the fitted line elicited different use of demonstratives across languages. While there are no obvious patterns related to the experimental manipulations, demonstrative use for some particular words differs substantially across languages. This might reflect cross-cultural differences with respect to specific objects, i.e. more/less exposure to certain objects, or differences in the semantics of specific words across languages. The plot also displays within-category variability in demonstrative use consistent across languages.

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sample and more fine-grained analyses of the semantic structure of the chosen stimulus set would help elucidating whether such variability can be accounted for in terms of other unpredicted semantic effects. Moreover, as reflected by the R^2 estimates for the statistical models, a large part of the variance remains unexplained. Elucidating whether such variance is unsystematic or whether it reflects consistent effects of unexplored variables remains an open challenge for future work.

A range of methodologies could prove crucial in tackling these questions. For instance, the use of large semantic knowledge databases (e.g. [52]) would open up a wealth of possibilities. Such databases can be integrated with corpus data on the distributional profile of demonstratives or with experimental data, in order to better characterize the mapping between usage patterns of spatial demonstratives and the semantic profile of referents. It is to be noted, however, that at the moment the availability of such databases is only limited to a very small language sample, which therefore partly limits the possibility of drawing inferences on a cross-linguistic scale.

Spatial context, biomechanics and object semantics: An integrated account

Taken together, our results show that spatial demonstratives are sensitive to functional properties of their referents, and they lend support to the hypothesis that the proximal/distal contrast is grounded in differences in affordances for manual interaction. While previous studies have focused on mapping demonstrative contrasts onto spatial properties of referents, our studies indicate that object semantics is a complementary factor in shaping the usage profile of spatial demonstratives.

However, in the present study we aimed at exploring the role of functional properties of referents independently of their spatial location, that is, without any spatial or perceptual context. Our results therefore cannot be used to generate any predictions on how object semantics and spatial properties interact, as it is likely to be the case in naturalistic contexts. For this purpose, new experimental paradigms will have to be used, where both the type of referent and its spatial properties are manipulated systematically.

The lack of perceptual context in this paradigm calls for a further remark. As no visual context was provided in the study, it might be objected that the effects observed rather reflect biases in visual imagery that would also partly be accounted for by as distance effect. For instance, it could be hypothesized that dangerous things tend to be mentally represented as further away compared to harmless objects, as a form of psychological distancing from undesirable objects. The same might hold for bigger objects, for instance those that could act as landmarks (such as buildings or natural entities), compared to smaller objects. Our paradigm does not directly allow us to test this possibility. This hypothesis, however, would only account for part of the effects (e.g. it would not explain the interactions), and it is hard to relate to the existing literature. Moreover, the notion of psychological distance in mental imagery would also likely reflect experiences and expectations about affordances for interaction, and the two hypotheses may thus reflect two sides of the same coin.

Conclusions

Previous experimental work on demonstrative reference converges on showing that the distinction between proximal and distal spatial demonstratives might be grounded in functional properties of referents, such as their affordances for manual interaction. However, all studies so far have focused on mappings between the proximal/distal contrast and manual affordances in terms of the position of the referent relative to the speaker, to the conversational dyad, or to competing referents.

Our work aimed at investigating whether functional semantic properties of objects systematically influence speakers' preferences for proximal or distal demonstrative forms, regardless of any spatial context.

Over two experiments, we presented speakers of English, Danish and Italian with words denoting animate and inanimate referents which differed in size (big/small) and harmfulness (harmful/harmless), and we asked them to match each word to either a proximal or a distal demonstrative form. Participants were more likely to use proximal demonstratives for harmless compared to harmful referents, and for small compared to big referents, that is for referents which are more likely to afford manual interaction. These effects provided robust evidence in favor of the hypothesis that the proximal/distal contrast is modulated by functional properties of objects, and specifically by their affordances for manual interaction.

Moreover, as predicted, such effects were stronger for inanimate objects, compared to animate referents. This is in line with the predictions of sensory-functional approaches to semantic knowledge, which claim that categorical distinctions between semantic representations of animate and inanimate beings can be mapped onto differences in the prominence of functional features over sensory features across the two categories.

Our study provides a two-fold contribution to the literature. On the one hand, our results provide further evidence for a grounding of spatial demonstratives onto manual affordances, with object semantics and biomechanical constraints being identified as complementary forces in shaping the usage profile of spatial demonstratives. On the other hand, they hint at the possibility of using demonstrative contrasts as proxies to investigate core aspects of the organization of human semantic knowledge.

Supporting information

S1 Table. Stimulus list for Experiment 1, all languages.

(DOCX)

S2 Table. Stimulus list for Experiment 2, Italian and Danish.

(DOCX)

S3 Table. Manipulability scores as a function of size, animacy and harmfulness, model summary.

(DOCX)

S4 Table. Demonstrative use as a function of experimental variables and manipulability scores for Danish data in Experiment 2.

(DOCX)

S5 Table. Overview of statistical model for Italian data from Experiment 1 without Soundness regressor.

(DOCX)

S6 Table. Overview of statistical model for Italian data from Experiment 1 including Soundness regressor.

(DOCX)

S7 Table. Overview of statistical model for parametric analysis.

(DOCX)

S1 Fig. Word frequencies for Experiment 1. Lemma occurrences per million words for each stimulus word in (A) Danish; (B) English; (C) Italian.

(TIF)

S2 Fig. Distribution of word frequencies from Experiment 2. Lemma occurrences per million words for each stimulus word in (A) Danish; (B) Italian.

(TIF)

S3 Fig. Overview of Italian data from Experiment 1.

(TIF)

S4 Fig. Manipulability scores for Experiment 2 as a function of size, harmfulness and animacy.

(TIF)

S1 Appendix. Analysis of Italian data from Experiment 1.

