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Review

Pronoun processing in post-stroke aphasia: A meta-analytic review of individual data

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ABSTRACT

Pronouns constitute a heterogeneous class of linguistic elements, allowing for expression of referential relationships. Pronouns have an important place in daily communication which speakers and listeners rely heavily on for. Aphasia literature has evidenced that pronoun processing is impaired in people with aphasia (PWA), although explanations underpinning pronoun impairments are mixed. To address this, through a systematic literature review, we identified 42 studies which examined pronoun processing (both production and comprehension) in 474 PWA across 16 different languages. An initial meta-analysis was conducted on the overall data with all PWA and pronoun conditions with an outcome measure indicating whether or not pronoun processing is individually impaired in PWA. Further meta-analytic models were built to compare certain conditions of particular interest (e.g. reflexives vs object pronouns, object vs subject *wh*-pronouns) in an attempt to further disentangle the explanations behind their difficulty in use. Outputs from our meta-analysis suggest that: (i) a form of pronoun impairment is consistently present in aphasia regardless of aphasia type, fluency or language spoken; (ii) pronoun variables show selectivity in their impairment, for instance, reflexives are better preserved over object pronouns, and the subject-advantage in who-pronouns is language-selective; and (iii) other important linguistic variables that largely predict pronoun impairments include aspects like argument position of subject/object phrases, case marking, cliticization, and the presence of relative clause constructions. These outputs are discussed in relation to neurolinguistic hypotheses that predict pronoun impairments in aphasia.

1. Introduction

Aphasia is an acquired language disorder that impacts expressive and receptive language abilities. It is a cross-modal linguistic impairment that can affect speaking, writing, listening and reading. The majority of aphasia cases result from strokes (post-stroke aphasia). Since the early studies on grammatical processing in people with aphasia (PWA), a difficulty in interpreting sentences of varying complexity has been reported (e.g., Caramazza & Zurif, 1976; Goodglass et al., 1979). This paper focuses on pronoun

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processing in aphasia, a linguistic element whose difficulty in use has been identified through previous studies looking into impaired grammatical processing in PWA. The literature has strongly evidenced that people with aphasia (PWA) experience difficulties processing pronouns (e.g. Blumstein, Goodglass, Statlender, & Biber, 1983; Choy & Thompson, 2010; Friederici, Weissenborn, & Kail, 1991; Grodzinsky, Wexler, Chien, Marakovitz, & Solomon, 1993; Vasić, Avrutin, & Ruigendijk, 2006 among many others). Although many attempts were made to theorize what underpins this difficulty, our understanding as to why and how pronoun processing impairments occur is limited. These limitations are partly due to small sample sizes, large variability in aphasiological factors (i.e. severity of aphasia, lesion locations, type of aphasia), conditions tested, and linguistic constraints specific to pronoun processing in different languages.

Pronouns are important grammatical units in language which are essential for successful communication in our daily lives by allowing us to refer to entities and individuals by replacing their names. Pronouns are often only interpretable when they refer to salient antecedents (i.e. to their referents; Mary gave a talk herself). In order for pronouns to be used successfully, a speaker/listener must be able to access and apply grammatical knowledge that allows them to link a pronoun to a contextual reference, building what is known as a co-referential link. There is an assortment of different types of pronouns across languages, such as personal pronouns (he/she), reflexive pronouns (himself, herself), demonstrative pronouns (that, there), interrogative and/or relative pronouns (who, which), possessive pronouns (his/her). The vast array of pronouns play important communicative and grammatical roles across many languages, and also across different contexts processed by speakers and listeners. Further, pronouns are structures which are often targeted in linguistic impairment-based therapies, but mixed results regarding pronoun processing outcomes in aphasia is problematic when designing beneficial therapy protocols. Because the nature of pronoun use is highly specified in language, there are often communicative breakdowns as a result of their incorrect or inefficient use, such as, using pronouns without antecedents, even sometimes when other compensatory communicative strategies are implemented (i.e. using an indefinite pronoun in places of a lexical which cannot be accessed). Thus, creating a more critical need to understand pronoun impairment in aphasia from both a theoretical and clinical perspective.

Pronouns are one of the most widely studied grammatical phenomena in aphasia. In Table 1, we present an overview of different pronoun variables with examples. Pronoun processing has been investigated in different modalities, that is, during online and offline comprehension (e.g. Baauw, Ruigendijk, Cuetos, & Avrutin, 2011; Caplan, Michaud, & Hufford, 2015; Caplan, Waters, DeDe, Michaud, & Reddy, 2007; Choy & Thompson, 2010; Edwards & Varlokosta, 2007; Jarema & Friederici, 1994; Ruigendijk, Vasić, & Avrutin, 2006 among several others) and during online and offline production (e.g. De Bleser & Luzzatti, 1994; Ishkhanyan, Sahraoui, Harder, Mogensen, & Boye, 2017; Law & Cheng, 2002; Martínez-Ferreiro, 2010; Martínez-Ferreiro, Ishkhanyan, Rosell-Clarí, & Boye, 2019; Rossi, 2015; Stavrakaki & Kouvava, 2003); as well as at different levels of communication (i.e. single word, sentence and discourse levels) through different experimental paradigms (see e.g. Truth-value judgement and sentence picture matching tasks for comprehension and elicitation tasks for production; for examples see Appendix 1). While many of these studies concentrated on sentence level

Table 1
An overview of different pronoun variables (please note that this list of variables and definitions are only illustrative and limited in scope to the variables included in aphasia studies) [Eng = English, Fre = French, Deu = German, Spa = Spanish, Tur = Turkish].

Pronoun type	Definition and theoretical consideration	Examples
Main pronoun types		
Personal pronoun	replaces names of persons; languages mark different features with personal pronouns (i.e. in English, grammatical person, number and gender)	[Eng] He, she, we, they.
Clitic pronoun	lacks independent stress and attaches to a stressed word. This is typical in many Latin languages.	[Fre] J'adore chocolate "*I love chocolate*"
Demonstrative	refers to entities within a certain context, in many languages, demonstratives represent proximal relation with an entity (i.e. whether or not it is close to the speaker).	[Eng] This, that
Possessive	kind of pronouns that represent a relationship of possession, in a number of languages possessive pronouns agree with either possessor (English), or/and possessee (almost all Latin languages), or both (German) depending on grammatical gender.	[Eng] My, his, mine, hers [Fre] son livre "*His book*" [Deu] sein Buch "*His book*"
Reflexive	an anaphor that has a co-reference relationship with a referent which is often positioned within the same clause.	[Eng] She gave a talk herself
Null pronoun (pro-drop)	the condition that a personal pronoun can be omitted from the sentence. In many languages subject pronouns can be dropped (Italian, Spanish) while some others also allow object dropping (Greek, Turkish).	[Spa] (Yo) necesito un libro "*(I) need a book*"
Who-pronoun (interrogative)	an interrogative pronoun asking for the object or subject person referent in a proposition. Note that in Germanic languages including English, object who-pronouns require fronting and wh-movement, but not in some other languages.	[Eng] Who kissed the girl? [Eng] Who did the girl kiss? [Fre] la fille an embrassé qui "The girl kissed *who*?"
Relative pronoun	an anaphoric pronoun that determines a relative clause.	[Eng] The man who smiled was happy
Pronouns by argument position and/or case marking		
Subject pronoun	personal pronouns which occupy the subject role in a sentence. These pronouns receive nominative case in many case-marking languages.	[Eng] He, she, we, they. [Tur] Ben "*I*"
Object pronoun (direct)	personal pronouns which occupy the direct object role in a sentence. These pronouns receive accusative case in many case-marking languages.	[Spa] lo, la "*him, her*" [Tur] Beni "*me*"
Object pronoun (indirect)	personal pronouns which occupy the indirect direct object role in a sentence. These pronouns receive dative case in many case-marking languages	[Spa] le "*to her*" [Tur] Bana "*to me*"

processing, and, in particular, personal subject/object pronouns and reflexives, other forms of pronouns have also been examined: clitic pronouns (Avrutin, Lubarsky, & Greene, 1999; Baauw & Cuetos, 2003; Baauw et al., 2011; Jarema & Friederici, 1994; Juncos-Rabadán, Pereiro, & Souto, 2009; Luzzatti et al., 2001; Martínez-Ferreiro, 2010; Martínez-Ferreiro, Ishkhanyan, et al., 2019; Miceli, Silveri, Romani, & Caramazza, 1989; Rossi, 2015; Sanchez–Alonso, Martinez–Ferreriro, & Bastiaanse, 2011), genitive pronouns (Stavrakaki & Kouvava, 2003), demonstrative pronouns (Ishkhanyan et al., 2017; Martínez-Ferreiro, Ishkhanyan, et al., 2019), impersonal pronouns referring to non-human referents (Rossi & Bastiaanse, 2005), possessive pronouns (Caplan et al., 2007; Ishkhanyan et al., 2017; Martínez-Ferreiro, Ishkhanyan, et al., 2019), relative pronouns (e.g.Abuom, Shah, & Bastiaanse, 2013; Shankweiler, Palumbo, Fulbright, Mencl, Van Dyke, Kollia, Thornton, Crain, & Harris, 2010) and null pronouns/pronoun dropping (e.g. de Roo, 2003; Garraffa, 2009, 2011; Peristeri & Tsimpli, 2013). Finally, there are also volumes of studies on the interpretation of interrogative-pronouns during sentence processing (including, Arslan, Gür, & Felser, 2017; Bos, Dragoy, Avrutin, Iskra, & Bastiaanse, 2014; Fyndanis, Varlokosta, & Tsapkini, 2010; Hanne, Burchert, & Vasishth, 2016; Hickok & Avrutin, 1996; Kljajevic, Gómez, López, & Bandeira, 2019; Kljajevic & Murasugi, 2010; Neuhaus & Penke, 2008; Nyvad, Christensen, & Vikner, 2014; Salis & Edwards, 2008; Thompson, Tait, Ballard, & Fix, 1999; van der Meulen, Bastiaanse, & Rooryck, 2005).

There is a consensus among authors that aphasia adversely impacts pronoun processing; however, there is only a little agreement on what causes it. Studies examining, for instance, pronouns and reflexives (i.e. she/herself) have shown mixed results, as some studies found that non-fluent PWA perform better with reflexives than direct object pronouns (Grodzinsky et al., 1993; Love, Nicol, Swinney, Hickok, & Zurif, 1998) while others have shown the opposite (Blumstein et al., 1983). Still others have shown similar levels of impairments in both pronoun and reflexive conditions (Edwards & Varlokosta, 2007), or no impairment at all in personal pronouns and reflexives (Bos et al., 2014). Another set of conflicting results come from studies that examined interrogative pronouns (i.e. who, which): while some studies found that PWA perform worse in object-questions than subject ones (e.g. Hanne et al., 2016; Neuhaus & Penke, 2008), others showed the reverse pattern of impairments (Arslan et al., 2017; Kljajevic et al., 2019; Kljajevic & Murasugi, 2010). Patterns of selective impairments have also been observed in clitic pronouns. While strong personal pronouns and genitive clitics were reported to be intact in Greek aphasia (Stavrakaki & Kouvava, 2003), an asymmetry between subject and object clitics was found in Italian (Chinellato, 2006).