(DOCX)

S2 Appendix. Parametric analysis.

(DOCX)

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Article 3

This is for you:

Social modulations of proximal vs. distal space in collaborative interaction

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Abstract

Human spatial representations are shaped by affordances for action offered by the environment. A prototypical example is the organization of space into *peripersonal* (within reach) and *extrapersonal* (outside reach) regions, mirrored by *proximal* (this/here) and *distal* (that/there) linguistic expressions. The peri-/extrapersonal distinction has been widely investigated in individual contexts, but little is known about how spatial representations are modulated by interaction with other people. Is near/far coding of space dynamically adapted to the position of a partner when space, objects, and action goals are shared?

Over two preregistered experiments based on a novel interactive paradigm, we show that, in individual and social contexts involving no direct collaboration, linguistic coding of locations as proximal or distal depends on their distance from the speaker's hand. In contrast, in the context of collaborative interactions involving turn-taking and role reversal, proximal space is shifted towards the partner, and linguistic coding of near space ('this' / 'here') is remapped onto the partner's action space.

Introduction

Representing space for action and interaction

A significant part of human spatial cognition is influenced by affordances for action and interaction offered by the environment (Goodale & Milner, 1992; Tatler & Land, 2011). The tendency to encode functional features of objects and locations finds expression in the organization of space into an immediate *peripersonal* and a distal *extrapersonal* region. This distinction maps onto a contrast between objects *within* and *outside* manual reach, optimizing sensorimotor representations for manual action and defensive behavior (Graziano & Cooke, 2006; Làdavas, 2002).

The link between manual affordances and spatial cognition has been explored extensively in the literature (Maravita & Iriki, 2004; Rizzolatti, Fadiga, Fogassi, & Gallese, 1997). However, the majority of studies on the topic have focused on solitary individuals manipulating an object, while a considerable portion of our everyday behaviors unfolds in the context of face-to-face social exchanges where multiple individuals engage in a dynamic interaction with each other and with the environment (Tylén et al., 2010; Vesper et al., 2017).

In a range of situations, from passing the salt at the dinner table to building a new house, we find ourselves in situations where actions are performed together with other people and coordinated via language. In these cases, space is often shared between interlocutors, and objects in this space lend themselves to collaborative joint attention (Tomasello et al., 2005) and action (Becchio, Sartori, Bulgheroni, & Castiello, 2008; Becchio, Sartori, & Castiello, 2010; Richardson, Marsh, Isenhower, Goodman, & Schmidt, 2007). Within such joint attentional scenes, objects' affordances for manipulation emerge as a result of complex interactions between their distance to other objects and agents, and their contribution to specific action goals. Representations of space are thus likely to be dynamically modulated by functional properties of objects with regards to both individual and social action possibilities.

These observations lead to a number of specific predictions. First, given the action-oriented nature of spatial representations, peripersonal space is hypothesized to be biased towards hand-centered coordinates, a format which facilitates fast movement execution (Makin, Holmes, Brozzoli, & Farnè, 2012).

Second, in activities involving other agents, functional representations of space may undergo structural changes to encode object affordances for joint action (Pellencin, Paladino, Herbelin, & Serino, 2018; Teneggi, Canzoneri, di Pellegrino, & Serino, 2013). Such dynamical social adaptations of near/far spatial coding are expected on the basis of a large number of studies on joint action showing that interlocutors spontaneously adapt to each other across a number of linguistic and non-linguistic behavioral measures, from the alignment of lexicon (Fusaroli et al., 2012; Pickering & Garrod, 2006) and situation models (Garrod & Doherty, 1994), to subtle bodily sway (Shockley, Santana, & Fowler, 2003), and even heart rate (Fusaroli et al., 2016). Furthermore, studies on recipient design in language have shown that individuals flexibly adjust their utterances to the specific interlocutor and the overarching goal of the interaction (Brennan & Clark, 1996; Campisi & Özyürek, 2013).

We tested these two hypotheses using a novel experimental paradigm that allows to investigate dynamic modulations of sensorimotor representations: a) in a multi-person interactive context; b) maintaining fundamental features of social task-oriented behavior; c) in a controlled and low-dimensional space. Using spatial demonstratives (words like *this* and *that*) as an online linguistic index of representations of proximal space, we aimed at systematically investigating how egocentric action-oriented biases and context-specific social modulations interact in shaping representations of space in everyday social interactions.

Demonstratives as linguistic indices of near/far spatial encoding

Spatial demonstratives are highly frequent lexical forms found across all natural languages (Diessel, 2013). Used in conjunction with pointing gestures and gaze cues, they constitute powerful interpersonal coordination devices (Cooperrider, 2016; García et al., 2017), that allow interlocutors to jointly attend to relevant locations, and to align on shared spatial representations. Whereas some languages have highly elaborate systems, most languages show a simple dyadic distinction between a so-called *proximal* (“this”, in English) and a *distal* (“that”) demonstrative (Diessel, 1999).

Experimental evidence shows that the contrast between these two forms is a reliable proxy of object reachability in individual contexts. Over a series of studies, Coventry and colleagues have shown that participants systematically prefer proximal demonstratives for objects within reach, and distal demonstratives for objects outside reach (Coventry et al., 2014, 2008; Gudde et al., 2016). Moreover, the choice of demonstrative forms is sensitive to the same dynamic manipulations affecting the boundaries of peripersonal space (di Pellegrino & Làdavas, 2015). For instance, participants spontaneously extend the space for which they use a proximal demonstrative if they point to referents using a stick (Berti & Frassinetti, 2000; Longo & Lourenco, 2006), and are similarly affected by perceptual and psychological parameters of the referent, such as its visibility, ownership and familiarity, when choosing a demonstrative form (Coventry et al., 2014).

The present study

Over two experiments, we investigated how coding of objects and locations as *near* vs. *far* is influenced by affordances for manual action, and modulated across contexts of social interaction. Using a novel experimental paradigm, we presented participants with targets appearing on a two-dimensional horizontal plane and asked them to point and refer to them using demonstratives. In Experiment 1, participants performed the task alone or with a confederate, who was either engaged

in a complementary naming task or in a collaborative communicative task. We hypothesized that targets located closer to the speaker on the sagittal plane and rightwards on the lateral plane (all participants were right-handed) would be more likely to be identified as proximal, which would support the hypothesis that proximal/distal encoding is tied to manual affordances of the referent. Crucially, we hypothesized that, in the context of collaborative interaction, targets located closer to the partner (that is to the participant's left) would be more likely to be labelled as proximal than in individual or non-collaborative social contexts, indicating that in this condition manual biases are modulated by social affordances.

In Experiment 2, we used a similar setup, but enhanced the interactive aspects of the task by introducing turn-taking and role reversal. Both experiments were pre-registered on the Open Science Framework. Pre-registrations, data and code are publicly available at osf.io/qjxg9/.

Experiment 1

Methods

Participants

Eighty right-handed participants (female = 43, age range = 19-48, median = 26, sd = 7.6) with Danish as first language took part in the experiment in return for monetary compensation. All participants gave written informed consent. The study received ethical approval from the Human Subjects Committee of the Cognition and Behaviour Lab at Aarhus University, and it was carried out in accordance with local ethical guidelines and procedures.

Design and Procedure

Upon arrival to the lab, participants were instructed that they would be presented with a spatial

working memory test, and that they were assigned to the “linguistic condition”. However, unbeknownst to the participants, there was no between-participant manipulation, that is, all participants did the same version of the experiment (in line with (Coventry et al., 2014, 2008; Gudde et al., 2016)).

Participants stood by the inferior edge of a 40’’ screen, placed horizontally on a table. At each trial, a grid of circles would appear on the screen. After 500ms, the grid disappeared and two target shapes (circles, triangles, squares, hexagons, stars) appeared on the screen for a random interval between 200ms and 800ms. The position of targets was randomized across trials. The grid would then reappear and the participant was prompted to designate the target positions. Participants were instructed to remember the locations of targets, then point to them while referring to the locations with the Danish demonstratives *den her* or *den der*, equivalent to the English *this* and *that*. Participants were explicitly instructed to use both demonstrative forms at each trial, one for each target, and were reminded to do so whenever they used only one of the expressions. No explicit instructions were given on the order of the pointing nor on the order of deictic forms. There were 132 trials per condition per participant.

Participants performed the task across three conditions. In the *baseline condition*, participants performed the task alone. In the *complementary condition*, a confederate stood to the left of the participant and named the target shapes (e.g. *star*, *circle*) after the participant had finished pointing. In the complementary condition, the two tasks were mutually independent. Neither the participant nor the confederate relied on the information provided by the other person in order to be able to perform their own task. In contrast, in the *collaborative condition*, the confederate’s task depended on the information conveyed by the participant’s pointing. In this condition, the confederate closed his or her eyes during target exposure and only opened them after hearing a click sound signifying the re-appearance of the grid. The participant then pointed at the location of both targets and referred to them using demonstratives. This allowed the confederate, who did not have perceptual access to

the targets, to report their positions on a touch screen device placed next to the screen.

The authors and two student assistants took turns in the role of experimenter (live-coding the participants' responses) and confederate. The baseline was always performed first. The order of the complementary and collaborative conditions was counterbalanced across participants. The setup of the experiment is displayed in Figure 1. Upon completion of the experiment, participants were informally debriefed. None of the participants reported to have realized that their use of demonstratives was the actual variable of interest and, in general, they reported no explicit awareness of how they had distributed the demonstrative forms spatially. Responses were coded as "invalid", if the participants reported not having seen where the targets had appeared, when participants failed to use both demonstrative forms, or when the experimenter could not hear the participant's response. There was a total of 286 invalid trials out of 31680 total trials. Missing trials were distributed as follows: 76 in the *baseline* condition (0.95 per participant on average), 77 in the *complementary* condition (0.96 per participant on average), 133 in the *collaborative* condition (1.66 per participant on average). Invalid trials were excluded from the analysis

Figure 1. Experimental setup for the three conditions.

Analysis

The relative distances between the x coordinates and the y coordinates of the two targets were used as predictors for a mixed effects logistic regression, fitted using the *glmer* function from *lme4* package in RStudio(Bates et al., 2014). For each trial, one of the two targets (henceforth: T1) was randomly selected and logged as target of interest. Relative distances on each of the axes were computed by subtracting the x coordinates and the y coordinate of the competitor target (henceforth: T2) from those of T1. The relative distance on the x axis (*RelativeX*) took positive values if T1 was further to the right than T2, whereas their distance on the y axis (*RelativeY*) took positive values if T1 was further away from the speaker than T2 on a sagittal axis. Figure 2 exemplifies how relative distances were computed in a sample trial.

Figure 2. Computation of relative distances between T1 and T2 on the sagittal (*RelativeY*) and lateral axis (*RelativeX*). The coordinate system is oriented from left to right for the x axis, and from the bottom to the top of the screen for the y axis. *RelativeX* is computed by subtracting the x coordinate of T2 from the x coordinate of T1. Since the x coordinate of T1 is larger, in this example *RelativeX* takes positive value. *RelativeY* is computed by subtracting the y coordinate of T2 from the y coordinate of T1. Since in this example the y coordinate of T1 is smaller, *RelativeY* takes a positive value.