Table 2 shows a number of theoretical accounts which have been proposed to explain the difficulty underlying pronoun processing observed in PWA. The *slower-than-normal syntax model* (e.g. Burkhardt et al., 2003; Burkhardt et al., 2008) holds that sentence interpretation deficits in aphasia are the result of slowed syntactic computation, suggesting that PWA maintain the capacity to resolve referential links for pronouns, but at significantly slower rates than unimpaired controls. This model is supported by evidence from cross-modal lexical decision tasks that examined reflexive-antecedent dependencies in Dutch capitalizing on the finding that non-fluent PWA took significantly longer when judging reflexive elements compared to unimpaired controls (see Burkhardt et al., 2008). The *resource reduction* model, by contrast, affiliates potential pronoun interpretation deficits in aphasia with reduced cognitive resources, which consequently leads to failures in interpretive processes due either to impaired lexical processes or reduced working memory capacity (see Caplan et al., 2013a; Caplan, Michaud, & Hufford, 2013b; Caplan et al., 2015 for an overview). This is based on evidence from word-by-word self-paced-listening studies with picture verification tasks examining object pronouns and reflexives (among many other syntactic structures), where the pronoun impairment correlated with impaired performance in working memory tasks (i.e. digit span). A third account that predicts pronoun processing difficulty is the *delayed lexical integration* account (Choy & Thompson, 2010; Thompson & Choy, 2009), which holds that sentence comprehension difficulty arises in aphasia due to delays in integration of lexical information into sentence interpretation. This account stands on data from eye-movement monitoring studies that measured both eye-fixations and end-of-sentence behavioural responses to visuals depicting the referents for object pronoun and reflexives while PWA listened to sentences online. Their findings concluded that PWA performed less accurately in behavioural responses, and similarly, for both pronoun and reflexive conditions; however, PWA's eye-movement data showed no differences when

Table 2
An outline of accounts predicting the nature of pronoun processing difficulty in aphasia.

Account	Predictions
Slower-than-normal syntax (e.g. Burkhardt, Avrutin, Piñango, & Ruigendijk, 2008; Burkhardt, Piñango, & Wong, 2003)	PWA have unimpaired representations of reflexive anaphors (i.e. than object pronouns), but they can only process them in a slower manner.
Resource reduction (Caplan et al., 2015; Caplan, Michaud, & Hufford, 2013a; Gutman, DeDe, Michaud, Liu, & Caplan, 2010)	PWA have reduced cognitive resources (i.e. working memory) to process sentence material, leading to failures in interpretive processes.
Delayed lexical integration (Choy & Thompson, 2010; Mack, Ji, & Thompson, 2013; Thompson & Choy, 2009)	Integration of lexical information during sentence processing is delayed, evidenced with longer eye-fixations to referents for noun phrases; object pronoun and reflexives in English are equally impaired.
Increased Interference (Dickey, Choy, & Thompson, 2007; Dickey & Thompson, 2009; Hanne, Sekerina, Vasishth, Burchert, & De Bleser, 2011)	PWA are susceptible to thematic-role assignments that are not licensed in a sentence, and hence, strong activation of non-target interpretation interferes the intended interpretation.
Structural Interveners (e.g. Engel, Shapiro, & Love, 2018; Garraffa, 2009; Sheppard, Walenski, Love, & Shapiro, 2015)	Intervening sentence material between pronoun and its antecedent is the reason for sentence interpretation difficulty.
Discourse-linking impairment (e.g., Bos et al., 2014; Hickok & Avrutin, 1995, 1996; Martínez-Ferreiro, Reyes, & Bastiaanse, 2017)	Pronouns referring to antecedents in earlier sentence material or previous discourse are proposed to be rather more impaired.
Grammatical vs. lexical (Ishkhanyan et al., 2017; Martínez-Ferreiro, Bastiaanse, & Boye, 2019; Martínez-Ferreiro et al., 2017)	Grammatical pronouns are predicted to be rather more impacted in non-fluent PWA based on Boye and Harder's (2012) usage-based theory of grammatical status.

compared to healthy controls, despite significant delays in fixations for noun referents. An affiliated account is the *Increased Interference model*, which suggests that PWA encounter sentence interpretation difficulty due to an interference from non-intended or non-target sentence meaning that is normally unlicensed in a given sentence structure. Sentence misinterpretation can be a direct result from an inability to correctly resolve referential information that links pronouns and their referents. The evidence for this view comes from eye-movement monitoring studies which showed that, during sentence listening, PWA's eye-fixations focused non-target visuals depicting a non-target interpretation for a given sentence (see e.g. Hanne et al., 2011).

The *Structural Intervener model* (e.g. Engel et al., 2018; Garraffa, 2009; Sheppard et al., 2015) accounts that intervening sentence material between pronouns and their antecedents (or for interrogatives, between who-pronoun and its base-generated position) cause aphasic sentence processing difficulty. Particularly, this account predicts that object pronouns are more severely impaired than reflexives, as the structural distance between an object pronoun and its antecedent is greater than it would be, for example, between a subject pronoun and its antecedent (e.g. Jack_i thought that Fred_j adored him_i/himself_j).

Beyond sentence processing, the *discourse-linking impairment model*, pronouns requiring reference to entities in the previous discourse are assumed to pose greater difficulty for PWA than, for instance, reflexives as reflexive anaphors refer to local referents in the same clause. A set of results from studies examining *wh*-pronouns have evinced that discourse-linked referents are harder to interpret for PWA than non-discourse-linked referents (Avrutin, 2006; Bos et al., 2014; Hickok & Avrutin, 1996). Finally, the *grammatical vs. lexical account* (Ishkhanyan et al., 2017; Martínez-Ferreiro, Bastiaanse, & Boye, 2019; Martínez-Ferreiro et al., 2017) posits a distinct dichotomy for grammatical and lexical pronouns based on the *ProGram theory* defined within a usage-based framework of grammatical status (Boye & Harder, 2012). According to Boye and Harder (2012), words (including pronouns) can be classified as lexical or grammatical depending on their inherent discourse prominence and dependency, whereas lexical items can be discursively primary and have the potential to convey meaning in isolation (e.g. Help!), grammatical items are discursively secondary and depend on a (discursively primary) host. Based on these properties, it can be predicted that grammatical pronouns are cognitively more demanding than lexical pronouns (as they require combination), but also that they can more easily be dispensed with for communicative purposes (as they are secondary; see Martínez-Ferreiro, Ishkhanyan, et al., 2019). This entails that grammatical pronouns are expected to be more severely impacted in aphasia compared to lexical pronouns.

In summary, there are a number of different explanations for why PWA experience pronoun processing difficulty, that range from linguistically motivated factors, such as structural interveners or discourse-linking, to a more general cognitive or syntactic difficulty in aphasia relating to reduction of cognitive resources or slowed-syntactic processes. Given the fact that many of these theoretical explanations are biased to well-studied languages and methods used, and due to the presence of mixed results in pronoun impairments in aphasia, it is impossible to see the 'big picture' as to what actually underlies these deficits. This meta-analysis study brings together a large number of individual cases from previously published papers, and analyses these data within an individual meta-analysis approach, critically evaluating the theoretical explanations for pronoun impairments in aphasia, hence further informing neurolinguistic theory in language processing breakdown in aphasia. The current meta-analysis study is built upon two important aims: (i) Our first aim is to understand whether and how pronouns are impaired in aphasia; and if so, to determine which factors predict pronoun impairments in aphasia. To achieve this aim, we used a ROC-curve approach to determine outcome values and used these values to model a meta-analytic random effects model, and we used a tree-based classification model (Random Forest) to predict outcomes while determining which factors are informative in a complementary analysis. (ii) Our second aim is to address certain controversies in the literature, especially for reflexive/object pronouns and *wh*-pronouns, where studies produced mixed results. This is important because these discrepancies may be emerging due to small samples sizes in individual studies, and hence, meta-analytic comparisons allow us to see the big picture with larger amount of PWA included in our data corpus. For this purpose, we subset relevant studies that directly compared these particular conditions and used a standardized mean difference approach to determine significant condition differences.

2. Methods

2.1. Data

We conducted an exhaustive search, illustrated in Fig. 1, in PubMed/MEDLINE and Web of Science in 2018 with the following key word combination: "aphasia AND [pronoun OR clitic]". A total of 105 papers were retrieved, and 51 papers were excluded due to: a) reports on individuals with right hemisphere lesions ($n = 4$); b) reports of individuals with non-aphasic symptoms (e.g., dementia, echolalia, SLI, $n = 20$) or of healthy individuals ($n = 7$); and, c) review articles ($n = 6$) and articles that report no accuracy data for pronouns ($n = 14$). Among the remaining articles, those reporting individual accuracy results from PWA were included ($n = 30$). Articles that merely report group means ($n = 24$) were noted and their authors were contacted in an attempt to access individual results. This effort led to the inclusion of 27 additional articles through private communications from authors (n = 9) and/or through a complementary Google Scholar research (using the same search terms) for important book chapters and dissertations which were not indexed in PubMed/Web of Science (n = 18). An initial screening into these reported data showed that some pronoun production studies used spontaneous speech techniques to elicit samples (15 studies, individual PWA $n = 73$). These spontaneous speech studies were removed from further statistical analyses, due to the fact that outcome measures from these studies did not contain a comparable measure to other studies included (i.e. studies reported raw counts or pronoun-to-noun ratios, and used different sample sizes, making it difficult for us to obtain scores with which we could calculate per cent accuracy per participant). Hence, the total amount of studies included were 42 (total unique individual PWA $n = 474$). These studies are documented in Table 3 (comprehension studies) and Table 4 (elicited production studies).