Notice that relative distances combine information on distance between T1 and T2, and distance between T1 and the speaker. To provide a concrete example, large positive values of relative distance

on the y axis not only indicate larger distance between the targets, but they also indicate that T1 is further away from the speaker, while the opposite holds for negative values. This metric makes it possible to investigate how the likelihood of coding a referent as *proximal* or *distal* is influenced by its position relative to the speaker and to competing referents, both relevant factors in linguistic organization of space into proximal vs. distal locations (Bonfiglioli et al., 2009; Coventry et al., 2008).

The *fixed effects* structure of the model included the relative distance between the two targets on the y axis (henceforth: *RelativeY*), the relative distance between the two targets on the x axis (henceforth: *RelativeX*), and a categorical predictor for condition (henceforth: *Condition*), as well as all interactions. The demonstrative word chosen to refer to T1 was used as outcome variable in the model. The distal demonstrative (*that*) was set as reference level, while the proximal form (*this*) was coded as success outcome.

The *random effect* structure included random intercepts for each participant as well as random slopes for *RelativeY*. Parameters were estimated using maximum likelihood estimation with Laplace approximation. The power simulation for the model is reported in the preregistration, yielding 70-100% power for fixed effects and two-way interactions. Planned contrasts for the categorical predictor *Condition* compared the participant's behavior in the baseline condition with cumulative behavior in the social conditions, as well as the complementary condition against the collaborative condition.

Results

Main effects of distance on the sagittal and lateral axes

Figure 3 displays the proportion of proximal demonstratives as a function of *RelativeY* and *RelativeX* across conditions.

Figure 3. Proportion of proximal demonstratives used to denote T1 as a function of its distance from the competing target (T2) on the *sagittal* (left) and *lateral* (right) axis across all conditions. As T1 moves further away from the participant on the sagittal axis, that is as the value of *RelativeY* increases, the probability of participants coding it as *proximal* decreases. As T1 moves further to the participant's right, that is as the value of *RelativeX* increases, the probability of participants coding it as *proximal* increases, speaking in favour of a right-lateralized bias for proximal space.

The proportion of proximal demonstratives decreases as *RelativeY* increases, i.e. as T1 moves further away from the speaker on the sagittal axis relative to T2. Additionally, figure 3 displays an increase in proportion of proximal demonstratives as a function of an increase in the value of *RelativeX*, i.e. as T1 moves further to the participant's right.

The mixed effects logistic regression model with *RelativeX*, *RelativeY* and *Condition* as predictors, and including all interactions, confirms the statistical reliability of these patterns. The model displays a significant effect of *RelativeY*, $\beta = -2.59$, $se = 0.27$, $z = -9.69$, $p < .001$ and of *RelativeX*, $\beta = 0.32$, $se = 0.02$, $z = 16.78$, $p < .001$.

Taken together, the effects of relative distance of targets on the sagittal and lateral plane are in line with the idea that proximal space is intrinsically linked to manual affordances. As distance from the pointing hand decreases, objects become more likely to be identified as *proximal*.

Effect of social manipulations

Planned contrasts reveal a significant interaction between *RelativeX* and *Condition* when comparing

the *complementary* and *collaborative* condition, $\beta = 0.05$, $se = 0.02$, $z = 2.17$, $p = .03$. No such effect is observed when cumulatively comparing the baseline to the social conditions, $\beta = -0.001$, $se = 0.01$, $z = -0.08$, $p = .936$.

The interaction between *RelativeY* and *Condition* reaches statistical significance both in the contrast between the baseline and the two social conditions, $\beta = -0.07$, $se = 0.03$, $z = -2.51$, $p = .012$, and between the *complementary* and *collaborative* condition, $\beta = -0.11$, $se = 0.05$, $z = -2.45$, $p = .014$. None of the three-way interactions reached statistical significance.

Figure 4 displays the proportion of proximal outcomes as a function of both *RelativeX* and *RelativeY* across conditions.

Figure 4. Proportion of trials in which T1 is coded as *proximal* as a function of distance of T1 from T2 on the sagittal (*RelativeY*) and lateral (*RelativeX*,) axis. Larger *RelativeY* values indicate that T1 is further away from T2 (and from the participant) on the sagittal axis. Larger *RelativeX* values indicated that T1 is further to the right of T2. The center of the plot represents the position of T2, providing a reference for the interpretation of relative distance values on the x and y axis. The heatmaps clearly display the effect of *RelativeY* across all conditions. The right-lateralized bias on the x axis detected in the statistical analysis is particularly salient in the baseline and complementary condition, whereas proximal space is shifted towards the left, that is towards the partner, in the collaborative condition. Maps are smoothed by averaging across 8 nearest neighbors in x-y 2D space.

Figure 5 zooms in on the differences between the collaborative and the complementary condition, displaying the difference in proportion of proximal demonstratives for all combinations of values of *RelativeX* and *RelativeY*.

Figure 5. Difference in proportion of proximal demonstratives between the collaborative and complementary condition. Positive values (red) indicate higher proportion of proximal demonstratives in the collaborative condition, while negative values denote higher proportion of proximal demonstratives in the complementary condition. In the collaborative condition, participants code targets located towards their right as distal more often than in the complementary condition. Conversely, participants have a stronger tendency to code as *proximal* those targets that are located towards the left side of the screen, an index of representations of proximal space shifting towards the interaction partner. The difference is especially salient on the top-left of the plot, indicating that participants display a markedly higher tendency for participants to use proximal demonstratives for targets that are located towards the left even when they are further away from them on the sagittal axis. This suggests that near/far coding of spatial locations in collaborative contexts might depend to a higher extent on distance from the partner, rather than on distance from oneself.

A full overview of the estimates from the statistical model is provided in Supplementary Table S1.