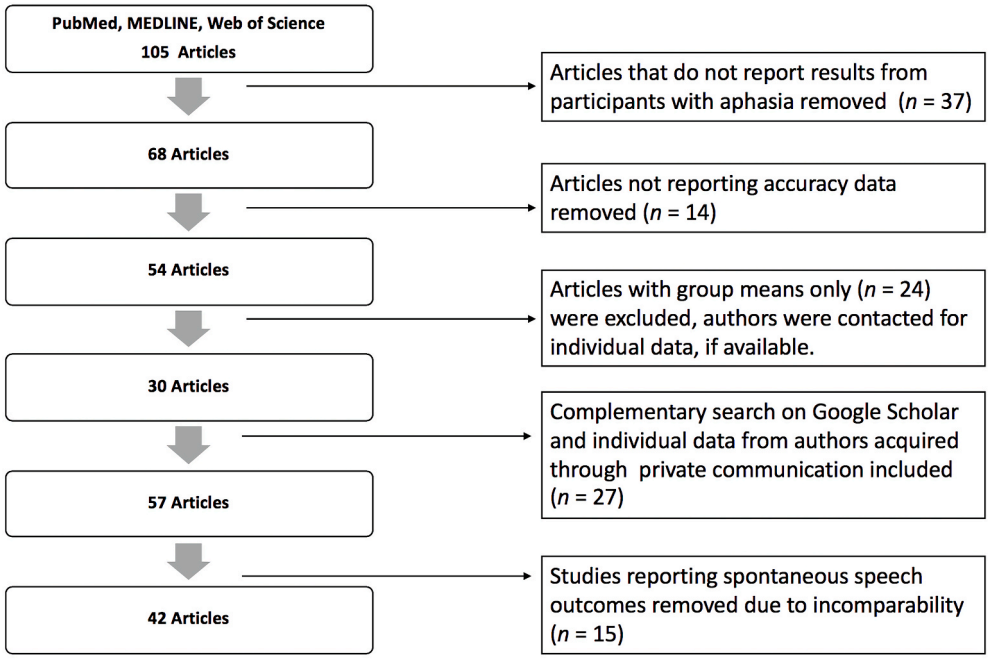

Fig. 1. Flow-chart of exclusion/inclusion of relevant articles to the data corpus.

2.2. Data analysis

2.2.1. Data preparation and binary outcome measure

Each individual PWA's averaged mean score per study per condition were coded into a data bank. Data coding was done by the authors, who first agreed on the coding convention, and then, disagreements were discussed and resolved.

A binary outcome measure was created containing binary classes (1 = unimpaired, 0 = impaired) reflecting whether or not each PWA included in the metadata was impaired in interpreting or producing pronouns in sentences. This binary variable was obtained with the following steps. First, percent accuracy for each PWA per task/condition was extracted from the above-mentioned literature. Second, a cut-off value at which pronoun processing becomes impaired was determined. Since all the studies included in this meta-data employed tasks with multiple conditions, and number of items was mostly different across different studies, a single-measure cut-off criterion was not appropriate (see Ingraham & Aiken, 1996).[2] Therefore, we used a Recipient Operating Characteristic (ROC) curve approach to determine the cut-off value by using the *pROC* package in R (Robin et al., 2011).

Comprehension. In order to calculate the cut-off value for comprehension modality, following what Caplan et al. (2015) reported for their non-impaired group of participants, we simulated unimpaired pronoun processing normative data points with a mean of 93.1% and a standard deviation of 4.4 using the *rnorm* function in R. An outcome measure was created with the simulated norm data points labelled as "unimpaired" and the data points from our PWA meta-dataset labelled as "aphasia". This outcome measure was submitted to a generalized logistic regression predicted by the continuous accuracy data, and fitted values from this regression model was plotted into a ROC-curve. The Area Under Curve (AUC) score was found to be 0.775; that is, given normative baselines, the PWA who performed above 77.5% accuracy were likely to be unimpaired, signalling that 77.5% accuracy is the diagnostic cut-off value for pronoun processing to be impaired in our sample of PWA. Therefore, an outcome variable with binary classes for impaired (<77.5%) and unimpaired (>77.5%) was created.[3]

Production. The same steps were taken for data from studies examining elicited production of pronouns. Unimpaired control norms were taken from Rossi (2015) who used a sentence completion task to examine pronoun/clitic production. The author's unimpaired group performed with a mean of 99.4% and a standard deviation of 1.56. These values were used to create a simulated distribution of

[2] We choose not to use classification based on chance-level performance (i.e. below vs. above 50% chance) here because chance level performance is a concept affiliated with guessing. In fact, simply guessing was not found to be a crucial factor in PWA's responses to pronominal elements in sentence processing tasks, suggesting that low sentence processing performance in aphasia is more likely to be results of interpretation errors, see Gutman et al. (2010) for discussion.

[3] Please note that AUC-based cut-off scores are also practiced in clinical diagnostic tests in aphasia assessment when there are several sub-tests with different number of items and difficulty levels. However, we should acknowledge a relative issue regarding that different tasks with varying levels of difficulty might yield different cut-off scores (i.e. sentence picture matching, truth-value judgements tasks, etc might require different task demands). Since the aim here was to calculate a global cut-off score for pronoun impairment overall, we did not determine cut-off scores per task type.

Table 3
A summary of included studies examining comprehension of pronouns in the meta-analysis data corpus. SPM = Sentence picture matching, TVJT = Truth Value Judgement Task. See Appendix 1 for details on different types of tasks and example sentence materials used.

Study	Language(s)	Number of PWA and aphasia profiles	Task	Pronominal conditions examined
Abuom et al. (2013)	Swahili – English	11 Agrammatic (bilingual) aphasia	SPM	Relative pronouns
Arslan and Felser (2018)	Turkish – German	2 non-fluent (bilingual) aphasia	SPM	Interrogatives: object & subject who-pronouns, and object & subject which-phrases.
Arslan et al. (2017)	Turkish, German	6 German, 11 Turkish non-fluent PWA	SPM	Interrogatives: object & subject who-pronouns, and object & subject which-phrases.
Avrutin et al. (1999)	English	8 Broca's aphasia	SPM	Stressed/Unstressed direct object clitics
Baauw and Cuetos (2003)	Spanish	4 Agrammatic Broca's aphasia	TVJT	Direct object clitics, reflexives.
Baauw et al. (2011)	Spanish	7 Agrammatic Broca's aphasia	SPM	Subject pronouns, direct object clitics under stressed and unstressed conditions.
Bos et al. (2014)	Russian	10 Agrammatic aphasia, 10 fluent (sensory) aphasia	SPM	Personal: Object pronoun, reflexives; Interrogative: subject who-pronoun and subject which-phrases.
Caplan et al. (2007)	English	42 PWA with diverse profiles	SPM & TVJT	Reflexives with genitive & possessive antecedents
Caplan et al. (2015)	English	61 PWA with diverse profiles	Self-paced-listening with SPM	Object pronoun, reflexive in simple, subject-relative and object-relative configurations.
Choy and Thompson (2010)	English	8 Agrammatic aphasia	Eye-tracking during listening (Visual World)	Object pronoun, reflexive
Edwards and Varlokosta (2007)	English	10 Broca's aphasia	TVJT	Object pronoun, reflexive in both unquantified and quantified subject antecedents, and Exceptional Case Marking conditions.
Friederici et al. (1991)	Dutch, French, German	Dutch: 8 Broca's and 8 Wernicke aphasia, French: 7 Broca's and 7 Wernicke aphasia, German 10 Broca's and 10 Wernicke aphasia,	SPM	Direct object and indirect object pronouns/clitics, with and without preposition and in single and double pronoun conditions.
Fyndanis et al. (2010)	Greek	3 non-fluent PWA	SPM	Interrogative: subject-who and object-who pronouns
Garraffa (2009)	Italian	1 Global aphasia	TVJT	Direct and indirect object clitics
Gavarró (2008)	Catalan	2 non-fluent aphasia	TVJT	Object pronoun, reflexive, Exceptional Case Marking, and pronoun doubling conditions
Grodzinsky et al. (1993)	English	8 agrammatic, 4 fluent PWA	TVJT	Object pronoun, reflexive in both unquantified and quantified subject antecedents
Hanne et al. (2016)	German	3 Broca's and 3 anomic PWA	Eye-tracking during listening (Visual World)	Interrogative: subject & object who-pronouns and which-phrases
Hickok and Avrutin (1995)	English	2 Broca's aphasia	SPM	Personal: object pronoun, reflexive Interrogative: subject & object who-pronouns and which-phrases
Hickok and Avrutin (1996)	English	2 Broca's aphasia	SPM	Interrogative: subject & object who-pronouns and which-phrases
Jarema and Friederici (1994)	French	5 Broca's aphasia	SPM	Direct object clitics
Juncos-Rabadán et al. (2009)	Galician – Catalan	14 non-fluent and 4 fluent (bilingual) aphasia	SPM	Clitic pronouns
Kljajevic and Murasugi (2010)	Croatian	3 Broca's and 3 mixed non-fluent PWA	SPM	Interrogative: subject & object who-pronouns and which-phrases across direct, indirect questions and long-distance *wh*-movement and passive configurations.
Kljajevic et al. (2019)	Spanish	6 Broca's and 1 mixed aphasia	TVJT	Relative: object, subject relatives; Interrogative: subject & object who-pronouns and which-phrases across direct, indirect questions
Luzzatti et al. (2001)	Italian	11 agrammatic, 6 conduction, 9 Wernicke's aphasia	SPM	Direct and indirect object clitics, subject pronouns across passive, active, and double-pronoun configurations.
Martínez-Ferreiro (2010)	Catalan, Galician, Spanish	5 Spanish, 5 Galician, 6 Catalan PWA with diverse profiles	SPM	Direct object clitics, reflexives
Neuhaus and Penke (2008)	German	9 Broca's aphasia	SPM	Interrogative: subject & object who-pronouns and which-phrases
Nyvad et al. (2014)	Danish	4 PWA	SPM	Interrogative: subject & object who-pronouns and which-phrases across cleft, long and short *wh*-movement, and with and without preposition modifier configurations.
	English	10 PWA		Subject pronouns

(*continued on next page*)

Table 3 (*continued*)

Study	Language(s)	Number of PWA and aphasia profiles	Task	Pronominal conditions examined
Rigalleau and Caplan (2004)			Cross-modal naming paradigm	
Ruigendijk et al. (2006)	Dutch	7 agrammatic Broca's aphasia	SPM	Object pronouns, reflexives
Salis and Edwards (2008)	English	2 Broca's and 3 mixed non-fluent aphasia	SPM	Interrogative: subject & object who-pronouns and which-phrases
Thompson et al. (1999)	English	4 PWA	SPM	Interrogative: subject & object who-pronouns and which-phrases across active and passive voice sentences
van der Meulen et al. (2005)	French	9 Broca's aphasia	SPM	Interrogative: subject-who and object-who pronouns with and without *wh*-movement

Table 4
A summary of included studies examining elicited production of pronouns in the meta-analysis data corpus. SPM = sentence poicure matching; see Appendix 1 for details on different types of tasks and example sentence materials used.

Study	Language(s)	Number of PWA and aphasia profiles	Task	Pronominal conditions examined
Caplan et al. (2007)	English	42 PWA with diverse profiles	Morpheme production task	Possessive pronouns
De Bleser and Luzzatti (1994)	Italian	3 non-fluent aphasia	Sentence completion	Direct and indirect object clitics
de Roo (2003)	Dutch	13 agrammatic aphasia	Spontaneous speech elicited with interviews	Demonstratives, (null and overt) subject and object pronouns
Fyndanis et al. (2010)	Greek	2 non-fluent PWA	Sentence elicitation	Interrogative: subject-who and object-who pronouns
Garraffa and Grillo (2008)	Italian	1 PWA	Sentence elicitation	Interrogative: subject-who and object-who pronouns
Goral, Levy, and Kastl (2010)	Hebrew – French – English	1 non-fluent PWA (trilingual)	Sentence elicitation	Pronoun – gender agreement (treatment study)
Law and Cheng (2002)	Cantonese	5 anomia, 3 Broca's, 1 transcortical motor	Cloze test	Personal, predicative, and adverbial pronouns
Martínez-Ferreiro (2010)	Catalan, Galician, Spanish	5 Spanish, 5 Galician, 6 Catalan PWA with diverse profiles	Sentence elicitation	Direct object clitics, reflexives
Neuhaus and Penke (2008)	German	9 Broca's aphasia	Sentence elicitation & repetition	Interrogative: subject-who & object-who pronouns
Reyes and Bastiaanse (2013)	Spanish	5 PWA	Sentence elicitation	Direct object clitics with and without *wh*-movement
Rossi (2015)	Italian	6 agrammatic aphasia	Sentence completion & syntactic priming	Direct and indirect object clitics
Sanchez–Alonso et al. (2011)	Spanish	11 agrammatic aphasia	Sentence completion	Direct object clitics, reflexives
Shankweiler et al. (2010)	English	3 non-fluent agrammatic aphasia	Sentence elicitation	Relative pronoun
van der Meulen et al. (2005)	French	3 Broca's aphasia	SPM	Interrogative object-who pronouns with and without *wh*-movement

unimpaired control data using the *rnorm* function. An outcome variable was created with factor levels for "impaired" for PWA in the meta-data and "unimpaired" for simulated controls. This outcome variable was submitted to a generalized linear model predicted by the continuous accuracy variable. The fitted values were then submitted to a ROC-curve plot, which turned an AUC score of 0.85, suggesting that <85% performance on pronoun production tasks are likely to be indicate an impairment. Hence the outcome variable for PWA were recoded accordingly.

2.2.2. *Meta-analytic screening and the meta-regression model*

An initial meta-analytic screening and was conducted using the *metafor* package in R (Viechtbauer, 2010). Since this meta-analysis used a single group (PWA), we calculated logit transformed proportions for each study as indicator of effect sizes (i.e. logit transformed proportion = log of $x/(n - x)$ where x represents number of PWA experiencing a pronoun impairment and n represents total number of PWA). These logit transformed proportions were used as a dependent variable in a random effects model using the *rma* function (see Viechtbauer, 2010). First a simple random effect model was built to calculate an overall estimate of proportion of PWA experiencing pronoun impairment, and then the model was re-computed with inclusion of mixed-effects for pronoun type, language, age, aphasia type as modulatory factors to check whether heterogeneity is due to these moderators. However, different linguistic variables might influence the estimates of PWA with pronoun processing difficulty. Therefore, subsequent models were then built separately for comprehension and production studies with mixed-effects of argument position (i.e. whether a pronoun is subject vs. object in a sentence), case marking (whether a pronoun received nominative, accusative, dative, or genitive case), clitics, syntactic constraints (presence of relative clause structures, wh-movement, passives, and null-pronouns).

2.2.3. Supplementary analyses with the tree-based classifier Random Forest

Our data corpus included a diverse number of factors that predict pronoun impairment in aphasia; since most of these variables showed strong multicollinearity, building linear meta-regression models was not an optimal solution with so many predicting variables. However, in line with our second aim, to determine which of these variables best determine pronoun impairment, we used the Random Forest classifier (RF; Breiman, 2001), a tree-based classification model, to predict whether or not each individual PWA experiences pronoun impairment, and which factors predict this impairment. RF is an ensemble machine learning algorithm, it generates several decision trees, each of which uses bootstrap aggregation, and decision nodes are selected based on majority voting to classify data sample (see e.g., Strobl, Malley, & Tutz, 2009). A total number of 20 predicting variables with theoretical relevance to pronoun processing in aphasia have been selected: (i) demographic and aphasiological variables (age, gender, months post-onset,[4] fluency); (ii) syntactic features of sentences with which pronouns were tested (presence of passives, wh-movement, relative pronouns), (iii) pronominal conditions tested (clitic, reflexive, null pronoun, personal pronoun, possessive pronoun, which phrase, who pronoun), (iv) variables relevant to argument position in which pronouns appear (subject, object, direct object, indirect object), (v) sentence modality (declarative, interrogative). See Tables 3 and 4 for a comprehensive list of pronoun variables the included studies addressed. To evaluate the extent to which these predicting variables was informative, we calculated conditional variable importance with the *VarImp* function of the *party* package (Strobl, Hothorn, & Zeileis, 2009). This function returns permutation importance metrics, variables close to zero provide no or little improvement to the model. Different models were built for comprehension and production data since some variables and languages were only available in one modality only (i.e. possessives were only examined for production, see Table 4). Conditional decision trees were generated with *ctree* function of the *party* package, after the removal of relatively unimportant variables. Such machine learning models in aphasia are not entirely unheard of, for instance, Yourganov, Smith, Fridriksson, and Rorden (2015) classified aphasia type based on clinical images; Arslan et al. (2017) used RF to classify accuracy of PWA in sentence comprehension tasks.

2.2.4. Particular condition comparisons

Further analyses were conducted on relevant subsets of the metadata that warranted in-depth investigation (i.e. reflexives vs. object pronouns, object vs subject *wh*-pronouns). In these supplementary analyses, studies that directly compared relevant conditions were extracted and standardized mean differences were utilized as effect sizes to investigate potential condition differences. Mean differences were corrected for positive bias following Hedges and Olkin (1985), and these effect sizes then submitted to subsequent random effects models using the *rma* function (see Viechtbauer, 2010).

3. Results

3.1. Meta-analytic screening and overview of pronoun variables

The 42 studies investigated 16 different languages yielding to a total number of 474 PWA (See Tables 3 and 4). The languages reported in our meta-analysis included Cantonese ($n = 10$), Catalan ($n = 8$), Croatian ($n = 6$), Danish ($n = 4$), Dutch ($n = 46$), English ($n = 187$), French ($n = 32$), Galician ($n = 22$), German ($n = 43$), Greek ($n = 3$), Hebrew ($n = 1$), Italian ($n = 44$), Russian ($n = 20$), Spanish ($n = 56$), Swahili ($n = 11$), and Turkish ($n = 13$). Of the total 42 studies, a total of 32 studies examined comprehension of pronoun (individual PWA $n = 405$), and 15 studies examined elicited production of pronouns (individual PWA $n = 127$), 5 studies examined both the modalities. An overview for PWA's mean percent correctness scores across different pronoun variables and morpho-syntactic factors that related to pronouns (see Fig. 2) indicated that most pronoun variables examined show a relative impairment when our above-calculated cut-off scores for comprehension and production studies were taken as a reference. Also, interestingly, a gradient pattern of impairments in pronoun production was evident, but not in comprehension, depending on which case marking they receive (see Fig. 2B). This pattern suggests that nominative marked pronouns (i.e. including subject pronouns) are the best retained ones while accusative and dative marked pronouns (object pronouns) are relatively more difficult to produce. Syntactic factors such as sentence complexity (passives, wh-movement and relatives) seem to impact pronoun processing (See Fig. 2C).

A Random Effect (RE) model was implemented with binary outcomes (i.e. impaired – not impaired) averaged across PWA per study. Fig. 3 exhibits the funnel plots for studies included in the meta-analyses, and Fig. 4 shows the forest plot with model estimates (log odds) per study across each language and task modality investigated. The plotted log odds represent a transformed proportion of PWA experiencing pronoun impairment. Although, the overall sample represented a large heterogeneity, as expected, ($I^2 = 85.49\%$, *Cochran's Q* $(58) = 290.79$, $p < 0.0001$), the RE model showed that studies included in this meta-analysis consistently report a form of pronoun impairment with an overall estimate size of 0.50 (SE = 0.15, z = 3.31, $p < 0.001$, 95%CIs = [0.21, 0.80]). Different type of pronouns examined showed a significant modulatory effect overall (*Cochran's* $Q_M(7) = 14.28$, $p = 0.04$). We found no modulatory effects of different languages on the pronoun impairment outcome for the overall data (*Cochran's* $Q_M(15) = 21.73, p = 0.11$). Important demographic factors, chronological age (*Cochran's* $Q_M(1) = 0.61$, $p = 0.43$), post-onset time (*Cochran's* $Q_M(1) = 2.92$, $p = 0.09$), and aphasia type (i.e. fluent vs. non-fluent, *Cochran's* $Q_M(1) = 0.24, p = 0.62$) did not seem to have strong moderator effect on proportion of PWA experiencing pronoun impairment.

[4] Missing values in age and post-onset time (months post-onset) were imputed with *rfImpute* function of the Random Forest algorithm (Liaw & Wiener, 2002), as these were not reported in certain studies. This function returns imputed values for missing values as proximity-weighted average of the non-missing values.