Interim discussion

In Experiment 1, we detected a functional bias in favor of the pointing hand when participants performed the task individually. The hand-oriented bias persisted if two participants were performing independent tasks. However, in contexts of collaborative interaction, that is, where participants

depended on each other to perform their tasks, proximal space is shifted towards the partner. In Experiment 2 we built on these novel findings and aimed at replicating the social effects on proximal vs. distal coding of space in interactions where participants take turns in performing speaker and addressee tasks. This role alternation mirrors the turn-taking structure of natural linguistic interaction, and enhances the collaborative nature and ecological validity of the task.

Experiment 2

Methods

Participants

We collected data from 40 pairs of participants (80 individual participants, female = 51, age range = 18-36, median = 22, sd = 2.68). All participants were right-handed and native speakers of Danish. Participants within each pair were recruited independently, and reported not knowing each other in advance. All participants gave written informed consent. The study received ethical approval from the Human Subjects Committee of the Cognition and Behaviour Lab at Aarhus University, and it was carried out in accordance with local ethical guidelines and procedures.

Design and Procedure

Participants took part in the experiment in pairs. The experiment was performed using the same horizontally placed 40'' screen as in Experiment 1. One participant (P1) stood by the inferior edge of the screen. The other participant (P2) stood by the adjacent side of the screen to the left of P1, in the same position occupied by the confederate in Experiment 1. In this experiment, participants performed the task over two conditions, a *complementary* and a *collaborative* condition.

At the beginning of each trial, a 7 x 7 square grid of different shapes (triangles, squares, circles, stars

and hexagons) was displayed on screen for 500ms. The distribution of individual shapes over the grid was randomized. All shapes were light grey against a black background. The square grid ensured that the extension of the target space along the sagittal and lateral axes was the same for both participants. At each trial, two figures from the grid changed colour for a short interval (200 – 800 ms), to either red or green, trimmed to the same relative light and saturation as the default grey colour. In the *complementary* condition, P1 was instructed to respond to green targets, while P2 responded to red targets. After a click sound, depending on the colour of the figure, either P1 or P2 indicated which two shapes on the grid had lit up by pointing at their location and uttering a proximal and a distal demonstrative, as in Experiment 1. There were no specific constraints on the order in which demonstratives were to be used.

The other participant then named the *shape* of the figures that changed colour (“star”, “triangle” etc). Participants took turns in performing each task, that is, pointing to and naming the shape of targets. Both participants had visual access to the colour changes of the targets, thus to all the perceptual information necessary for their own task. The two tasks were therefore mutually independent.

In the *collaborative* condition, participants wore glasses with either red or green lenses. This prevented participants from being able to see targets of the same colour as their lenses. Trials unfolded as in the complementary condition. Participants were made aware that, at each trial, only one of them would be able to see the targets. In this condition, the participant who could see the targets changing colour indicated them using demonstrative forms and a pointing gesture. However, here the partner depended on this information to perform his/her task, that is, to name the figure shapes. In other words, in contrast to the *complementary* condition, here the demonstrative task was truly informative for the addressee’s naming task.

The order of presentation of conditions was counterbalanced across participant pairs. After completion of the experiment followed a short debriefing session, and again none of the participants

reported awareness of the spatial distribution of their demonstrative use or how this was modulated across conditions.

The experiment was originally intended to include 170 trials per condition per pair, but the number of trials was readjusted over the course of the experiment due to lab time constraints. Overall, out of 40 pairs, 2 pairs performed the experiment with 170 trials per condition, 13 pairs performed 150 trials, and the remaining 25 pairs performed 160 trials.

As in Experiment 1, an experimenter live-coded participants' responses. Responses could be coded as missing, when the participants reported not to be able to indicate the position of the targets, when participants failed to use both demonstrative forms, or when the participant's response was unintelligible to the experimenter.

Overall, for P1, there were 225 trials with missing responses out of 3145 trials in the complementary condition, corresponding to 5.62 trials per participant on average, and 128, corresponding to 3.2 per participant on average, in the collaborative condition. For P2, there were 64 missing trials (1.6 on average) in the complementary condition, and 196 missing trials (4.9 on average) in the collaborative condition. The experimental setup is represented in Figure 6.

Figure 6. Setup for Experiment 2

Analysis

We analysed the data using logistic mixed-effects regression as in Experiment 1. After discarding invalid responses, a total of 11967 out of 12580 data points were included in the analysis.

As in Experiment 1, at each trial, one target was randomly selected as reference target (T1), and the demonstrative used to refer to this target was used as outcome variable. Responses were coded as *distal* when participants used the distal forms *den der* when pointing to T1, and as *proximal* when participants used the proximal forms *den her* when pointing to T1. Distal was chosen as reference level, while proximal was the success outcome.

Distance between the two targets (relative to the position of each participant) was used as outcome variable. For trials where P1 responded, the relative distance on the x axis (*RelativeX*) was computed as the difference between the x coordinate of T1 and the x coordinate of T2. For this participant, relative distance on the y axis (*RelativeY*) was computed as the difference between the y coordinate of T1 and the y coordinate for T2. For P2, *RelativeX* was computed as the opposite of the difference between the y coordinate of T1 and the y coordinate of T2, while *RelativeY* was computed as the difference between the x coordinate of T1 and the x coordinate of T2. For both participants, *RelativeX* assumed positive values when T1 was located more towards the right of the participant, while *RelativeY* assumed positive values when T1 was located further away from the participant on the sagittal axis.

The complementary condition was set as reference level for the condition predictor variable. The categorical variable *color* coded for the color of the targets (*green* vs *red*), and therefore for which participants performed the demonstrative task at a specific trial. *Green* was set as reference level for this variable.