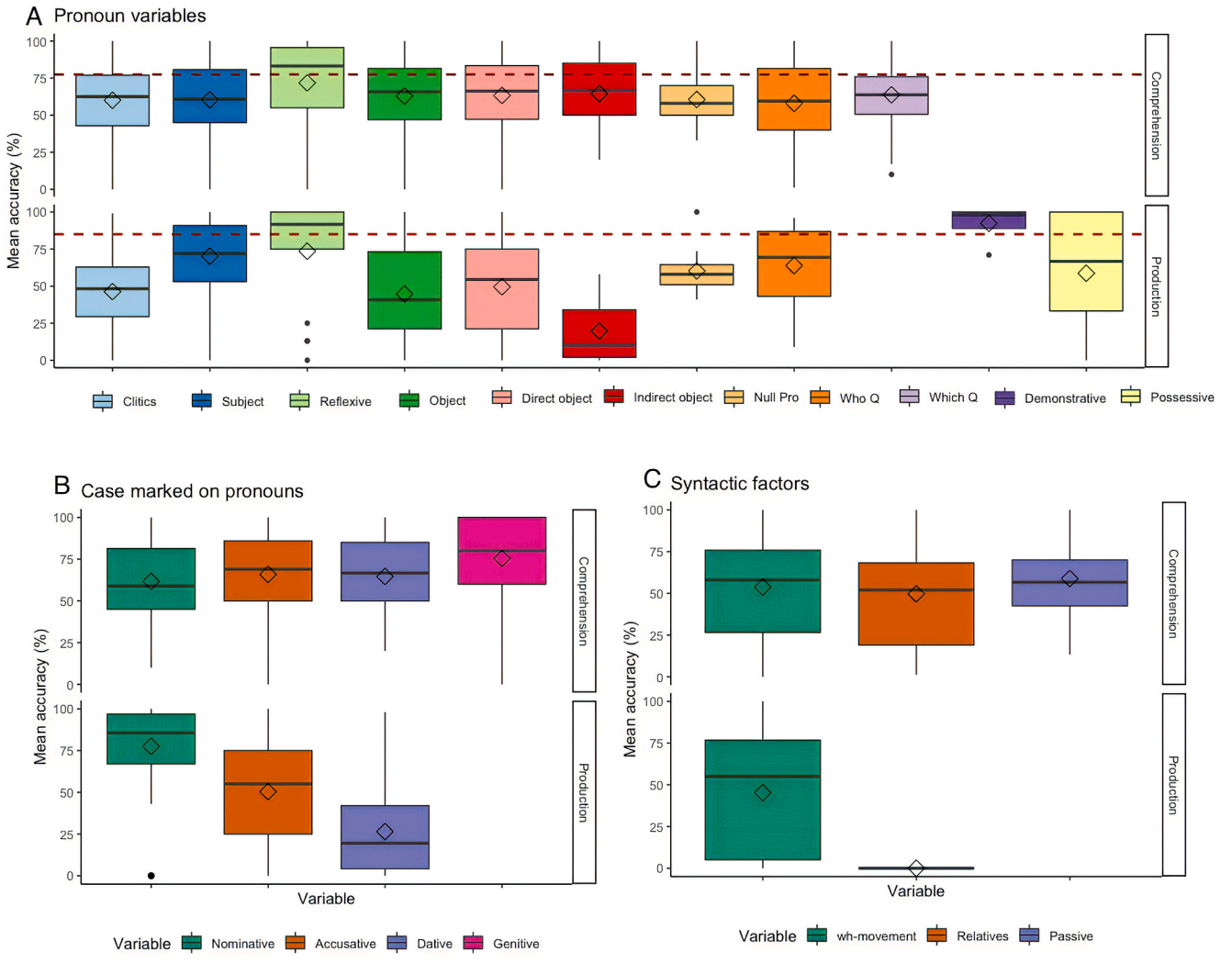

Fig. 2. Boxplots showing PWA's ($N = 474$) mean percent accuracy for A) different pronoun variables included in the meta-data, B) pronouns expressing case-marking, and C) syntactic constraints relevant to sentence structures in which pronouns appeared (e.g., *wh*-movement means the sentence structure required overt movement of *wh*-phrase). Boxes in boxplots indicate quartiles around the median, whiskers indicate the outer quartiles, diamond in each box points to the mean. Red dashed lines indicate the cut-off values from our ROC-curve analysis (77.5% for comprehension and 85% for production studies).

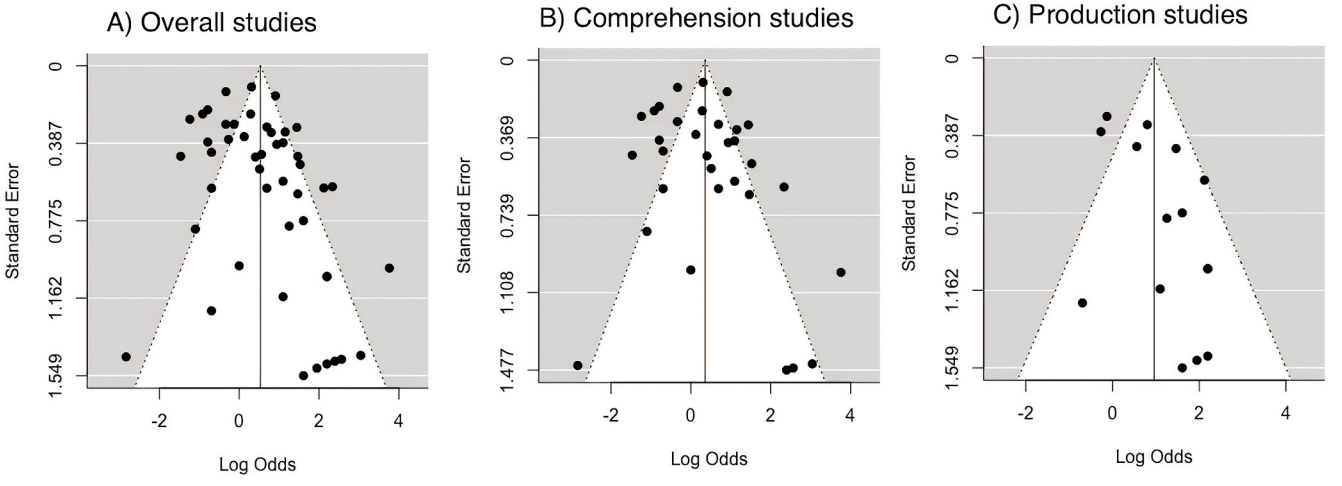

Fig. 3. Funnel plots for all studies (A), comprehension (B), and production (C) studies showing the effect sizes (logit transformed proportions) against standard error. The funnel plots indicate that when sample sizes (number of PWA) increase standard error decreases cumulating to greater precision in predicting target outcome (pronoun impairment). Studies closer to the bottom of these plots have relatively smaller precision.

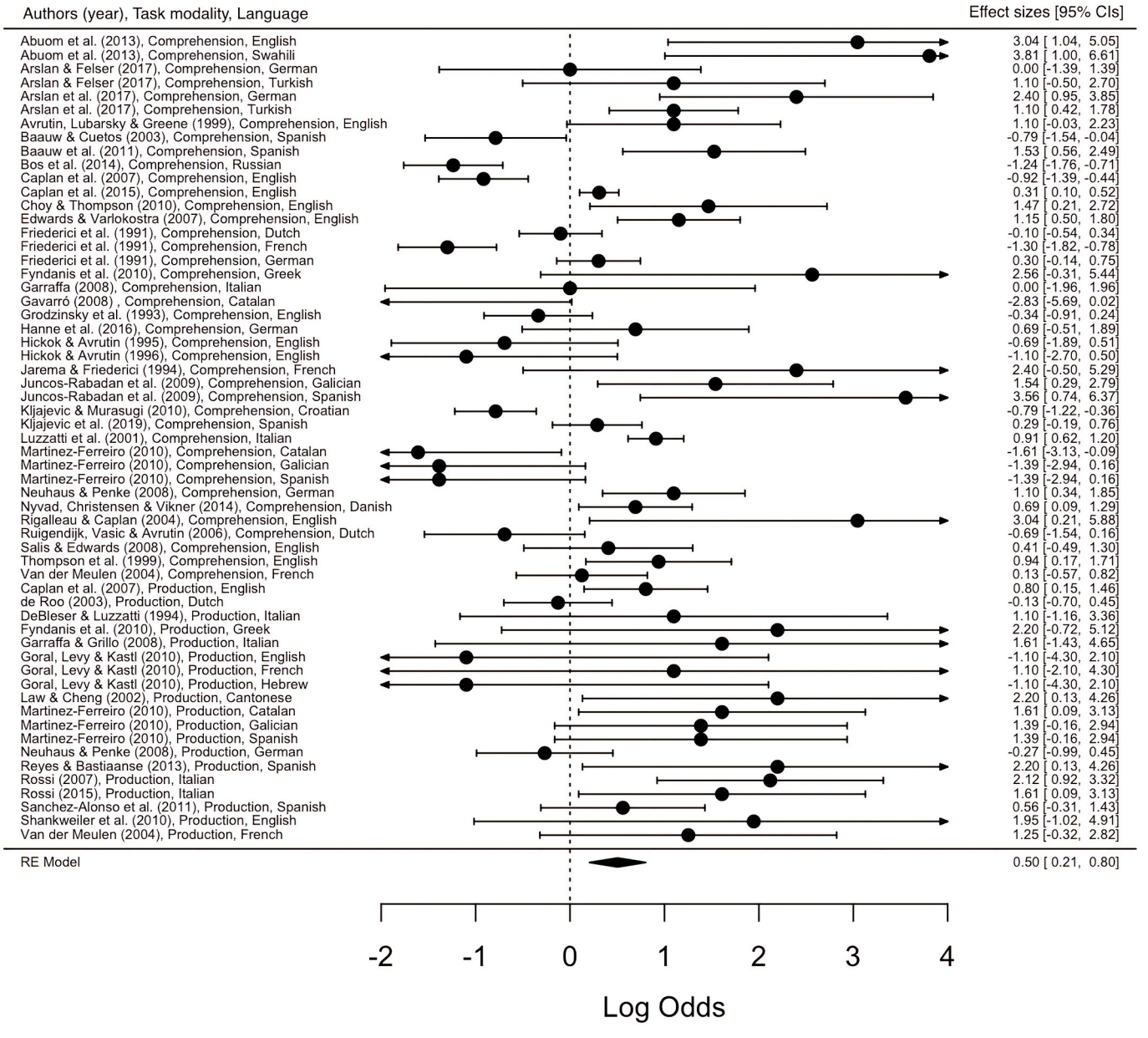

Fig. 4. Forest plot showing the log odds (logit transformed proportions) for each study included in the meta-data organised by Task Modality (comprehension, production) across different languages investigated by the authors. Positive side of the log-odds scale indicate higher proportion of PWA experiencing forms of pronoun impairment.

A set of subsequent models were implemented to unveil whether or not certain linguistic factors of interest influence the pronoun impairment. Argument position (i.e. subject vs. object) proved to be a significant moderator of pronoun impairments in overall data (*Cochran's* $Q_M(1) = 4.60$, $p = 0.03$), as well as in both comprehension (*Cochran's* $Q_M(1) = 4.69$, $p = 0.03$) and production modalities (*Cochran's* $Q_M(1) = 10.50$, $p = 0.001$). Furthermore, the presence of indirect objects significantly modulated model outputs for production modality (*Cochran's* $Q_M(1) = 8.93$, $p = 0.002$) while this was not significant for overall data or comprehension modality (*ps* > 0.24). A model looking into the effects of case marking has mirrored argument position effects. Different case markers did not modulate overall (*Cochran's* $Q_M(1) = 0.73$, $p = 0.39$), comprehension pronoun outcomes (*Cochran's* $Q_M(1) = 0.18$, $p = 0.66$). However, in production there was a significant modulation of the presence of accusative and dative case markers opposed to nominatives (*Cochran's* $Q_M(1) = 9.84$, $p = 0.001$). Impact of clitic pronouns proved significant for production modality (*Cochran's* $Q_M(1) = 5.33$, $p = 0.021$), evidencing a large proportion of PWA experiencing clitic difficulty in elicited production ($\beta = 0.94$, SE = 0.41, z = 2.31, $p < 0.001$, 95%CIs = [0.14, 1.78]). The clitic difficulty did not hold in comprehension modality or overall data (ps > 0.48). A number of syntactic constraints have also been critically examined. One significant factor was whether or not pronouns appear in relatives (*Cochran's* $Q_M(1) = 4.55$, p = 0.03) signalling that relative clause structures cause greater pronoun interpretation difficulty than non-relative structures ($\beta = 1.19$, SE = 0.45, z = 2.61, $p < 0.001$, 95%CIs = [0.29, 2.08]). On the other hand, the presence of wh-movement-requiring structures (*Cochran's* $Q_M(1) = 0.69$, $p = 0.40$), passives (*Cochran's* $Q_M(1) = 0.03$, $p = 0.85$) and null-pronouns (*Cochran's* $Q_M(1) = 0.12$, $p = 0.73$) did not prove significant. We will turn to some of these factors below.