The fixed effects structure of the mixed effects logistic regression model included *RelativeX*

RelativeY, *Condition* and *Color* as regressors, as well as the full interaction structure. The demonstrative form chosen to refer to T1 was used as outcome variable in the model. The random effects structure included a random intercept for each pair and random slopes for the effect of *RelativeY*. The model mirrors the one used for Experiment 1, with the addition of the *Color* regressor accounting for differences in behavior between the two participants.

Results

Main effect of distance on sagittal and lateral axes

Figure 7 displays the average proportion of proximal demonstratives as a function of relative distance on the participant's sagittal and lateral plane, condition, and participants within pairs.

Figure 7. Proportion of trials in which T1 is coded as *proximal* as a function of relative distance of T1 from T2 on the sagittal and lateral axis. To ease interpretation, here relative distance is displayed from the perspective of the participant standing by the lower edge of the screen. Targets with higher values of *RelativeX* correspond to T1 being located more towards the right of the screen, whereas higher values of *RelativeY* correspond to T1 being located further towards the top of the screen.

In the complementary condition, for both participants, the probability of coding a referent as *proximal* highly depends on its distance to the competing referent on the participant's sagittal axis. Moreover, a minor left-lateralized bias towards the co-participant might already be in place especially for P1. Crucially, the heatmaps clearly show how participants remap their proximal space towards the partner's action space. In the collaborative condition, they tend to label as *proximal* those locations which lie closer to their partner, i.e. towards their own left (P1), or right (P2). Maps are smoothed by averaging across 8 nearest neighbors in x-y 2D space.

The analysis displayed a main effect of *RelativeY*, $\beta = -2.21$, $se = 0.23$, $z = -9.69$, $p < .001$, denoting a decrease in proportion of proximal demonstratives as T1 moves further away from participants on the sagittal axis. This effect is in line with what was observed in Experiment 1.

Interestingly, however, the model also detects a main effect of *RelativeX*, $\beta = -0.94$, $se = 0.12$, $z = -8.16$, $p < .001$, indicating that the proportion of proximal demonstratives decreases as T1 moves further towards the *left* of the speaker relative to T2. This effect is driven by the behavior of P1. In fact, the interaction between *Color* and *RelativeX* indicates that no such bias (or a significantly smaller one) is there for P2, i.e. the participant standing by the lateral edge of the screen, $\beta = 1.16$, $se = 0.16$, $z = 7.27$, $p < .001$, who rather displays a small right-ward bias. Contrary to what was observed in Experiment 1, here proximal space might already be slightly shifted towards the addressee in the complementary condition.

Effect of social manipulation

A significant interaction between *RelativeY* and *Condition* indicates that the effect of *RelativeY* is attenuated in the collaborative condition, $\beta = 1.43$, $se = 0.17$, $z = 8.36$, $p < .001$, and a three-way interaction with *Color* shows that this modulation is even stronger for P2 than for P1, $\beta = 1.05$, $se = 0.24$, $z = 4.29$, $p < .001$. This indicates that, overall, the probability of participants coding a target as

proximal depends significantly less on the distance from the target on their sagittal axis (even less so for P2) when participants are collaborating.

Figure 8 shows the proportion of proximal demonstratives across values of *RelativeY*, *Condition*, and participants within pairs.

Figure 8. Proportion of trials in which T1 is coded as *proximal* by relative distance from T2 on the participant's sagittal axis. In the complementary condition, the probability of participants coding a target as proximal decreases as it moves away from the speakers on the sagittal axis relative to competing targets. This effect is absent or significantly attenuated in the collaborative condition.

Crucially, the effect of *RelativeX* is also modulated by *Condition*. In the collaborative condition, the tendency to code leftward locations as *proximal* was significantly stronger, an effect which is driven by P1's behaviour, $\beta = -1.8$, $se = 0.17$, $z = -10.43$, $p < .001$.

In the collaborative condition, while distance on the sagittal plane becomes less relevant for both

participants, the probability of coding a target as *proximal* now depends significantly more on the location of the target on the left-right axis. For P1, targets located towards the left, and therefore closer to the partner, are more likely to be labelled as proximal. A modulation in the opposite direction is observed for P2, who displays a significant tendency to code as proximal those targets that appear towards the right, i.e. towards the partner. This is indicated by the three-way interaction between *RelativeX*, *Condition*, and *Color*, $\beta = 4.83$, $se = 0.25$, $z = 19.47$, $p < .001$. These effects suggest that in the collaborative condition proximal space is shifted towards the partner for both participants. Figure 9 displays the proportion of proximal demonstratives across values of *RelativeX*, conditions and participants within pairs.

Figure 9. Proportion of trials in which T1 is coded as *proximal* by relative distance from T2 on the participant's lateral axis. In the complementary condition, there seems to be a small bias towards

labelling as proximal those targets located towards the partner on the lateral axis. This is observed in terms of a left-ward bias for P1, corresponding to higher proportion of proximal demonstratives for negative values of *RelativeX*, and the opposite right-ward bias for P2, corresponding to higher proportion of proximal demonstratives for positive values of *RelativeX*. In the collaborative condition, the effect of *RelativeX* is very strong. As targets move further to the left of P1, the probability of it being coded as *proximal* increases. The opposite effect is observed for P2. In this condition, *proximal* space is remapped as a function of the partner's position.

The model also displayed a marginally significant interaction between *Color* and *RelativeY*, $\beta = -0.4$, $se = 0.18$, $z = -2.26$, $p = .024$, indicating that the effect of *RelativeY* was stronger for P2 than for P1. A full overview of the estimates from the statistical model is provided in Supplementary Table S2.

Exploratory analysis

The analyses reported above show that proximal space tends to be shifted towards the partner in collaborative contexts, arguably as a means to facilitate coordination for task performance. But what is the extent of such adaptations, and what type of coordination dynamics do they support? Do participants stably align on a new shared “compromise” reference frame? Or does each speaker fully remap *proximal* space onto the addressee's action space, with participants oscillating between two distinct reference frames, each centred on the current addressee on a trial-by-trial basis?