3.2. Predictors of pronoun deficits in aphasia: results from tree-based classification approach

PWA included in this metadata have shown a considerable amount of variability regarding their pronoun processing abilities, and a large number of predicting variables were present. We used RF models to classify the individual PWA into classes (i) PWA with impaired pronoun processing ability (coded as 0) and PWA with intact pronoun processing ability (coded as 1). Recall that we used a total number of 20 predicting variables (see above), in order to inform our understanding into which of these predicting variables best classify PWA to have pronoun impairments in language. The outputs from the RF models are given in Fig. 5.

Comprehension. According to the variable importance metrics (see Fig. 5A), important variables that influenced pronoun impairment in PWA included the presence of reflexive anaphors (0.027), relative pronouns (0.017), and months post-onset (0.01). The other variables made no or little difference suggesting their removal would not affect the model predictions. That is, variables such as age (0.003), null pronoun (<0.001) contributed little to the predicted proportion of PWA with pronoun impairments. The most prevalent conditional inference tree for comprehension modality was built with two most important variables: relative pronouns and reflexives (see 5B). The decision tree indicated that the sentences with relative pronouns (represented at the highest branching node $p < 0.001$) significantly predicts the largest proportion of PWA with a pronoun impairment. Within non-relative pronouns, interpreting reflexive anaphors proved spared in a greater number of PWA as compared to interpreting non-reflexive anaphors (i.e., other type of pronouns including object pronouns), see the second significant branching node ($p < 0.001$).

Production. Variable importance metrics have indicated for production modality (see Fig. 5C) that the most informative variables predicting individual PWA to be impaired in producing pronouns were whether or not pronouns appear in subject position (0.012), object position (0.011), and indirect object position (0.006). The other variables ranked suboptimal contributing to model outcomes. These included variables such as reflexives (<0.001), fluency of PWA (<0.001) proving largely uninformative. Based on the variable importance metrics, the RF models were re-built with Subject, Object and Indirect Object variables. The most pertinent conditional inference trees built showed that subject pronouns predicted greater proportions of PWA to be significantly better preserved over object pronouns would, be it direct or indirect objects ($p < 0.001$; see Fig. 5D).

3.3. Results from particular condition comparisons

An aim of this meta-analysis was to shed further light on certain controversies across published studies, which included: (i) whether or not reflexives are better preserved in aphasia, and (ii) whether there is an object-subject asymmetry in interrogative pronoun comprehension (i.e. *wh*-questions).

3.3.1. Are reflexives better preserved than object pronouns?

An interesting question here was whether reflexives are better preserved than object pronouns in aphasia. To be able to compare PWA's processing ability of reflexives to object pronouns, we have subset data from the meta-set with studies that directly compared reflexives and object pronouns. In this data subset the following studies directly compared object pronouns vs. reflexives: in comprehension (Baauw & Cuetos, 2003; Baauw et al., 2011; Bos et al., 2014; Caplan et al., 2015; Choy & Thompson, 2010; Edwards & Varlokosta, 2007; Gavarró, 2008; Grodzinsky et al., 1993; Hickok & Avrutin, 1995; Ruigendijk et al., 2006) in elicited production (Sanchez–Alonso et al., 2011) and in both the modalities (Martínez-Ferreiro, 2010).

Fig. 6 shows the forest plot for standardised mean differences between reflexive and object pronoun conditions. Heterogeneity of the sample was insignificant ($I^2 = 33.47\%$, *Cochran's* $Q(10) = 14.68$, $p = 0.14$) suggesting that percent variation across the data sample can be considered as low. Outcomes from the overall random-effect model have shown that PWA performed better with reflexives than object pronouns ($\beta = 0.42$, SE = 0.17, $z = 2.40$, $p = 0.01$, 95%CIs = [0.08 0.77]). Type of aphasia (i.e. fluent vs. non-fluent) did not turn out to be a significant modulator of this outcome ($k = 13$, *Cochran's* $Q_M(1) = 0.05$, $p = 0.83$).

3.3.2. Is there a subject-object asymmetry in interrogative wh-pronoun comprehension?

A curious case concerned whether or not an object-asymmetry exists in PWA's *wh*-pronoun interpretation. Controversial findings across several languages showed that some studies found object questions to be harder to process in aphasia than subject questions (e.g. Hanne et al., 2016; Neuhaus & Penke, 2008), while others showed the reverse pattern, that is, subject questions to be harder than

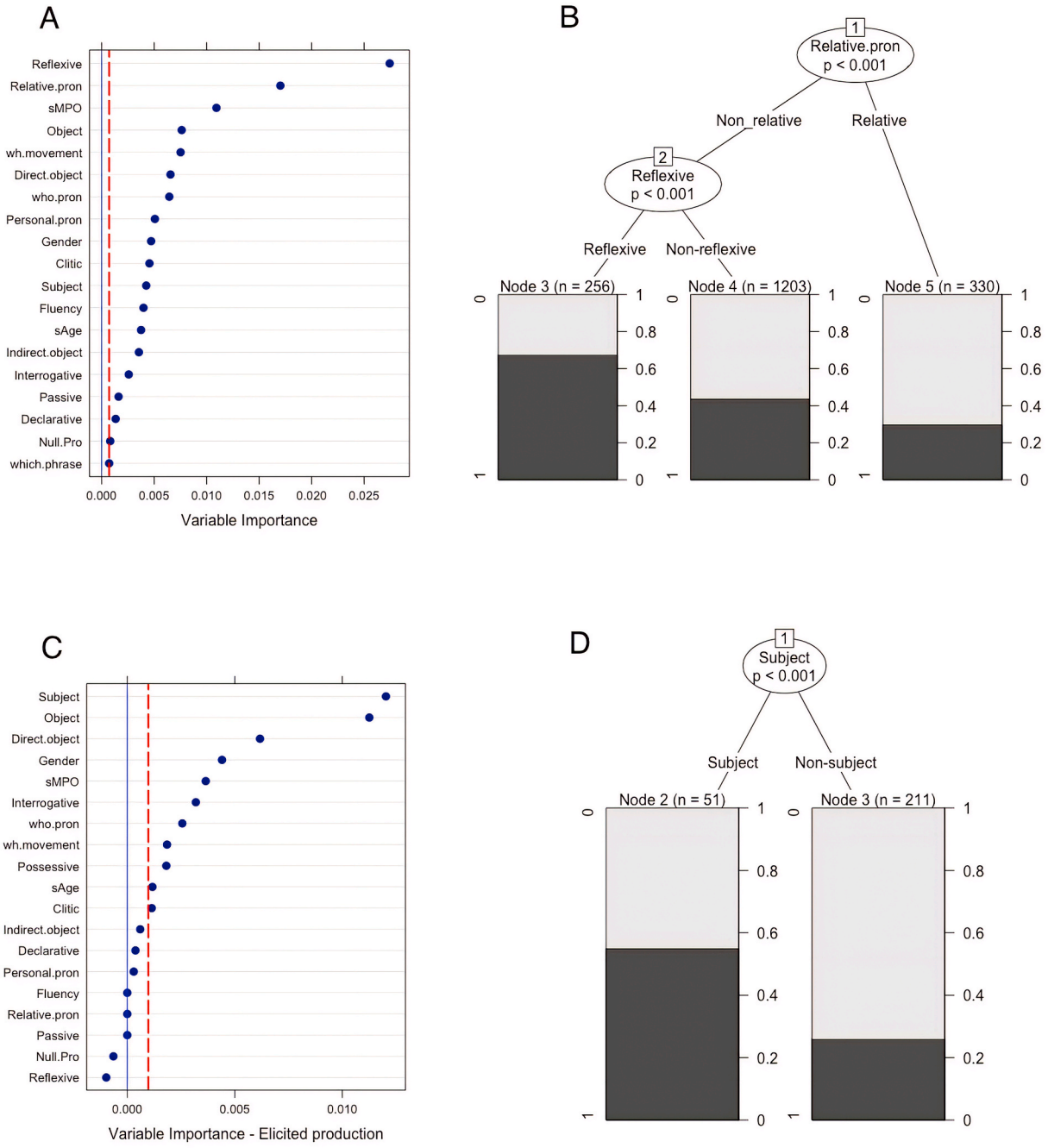

Fig. 5. Outputs from Random Forest models. The models classified individuals with PWA into two response categories – PWA with intact pronoun interpretation/production and PWA with impaired pronoun interpretation/production (scaled as proportions on right sides of bar plots 1 = intact PWA and 0 = impaired PWA). Outputs show for comprehension modality that the most important variables included Reflexives, Relative Pronouns and Months Post Onset (MPO; see 5A), and that the most pertinent conditional inference tree suggests that Reflexive pronouns would be best variable prediction greater proportion of PWA with intact pronoun ability (5B). For production modality, variable importance metrics indicate Subject, Object and Indirect Object variables to be the most important variables (5C); the most pertinent conditional inference tree for production modality significantly predicts a greater proportion of PWA with intact ability in subject pronouns (5D).

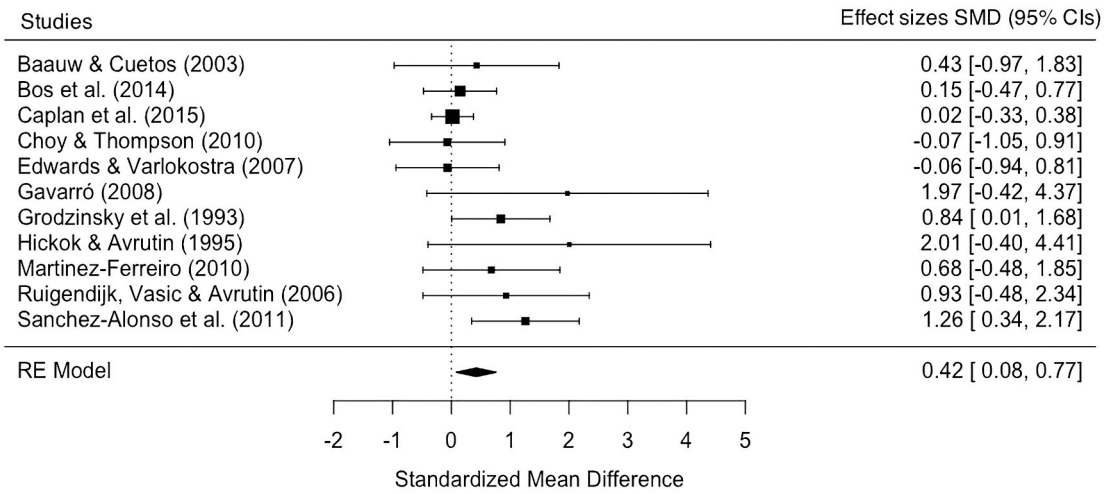

Fig. 6. Forest plot indicating effect sizes based on standard mean differences (SMD) between reflexive and object pronoun conditions. Positive SMDs indicate greater performance on reflexive condition, SMD closer to zero indicates low or no mean difference. Overall Random Effect (RE) Model estimate signals that reflexives are better preserved than object pronouns with a SMD estimate of 0.42.

object questions (Arslan et al., 2017; Kljajevic et al., 2019; Kljajevic & Murasugi, 2010), warranting further analysis into this indispensable subject-object asymmetry in *wh*-pronouns across languages. Particular studies that directly compared subject and object *wh*-pronouns were extracted from the data corpus into a subset (Arslan et al., 2017; Arslan & Felser, 2018; Fyndanis et al., 2010; Garraffa & Grillo, 2008; Hanne et al., 2016; Hickok & Avrutin, 1995, 1996; Kljajevic et al., 2019; Kljajevic & Murasugi, 2010; Neuhaus & Penke, 2008; Nyvad et al., 2014; Salis & Edwards, 2008; Thompson et al., 1999; van der Meulen et al., 2005). All PWA included in this subset were reported to be non-fluent.