If participants do converge on a single shared reference frame when collaborating, participants' coding of space into *proximal* and *distal* locations in the collaborative condition should be more similar to their partner's behaviour in the same condition, than to the partner's behaviour in the complementary condition (where proximal/distal coding of space depends on one's individual action space). On the contrary, if targets are coded as proximal or distal depending on their distance from the action partner, the opposite scenario is expected, with higher similarity between one's behaviour in the collaborative condition and the partner's in the complementary condition.

If, however, *proximal* space is only minimally modulated in collaborative contexts, then similarity with one's own behaviour in the complementary condition should be higher than similarity with the

partners' behaviour in any condition.

To answer these questions, for each participant, condition and unique combination of values of RelativeX and RelativeY, we computed the proportion of trials where the outcome variable was a *proximal* demonstrative. This yielded, for each participant and condition, a map of empirical probabilities of targets being coded as *proximal* as a function of their sagittal and lateral distance from competing targets. For each participant, we then computed similarity (Pearson's correlation) between this map in the collaborative condition and a) the partner's map in the complementary condition; b) the partner's map in the collaborative condition; c) the participant's own map in the complementary condition. Figure 10 displays the distribution of correlation values for each participant. Higher correlations denote larger overlap in participants' coding of space.

Figure 10. Density distributions of correlation between proportion of proximal demonstratives for each RelativeX-RelativeY value combination in the collaborative condition, and proportion of proximal demonstratives for their partner in the complementary condition (top), their partner in the collaborative condition (middle), themselves in the complementary condition (bottom). Higher

correlation values denote higher similarity in coding of space as *proximal* vs. *distal* across participants and conditions.

As Figure 10 shows, participants' coding of space in the collaborative condition is overall most similar to their partner's coding of space in the complementary condition. This pattern is statistically reliable. We fitted a mixed-effects linear regression with correlation values as outcome variable, and Correlation Type and Color (P1 and P2) and their interaction as fixed effects.

Correlation Type coded for whether a correlation value denoted similarity between one's behaviour in the collaborative condition and either the partner's behaviour in the complementary condition (*other complementary*), the partner's behaviour in the collaborative condition (*other collaborative*), and one's own behaviour in the complementary condition (*self complementary*).

The model included a random intercept for each pair and a random slope for the effect of correlation type. The model indicates that spatial coding in the collaborative condition was significantly more similar to the partner's complementary condition than to the partner's collaborative condition, $\beta = -0.34$, $se = 0.06$, $t(73.35) = -5.35$, $p < .001$, and with one's own complementary condition, $\beta = -0.38$, $se = 0.07$, $t(65.07) = -5.42$, $p < .001$. No other effects were significant. This lends support to the hypothesis that, in the collaborative condition, speakers remap their *proximal* space onto the partner's action space. Details on the statistical model are reported in Supplementary Table S3.

Discussion

Over two large-sample studies, we investigated how coding of spatial locations as functionally proximal vs. distal depends on the interaction between affordances for individual and joint action.

Using demonstrative reference as a proxy of near/far coding of space, we observed an overall prominence of spatial encoding strategies oriented to manual action in individual contexts or social contexts involving no collaboration. Objects were identified as *proximal* not only when located closer

to participants on the sagittal axis but also when closer to the pointing hand on the lateral axis. In line with previous literature, we interpret this bias as a cognitive optimization strategy, responding to the need of minimizing sensorimotor transformations to perform manual action (Makin et al., 2012).

The link between proximal/distal encoding of space and manual actions finds resonance in existing experimental literature on linguistic (Bonfiglioli et al., 2009; Coventry et al., 2008; Rocca, Tylén, et al., 2019) and non-linguistic (Makin, Holmes, & Zohary, 2007; Rizzolatti et al., 1997) spatial encoding. However, a major limitation of existing work on near/far spatial coding consists in its reliance on experimental paradigms where behavior is probed in single-participant settings. Crucially, these settings are not representative of a large portion of real-life experiences, where space is shared among individuals who are acting together, and where objects lend affordances for joint action.

In our studies, we investigated the *near/far* space distinction in both single- and multi-participant settings mirroring the structure of everyday interactions. We showed that the influence of manual affordances on space encoding observed in individual contexts is radically modulated by social factors. When participants label spatial locations as *proximal* or *distal* in collaborative contexts, their *proximal* space tends to shift towards the partner's, a strategy which might facilitate the addressee's task of disambiguating the intended locations (Gianelli, Scorolli, & Borghi, 2013) and therefore smooth action performance. These partner-oriented adaptations are in line with characteristics of social behavior observed in non-linguistic joint action, where individuals adapt their behavior to minimize joint effort and optimally achieve shared goals (Vesper et al., 2011). Such flexible modulations of spatial representations are possibly aimed at facilitating the partner's task, thus optimizing the outcome of the joint action. However, further research is needed to test whether this is indeed the case by quantifying the impact of these modulations on the accuracy in joint task performance.

Modulations of peripersonal space triggered by engagement in social interaction have been previously reported in the literature. Teneggi and colleagues probed peripersonal space boundaries before and after engagement in an economic game, and found that they are shrunk or expanded as a function of the partner's attitude in the game (Teneggi et al., 2013). Similarly, peripersonal space boundaries interact with the social perception of others' behavior and shared sensory experiences (Maister, Cardini, Zamariola, Serino, & Tsakiris, 2015; Pellencin et al., 2018).