Fig. 7 demonstrates the forest plot for standardized mean differences between subject and object *wh*-pronouns across several studies and languages. Heterogeneity of the sample was insignificant with rather low variation observed across studies ($I^2 = 13.25\%$, *Cochran's Q* (14) = 12.49, $p = 0.57$). Outcomes from the overall random-effect model have shown that an object-asymmetry for *wh*-pronouns is not observed in the meta-data ($\beta = 0.02$, SE = 0.18, $z = 0.12$, $p = 0.91$, 95% CIs = [-0.33, 0.37]).

Although modulatory effect of language was insignificant ($k = 15$, *Cochran's* $Q_M(7) = 10.68$, $p = 0.15$), there seemed to be important differences across languages (see Fig. 6). That is, variation of standardized mean difference estimates across languages was minimal except for certain languages. The classical subject-object asymmetry, as evidenced in better preservation of subject *wh*-pronouns, was found to be present only in German ($\beta = -1.42$, SE = 0.57, $z = -2.48$, $p = 0.01$, 95% CIs = [-2.54, −0.29]) and English ($\beta = -1.18$, SE = 0.51, $z = -2.34$, $p = 0.02$, 95% CIs = [-2.18, −0.19]). In all other languages, either a reversed asymmetric pattern (i.

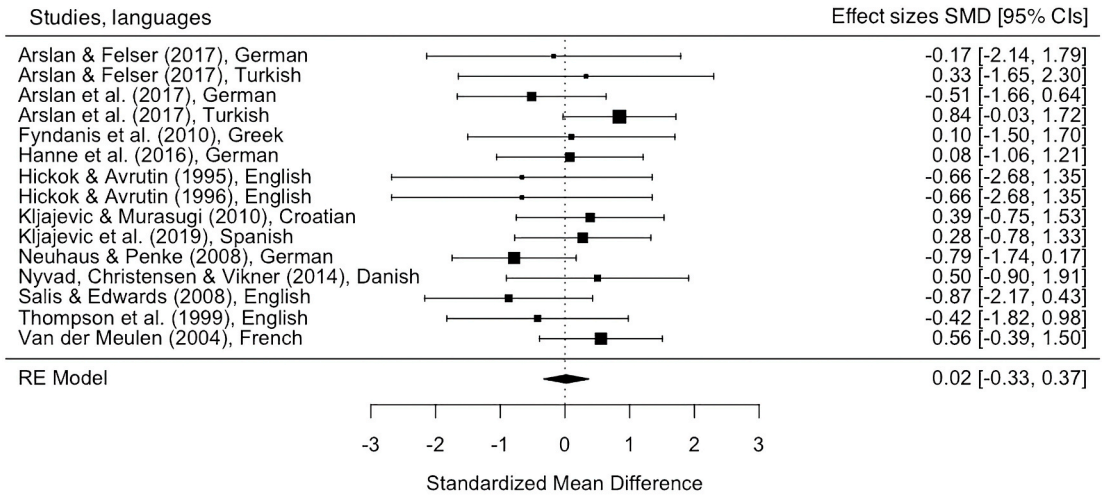

Fig. 7. Forest plots indicating effect sizes based on standard mean differences (SMD) between object and subject *wh*-pronoun conditions. Negative SMDs indicate better performance in object and positive SMDs indicate better performance with subject conditions; values closer to zero indicates low or no mean difference. Overall Random Effect (RE) Model estimate signals that object and subject *wh*-pronouns do not dissociate with a SMD estimate of 0.02.

e. better preservation of object *wh*-pronouns over subject ones) was observed, or no asymmetry between object and subject wh-pronouns was present at all. Interestingly, however, PWA's difficulty with *wh*-pronouns was modulated by the presence of *wh*-movement in constructions tested across these languages ($k = 15$, *Cochran's* $Q_M(1) = 5.49$, $p = 0.02$). Specifically, PWA performed better processing non-*wh*-movement interrogative pronouns than those which require *wh*-movement ($\beta = -1.03$, $SE = 0.44$, $z = -2.34$, $p = 0.02$, 95% CIs = [-1.89, −0.17]).

4. Discussion

In this meta-analysis study, we reviewed individual data from 474 PWA reported in studies investigating different pronoun conditions in aphasia. Through a systematic literature review, we included 42 studies which examined PWA speaking 16 different languages (see Tables 3 and 4). This meta-analysis stood on two important aims: (i) our first aim was unveiling whether and how pronouns are impaired in aphasia; and if so, determining factors predicting pronoun impairments in aphasia using a complementary tree-based classification model (Random Forest); and (ii) addressing mixed-results reported for reflexive/object pronouns and *wh*-pronouns.

Our systematic review revealed an important number of key asymmetries across studies that have constrained the analysis. The first challenge was related to the background information reported about participants across studies. As only very small number of studies reported specific lesion sites and detailed aphasiological backgrounds of the individual with aphasia, we had to limit our review to age, months post-onset and fluency, which was the most reliably reported information. Another challenge was the evident bias of nonfluent participants across studies, producing an unbalanced dataset between fluent and nonfluent PWA; naturally creating an unclarity of fluent PWA performance on pronoun processing, and a lack of importance of this variable in the current analysis. These challenges evidenced a need for a consensus in data reporting across studies to understand the study of pronouns across all PWA.

Although the studies included in this critical review reported a relative impairment of pronoun processing in aphasia, task and task modality (i.e. comprehension vs. production) utilized to investigate pronoun processing varied. These tasks mainly included ones that required individuals to provide meta-linguistic judgements (i.e. truth-value judgement tasks), sentence-picture matching tasks, and relatively smaller number of studies used word-by-word sentence listening, elicited production and sentence repetition tasks. We should note that both the individual PWA and the pronoun variables analysed here should be interpreted under the presence of large heterogeneity.

With regard to our first aim, the overall meta-analytic screening outcomes have shown that pronoun impairments are likely to be present in aphasia with no or little modulation of language spoken, chronological age, post-onset time, or aphasia type. Importantly, proportion of PWA experiencing pronoun deficits depends on types of pronouns, while some pronouns are more challenging some others seem to be rather spared in aphasia. According to our meta-analytic screening, there might be three important linguistic factors that predict these selective impairment patterns: argument position and case marking, cliticization, and the presence of relative clause constructions.

First, we have identified argument position (subject vs object) to be a paramount linguistic factor that predicts number of PWA with impaired pronoun processing, as our models have indicated that there would be more individuals suffering from sentence interpretation difficulty when pronouns appear in object positions than in subject positions. In relation to production modality specifically, an intriguing pattern emerged, PWA found accusative and dative pronouns to be more effortful to produce than nominative pronouns. In languages where case on pronouns is overtly marked (including English: e.g., nominative – *she* vs. accusative – *her*) this difficulty interrelates with function as accusative pronouns, indicating direct object roles, are more likely to be impaired than nominative pronouns signalling subject roles. In some other languages the accusative and the dative forms of pronouns are distinct (e.g., Spanish – unlike in English), and indirect objects have been shown to be problematic in aphasia. These findings have also received support from our complementary analyses using RF models, especially for production, where PWA were shown to perform better when pronouns expressed subjects than non-subject arguments (see Fig. 5). As also pointed out by an anonymous reviewer, an important variability was present in pronoun conditions examined and there were differences between PWA's pronoun production and comprehension ability. We believe that the greater number of pronoun conditions examined in the production modality has to do with the use of elicited production tasks which bear a possibility of examining relatively larger number of variables in comparison to comprehension modality. It is conceivable that in certain pronoun conditions including object pronouns (both direct and indirect objects) and clitic pronouns PWA performed better in comprehending than producing pronouns (see Fig. 2). Although this finding seems at odds with outcomes from many spontaneous speech studies reporting that PWA often overuse pronouns, this should be a methodological issue as in elicited production tasks PWA are expected to produce pronouns within a highly specified context while in spontaneous speech, overuses of pronouns often result from inappropriate uses of indefinite pronouns or pronouns without appropriate antecedents. We believe that the comprehension – production asymmetry emerged here could partly be due to the fact a large number of PWA included in this meta-analysis were reported to suffer from non-fluent aphasia. However, a curious case of grater variability in PWA experiencing difficulty producing pronouns over comprehending them definitely warrants further investigations into.

Secondly, there seems to be a greater proportion of PWA demonstrating difficulty producing clitics in contrast to non-clitic pronouns. This finding seems to fit in with the previous literature (Ishkhanyan et al., 2017). Interestingly, our meta-analysis showed no or little effect of clitics during sentence comprehension. This only relates to languages where clitics may lack stress (mainly Latin languages: Italian, Spanish, French, etc). One important limitation on our analysis for clitic pronouns was that there were less than a handful of empirical studies, especially in comprehension, that compared clitic pronouns to non-clitic counterparts. Therefore, we were not able to critically examine clitic – non-clitic contrast in greater detail, which created a limitation in how far we were able to interpret the data.

A third factor that modulated the likelihood of greater number of PWA with pronoun deficits was whether the sentence material

used to test pronouns included relative clause constructions and/or relative pronouns. This is an insightful finding in that most experimental designs utilize a relative clause structure for methodological reasons to examine locality effects (e.g. Jack told Jane that Maria likes her/herself) or directly use a construction with a relative pronoun where the relative clause refers to a person referent (e.g. Jack spoke to the girl who likes him). Pronoun resolution, and sentence interpretation in general, is found to be more severely disrupted in aphasia in the presence of relative clause constructions with increasing length and complexity as opposed to simple declarative clauses (Caplan et al., 2007). We found that other syntactic factors (wh-movement, null-pronouns, passives) were not significantly modulating outcomes for proportion of PWA experiencing pronoun impairments, suggesting that these factors may entail less associated processing costs. These findings are entirely compatible with outcomes from complementary RF models, which showed that PWA's pronoun processing is largely characterised by better interpretation of reflexives and the presence of relative clause constructions. Moreover, the RF model outputs showed that null pronouns and passive constructions influenced pronoun impairment to much lesser extent. No modulation of *wh*-movement is interesting. In languages, such as English and German, formulating a word-order changing question requires extraction of noun phrases and movement of the *wh*-pronoun to sentence-initial position, while in some other languages this movement is not realised since a *wh*-pronoun can replace the noun phrase in the base-generated position (i.e. the boy likes *whom*?). We should note however, that the previous literature consistently showed an effect of syntactic movement (Drai & Grodzinsky, 2006), and that our findings here only concern aspects of pronoun resolution. We can only conclude based on this meta-data that *wh*-movement has perhaps little impact on pronoun interpretation but not on sentence interpretation in general. With regard to no modulation for null pronouns could well be due to small number of studies that looked at it in relation to pronoun resolution. Null pronoun condition is very interesting, but a lesser studied pronominal phenomena in aphasia, and often manifests itself as subject-position pronoun elements to be omitted in speech production (de Roo, 2003). In languages that allow pronoun dropping (i.e. Greek), one study showed PWA performed better with null subject pronouns than overt pronouns in comprehension (Peristeri & Tsimpli, 2013). However, whether and how pronoun dropping, including null objects, is affected or whether it facilitates comprehension in aphasia is much less understood.

With regard to our second aim, the findings from a subset meta-analysis with studies that compared reflexives and object pronouns have shown that PWA performed better with reflexives than object pronouns. For this subset model of reflexive and object pronouns, heterogeneity was insignificant, and hence, we conclude that the better preservation of reflexives over object pronouns is robust. Although in some studies standardized mean differences between reflexive and object pronoun conditions were closer to zero than in some other studies, the overall estimate showed an advantage for reflexives. The meta-analytic results therefore support studies that predict reflexives to be rather well preserved in aphasia (e.g., Gavarró, 2008; Grodzinsky et al., 1993; Hickok & Avrutin, 1995; Ruigendijk et al., 2006). Interestingly, this pattern of impairment was not influenced by fluency. We should, however, note that the majority of PWA investigated were non-fluent individuals, only a minority suffered from fluent aphasia. Pronoun comprehension has been shown to be compromised in fluent PWAs, nonetheless, the underlying reason for such a compromised processing may be different from non-fluent PWAs as fluent PWAs have difficulty in accessing lexical information (e.g. Grodzinsky et al., 1993; Vasić et al., 2006).

A second domain with mixed results that was analysed regarded whether or not a subject-advantage is present in processing of *wh*-questions. Although the literature includes opposing results, differences across these studies cannot be defined as a controversy because they tested different languages, and in fact, our meta-analysis showed that whether subject or object *wh*-questions are better preserved in aphasia largely depends on the language tested. German and English speaking PWA are more likely to have better preserved subject *wh*-pronouns but in other languages the reverse or no asymmetry are likely outcomes. One possibility is that in Germanic languages where *wh*-movement is enforced, object extracted questions pose additional challenges to sentence interpretation. We support the idea that word-order changing *wh*-movement puts further difficulty in off-line aphasic pronoun interpretation (Dickey et al., 2007; Dickey & Thompson, 2009; Friedmann, Reznick, Dolinski-Nuger, & Soboleva, 2010; van der Meulen et al., 2005), yet we rule out a global subject-advantage in *wh*-question processing as this seems to be largely language dependent.

These results have certain implication on the theories that predicted underlying reasons for aphasic pronoun impairments (see Table 2 for an overview). It is important to note that based on this critical meta-analysis we can only discuss implications for theoretical accounts that particularly predict correctness scores of PWA, tapping into offline sentence processing ability. Recall that one group of accounts predicted a delayed or slowed processing in aphasia at the presence of declining cognitive resources. One such model is the *slower-than-normal syntax model* (e.g. Burkhardt et al., 2003; Burkhardt et al., 2008) which holds that PWA would be able to identify referents for anaphors (i.e. reflexives) in a delayed manner under processing limitations but opposes to the idea that PWA lacks syntactic representations. The *Increased Interference model* (see e.g. Dickey et al., 2007; Dickey & Thompson, 2009; Hanne et al., 2011) affiliates PWA's pronoun/proform resolution difficulties with an increased interference from non-intended or unlicensed interpretations as PWA tended to often turned their gaze to distractor pictures in eye-tracking experiments. As this possibility regards online sentence processing in aphasia, it is rather strenuous to contemplate on it based on accuracy scores, however, it is possible to speculate on a possible scenario that many pronouns receive sentential focus, and focused elements bring alternatives to mind. Another account is Thompson and her colleagues' *delayed lexical integration* model (Choy & Thompson, 2010; Thompson & Choy, 2009) which proposed delayed processing of pronouns in aphasia but no critical differences for object pronoun and reflexive conditions. The meta-data provides little support for these accounts in the sense that reflexives are found to be better preserved in PWA than object pronouns. The *resource reduction* model (see Caplan et al., 2013a, 2013b; Caplan et al., 2015 for an overview), also predicts lower correctness scores in PWA due to reduced cognitive resources. This model indicates that the more complex syntactic analysis sentence materials require the more severe sentence impairments would be observed (Caplan et al., 2013a). This prediction is supported as the meta-data showed a significant modulatory effect for whether or not pronouns are used in relative clause structures, suggesting that pronoun interpretation difficulty increase when greater syntactic processing demands are needed.

A second cluster of studies based their explanations for why pronouns are impaired in aphasia on certain linguistic configurations, as these configurations are either not accessible to PWA or require greater processing demands that PWA can meet. The *Structural Intervener model* (e.g. Engel et al., 2018; Garraffa, 2009; Sheppard et al., 2015) is an example, following which one expects reflexives –and subject *wh*-pronouns– to be better preserved than object pronouns as structural distance from the critical pronoun to the antecedent is shorter in the former. That is, in the case of object pronouns, the structural distance between the pronoun and the antecedent acts as an intervention, leading to failures in sentence interpretation. We can confirm that the meta-data supports this model as object pronouns were found to be more severely impaired than reflexives, however, a similar analogy does not apply to *wh*-pronouns, as subject *wh*-pronouns were not consistently better preserved than object pronouns. Therefore, the idea of intervening sentence material leading to impairments may be language and/or variable dependent yet not an overall cause for pronoun impairments in aphasia. The *discourse-linking impairment model*, by contrast, posits that pronouns requiring linking to discourse antecedents are harder to resolve, and hence, are more impaired in aphasia than non-discourse linked pronouns and *wh*-phrases (e.g., Bos et al., 2014; Hickok & Avrutin, 1995, 1996; Martínez-Ferreiro et al., 2017). While this model accounts for the difference between, for instance, *which*-phrases and who-pronouns, the nature of resolving pronouns referring to discourse antecedents (i.e. when the antecedent is placed in the previous sentence) is less understood in experimental sentence elicitation and comprehension tasks. A better preservation of reflexives over object pronouns can indirectly be accounted for by a potential discourse-linking difficulty, since in the so-far-investigated languages, reflexives cannot refer to antecedents outside their local binding domains, and hence, object pronouns can be used in reference to both intra-sentential and inter-sentential (discourse) referents. However, in the absence of data from certain languages which express long-distance reflexives, such as, Turkish, Mandarin Chinese, or Japanese, where the reflexive can bind a non-local even sometimes discourse antecedents, this conclusion remains as a speculation. The *grammatical vs. lexical account* for pronouns (Ishkhanyan et al., 2017; Martínez-Ferreiro, Bastiaanse, & Boye, 2019; Martínez-Ferreiro et al., 2017) predicts that grammatical pronouns would be more severely affected than lexical pronouns. This model accounts for the asymmetry between subject and object pronouns in many (but not all e.g. French) languages, being further compatible with the absence of differences between fluent and non-fluent individuals. Assuming that grammatical pronouns refer to a preserved lexical antecedent, the traditional dichotomy for grammatical impairment – non-fluent deficit vs. lexical impairment – fluent deficit may entail more complexity than expected. Further studies examining fluent PWA's pronoun processing may test this proposal.

In conclusion, based on this meta-analysis, we can confidently confirm that (i) some kind of pronoun difficulty is present across languages and pronominal variables in aphasia, (ii) reflexive anaphors are better preserved than object pronouns, (iii) an overall subject-advantage in *who*-pronouns is language-specific, and (iv) subject/object position and case marking predict pronoun impairments broadly in production. These findings provided important outcomes regarding the theories explaining pronoun processing difficulty in aphasia. We provide support for theories that predict cognitive limitations and complex syntactic features to render pronoun interpretation rather difficult in aphasia (e.g. see Caplan and his colleagues' resource reduction account). This meta-analysis provides partial support for theories based on which pronouns are anticipated to be more impaired in aphasia over reflexive anaphors (i.e. structural intervener and discourse-linking accounts), and on which object pronouns are expected to be impaired over subject pronouns in non-fluent aphasia (i.e. lexical-grammatical account). However, despite the large amount of studies completed on pronoun processing in aphasia, there is still a lot more to understand. In Fig. 1, we showed a large number of pronominal variables examined in aphasic sentence comprehension and production tasks, however, with the very few exceptions discussed in this paper, most pronoun types are still underrepresented in pronoun studies in aphasia. For instance, best to our knowledge, two studies examined possessive and demonstrative pronouns in production, and none in comprehension. Likewise, only few studied null pronouns, and greater research is needed for languages where pronouns are expressed as clitics. Furthermore, presently, the precise nature of how pronominal elements interact with morpho-syntactic and semantic factors, such as case marking and gender marking – as these offer interesting cross-linguistic variability, are far from being well understood.

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Appendix 1. Example trials and sentence materials used in typical comprehension and production paradigms used in pronoun processing experiments in aphasia research

Task	Examples
Comprehension	
Truth value judgement tasks (TVJT)	Picture: A father and a boy drawing. Prompt: "This is a picture about drawing. Here we have a father and a

(*continued on next page*)

(*continued*)

Task	Examples
	boy'. Is the father drawing him? Target answer: true/false. (Edwards & Varlokosta, 2007)
Sentence picture matching (SPM)	Picture A: The older sister is combing herself. Picture B: The older sister is combing her little sister. Prompt: "The older sister combs her". Target answer: Picture B. (Martínez-Ferreiro, 2010)
Cross-modal naming paradigms	Orally presented prompt: "Brian cried in front of the grave, … Visually presented target to be named: **he** ("… had a tissue") Rigalleau and Caplan (2004)
Production	
Morpheme production tasks (e.g. Cloze test, Cross-Modal Morphosyntax Battery (Goodglass, Christiansen, & Gallagher, 1993))	Prompt: ngo daidai hai hoksaan, keoi gamnin sapseoi I younger-brother be student, PRO this-year ten-years-old ''My younger brother is a student; he is ten-years-old'' (Law & Cheng, 2002)
Sentence completion (with & without priming)	Prompt: "I turisti sono arrivati sull'isol**a**, e … [The tourists arrived to the island, and …] Target answer: **la** hanno visitat**a**. [They have visited it.] (De Bleser & Luzzatti, 1994)
Sentence elicitation (with & without pictures)	Picture: A boy is washing a car. Prompt: What is the boy doing with the car? Target answer: The boy is washing it. (Martínez-Ferreiro, 2010)

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