Our results are compatible with these findings and extend them both in scope and methodology. In our paradigm, we investigated social modulations of spatial representations online, *during* task performance, focusing on how such adaptations mediate collaboration. As we show in our study, the effects of social adaptations can vary across tasks, ranging from subtle modulations of peripersonal space to an entire remapping into partner-centered coordinates. In interactions involving a symmetrical alternation of roles, egocentric manual biases are fully overridden by social ones, i.e. *proximal* space is entirely remapped onto the partner's action space.

Participants thus modulate their spatial representations in a markedly *context-dependent* fashion, i.e. flexibly optimizing them for social action (Pellencin et al., 2018). On the one hand, very asymmetrical modulation patterns might be optimal in cases where individual parts of the social task are independent, or where participants' contribution to the joint task are unbalanced, congruent with asymmetrical motor coordination strategies observed in non-linguistic joint tasks (Vesper & Richardson, 2014). On the other hand, a more symmetrical form of convergence towards a single shared model of space might be advantageous for tasks building on bidirectional sharing of information along different turns, as in mutual adaptations characterizing alignment in linguistic interaction (Fusaroli & Tylén, 2016; Pickering & Garrod, 2006). Further research is needed to investigate in detail the relationship between information asymmetries and context-specific social adaptations in spatial reference.

Conclusion

Over two experiments, we investigated how functional organization of space into near and far locations is modulated by affordances for manual action and social interaction. We found that, in individual contexts, proximal space was centered on the hand, arguably optimizing representations for manual action. Manual biases were overridden by social factors in collaborative contexts, where proximal space was fully remapped onto the partner's action space in interactions involving turn-taking. Action-oriented biases and social modulations interact in shaping spatial representations, a flexible adaptation strategy potentially facilitating joint task performance. This flexible coding of space provides humans with a powerful tool to efficiently adapt to a virtually unlimited range of social contexts, a unique and highly advantageous feature of human social behavior.

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Data availability

Data and code are publicly available on the Open Science Framework at <https://osf.io/qjxg9/>.

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Supplementary Material

Supplementary Table S1. Overview of statistical model for Experiment 1.

	Beta	SE	z	95%CI lower	95%CI upper	Odds Ratio	p
(Intercept)	0,01	0,01	0,47	-0,02	0,04	1,01	0,641
RelativeY	-2,59	0,27	-9,69	-3,11	-2,06	0,08	<0.001***
RelativeX	0,32	0,02	16,78	0,28	0,35	1,37	<0.001***
RelativeY x RelativeX	0,04	0,06	0,67	-0,08	0,16	1,04	0,503
RelativeY x Condition1 (baseline vs. other)	-0,07	0,03	-2,51	-0,12	-0,02	0,93	0,012*
RelativeY x Condition2 (complementary vs. collaborative)	-0,11	0,05	-2,45	-0,21	-0,02	0,89	0,014*
RelativeX x Condition1 (baseline vs. other)	0	0,01	-0,08	-0,03	0,03	1	0,936
RelativeX x Condition2 (complementary vs. collaborative)	0,05	0,02	2,17	0	0,1	1,05	0,03*
RelativeY x RelativeX x Condition1 (baseline vs. other)	0	0,04	-0,02	-0,08	0,08	1	0,987
RelativeY x RelativeX x Condition2 (complementary vs. collaborative)	-0,02	0,07	-0,31	-0,16	0,12	0,98	0,755

Supplementary Table S2. Overview of estimates from the statistical model for Experiment 2.

	Beta	SE	z	95%CI lower	95%CI upper	Odds Ratio	p
(Intercept)	0,01	0,04	0,22	-0,07	0,09	1,01	0,824
Color	0,01	0,06	0,1	-0,11	0,12	1,01	0,922
RelativeX	-0,94	0,12	-8,16	-1,17	-0,72	0,39	<0.001***
RelativeY	-2,21	0,23	-9,69	-2,66	-1,76	0,11	<0.001***
Condition	0,05	0,06	0,89	-0,06	0,17	1,05	0,374
Color x RelativeX	1,16	0,16	7,27	0,85	1,47	3,19	<0.001***

Color x RelativeY	-0,4	0,18	-2,26	-0,74	-0,05	0,67	0,024*
RelativeX x RelativeY	-0,1	0,35	-0,3	-0,8	0,59	0,9	0,767
Color x Condition	-0,04	0,08	-0,49	-0,2	0,12	0,96	0,624
RelativeX x Condition	-1,8	0,17	-10,43	-2,13	-1,46	0,17	<0.001***
RelativeY x Condition	1,43	0,17	8,36	1,1	1,77	4,19	<0.001***
Color x RelativeX x RelativeY	0,43	0,51	0,85	-0,56	1,42	1,54	0,396
Color x RelativeX x Condition	4,83	0,25	19,47	4,34	5,31	124,83	<0.001***
Color x RelativeY x Condition	1,05	0,24	4,29	0,57	1,52	2,85	<0.001***
RelativeX x RelativeY x Condition	0,1	0,5	0,2	-0,89	1,09	1,11	0,841
Color x RelativeX x RelativeY x Condition	0,27	0,74	0,37	-1,17	1,72	1,31	0,712

Supplementary Table S3. Estimates from the statistical model for the exploratory correlation analysis.

	Beta	SE	df	t	p
(Intercept)	0,42	0,04	77,28	9,74	<0.001***
CorrelationType (other complementary vs other collaborative)	-0,34	0,06	73,35	-5,35	<0.001***
CorrelationType (other complementary vs self complementary)	-0,38	0,07	65,07	-5,42	<0.001***
Color	-0,04	0,05	114	-0,74	0,463
CorrelationType x Color (other complementary vs other collaborative)	0,04	0,07	114	0,52	0,604
CorrelationType x Color (other complementary vs self complementary)	0,15	0,07	114	2,11	0,037*