A behavioral study of the nature of verb-noun dissociation in the nonfluent variant of Primary Progressive Aphasia

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ABSTRACT

Background: Patients with nonfluent/agrammatic variant primary progressive aphasia (nfvPPA) have more difficulty producing verbs than nouns, but the reason for this discrepancy remains unclear. One possibility is that it results from impaired access to motor programs integral to semantic representations of actions. Another is that the disruption affects specific lexical or grammatical features of verbs.

Aims: To use an oral picture naming task to examine the effects of motor associations on verb production in patients with nfvPPA.

Methods & Procedures: We administered noun and verb naming tasks to 12 nfvPPA patients and 9 controls. We varied the manipulability of target items across categories as a proxy for the degree to which lexical access depends on motor knowledge.

Outcomes & Results: Nonfluent PPA patients were significantly more impaired in both noun and verb naming compared to control participants. However, the nfvPPA patients were significantly more impaired in naming verbs than nouns, but there was no effect of manipulability.

Conclusion: The results suggest that the verb naming deficit in nfvPPA is not directly related to impaired motor knowledge, and is more likely to be related to other properties that distinguish verbs from nouns.

Keywords: Primary progressive aphasia; grammatical dissociation; verb; nouns; semantics; naming

INTRODUCTION

Dissociations in the production of nouns and verbs have been described in several different clinical groups, including patients with acquired lesions due to stroke and patients with neurodegenerative disease. There is considerable controversy as to what level of lexical processing is affected in these cases, as nouns and verbs differ along several psycholinguistic dimensions. On the one hand, nouns prototypically describe concrete objects, whereas actions are typically denoted by verbs. Thus, an apparent dissociation between nouns and verbs in speech may actually reflect an underlying loss of access to sensorimotor knowledge relevant either to objects (e.g., visual or tactile information) or to actions (motor programs). On the other hand, nouns and verbs have different syntactic roles and may be distinguished by language-specific grammatical, morphological and phonological features, access to which may be disrupted following brain damage. Indeed, it is likely that the locus of disruption in language processing differs among patients according to the pathology and distribution of their brain lesions.

Studies with individuals who have aphasia due to focal vascular lesions have generally suggested that noun processing is subserved by left temporal areas, while verb processing relies on the left frontal lobe. However, neuroimaging experiments which have investigated differences in noun and verb representation have yielded inconsistent results, and overall do not support the simplistic theory that verbs and nouns are processed in the frontal and temporal lobes, respectively. One review found 14 studies that showed that verbs were specifically activated by frontal areas, while six demonstrated noun-specific frontal area activation (Crepaldi, Berlingeri, Paulesu & Luzzati, 2011). The results of a more recent meta-analysis of neuroimaging studies of verb and noun processing suggest that the neural circuits involved in verb and noun processing are not spatially segregated in different brain areas, but rather are interleaved with each other in a mainly left-lateralized fronto-temporo-parietal network (Crepaldi et al 2013).

Interestingly, certain pathological processes that produce lesions within local brain networks, rather than arbitrary vascular territories, also result in differential impairment in noun and verb processing. Several studies have reported that verb production is more impaired than noun production in patients with nonfluent variant primary progressive aphasia (nfvPPA). This holds true across a variety of tasks including oral picture naming (Cotelli et al., 2006; Hillis, Oh, & Ken, 2004; Hillis, Tuffiash, & Caramazza, 2002; Silveri & Ciccarelli, 2007; Thompson, Lukic, King, Mesulam, & Weintraub, 2012), verb (action) fluency (Davis et al., 2010), and connected speech (Wilson, et al., 2010). Clinically, nfvPPA is characterized by agrammatism and effortful, halting speech with speech sound errors and distortions. Like patients with agrammatic aphasia due to acquired vascular lesions, patients with nfvPPA may be impaired in comprehension of syntactically complex sentences, but typically have spared comprehension at the single-word level (Ash et al., 2013; Charles et al., 2014; Gorno-Tempini et al., 2011; Silveri et al., 2014). Anatomical studies show a pattern of atrophy that predominantly affects the left inferior-posterior frontal lobe, insula, and underlying white matter tracts (Gorno-Tempini et al., 2011; Mandelli et al., 2014; Wilson et al., 2010).

Explanations for the noun-verb discrepancy in nfvPPA patients may be of the sensorimotor variety: that is to say, the impairment in retrieval of verbs, or action words, may result from the involvement of anterior motor systems that encode aspects of conceptual knowledge about actions (Aziz-Zadeh & Damasio, 2008; Bak, O'Donovan, Xuereb, Boniface, & Hodges, 2001; Hauk, Johnsrude, & Pulvermüller, 2004). We will refer to this explanation as the "motor hypothesis." Many, though not all, of these patients show other, more overt signs of sensorimotor dysfunction, such as motor speech disorders, apraxia, rigidity, tremor, or cortical sensory loss actions (Boeve, Lang, & Litvan, 2003; Frattali, Grafman, Patronas, Makhlouf, & Litvan, 2000; Kertesz, Martinez-Lage, Davidson, & Munoz, 2000). In some other patient populations in which the motor impairment is more prominent—for example, corticobasal degeneration and progressive supranuclear palsy (Chow, Brambati, Gorno-Tempini, Miller, & Johnson, 2010)—it has been shown that the manipulability of objects significantly affects the ability to produce object names, supporting the idea that retrieval of action-related semantic knowledge relies on motor regions.

The motor hypothesis is by no means the only potential explanation for the verb naming deficit in nfvPPA. It is also possible that the relative impairment of verbs in nfvPPA is related to an impairment in one or more syntactic and morphological processes that tend to affect verbs more than nouns. For example, verbs may be grammatically more complex than nouns along any of several dimensions (such as syntactic agreement, argument structure, or marking for tense, mood, or aspect), and therefore more likely to be sensitive to disruption with damage to the left inferior frontal gyrus (IFG) and other areas engaged in grammatical processes (Uddén & Bahlmann, 2012). Other distinct possibilities include the hypotheses that there are circuits or brain regions that are differentially sensitive to verbs and nouns as grammatical classes, or that dissociations between nouns and verbs are artefacts of differences in multimodal conceptual-semantic associations, reflected in notions like concreteness or imageability, as opposed to the specific dimension of motor knowledge (see Bird, Howard, & Franklin, 2003; Kemmerer, 2014; Luzzatti et al., 2002; Mätzig, Druks, Masterson, & Vigliocco, 2009; Shapiro & Caramazza, 2003 for reviews and discussion).

Here, we will focus specifically on the motor hypothesis as a potential explanation for the noun-difference in nfvPPA. One straightforward prediction of this hypothesis is that verbs more strongly associated with actions involving a manipulable object (e.g. to squeeze) will be more susceptible to disruption than verbs which do not necessarily refer to actions involving manipulable objects (e.g. to drip). A similar dissociation should also be observed for nouns that refer to manipulable objects (e.g., comb) as opposed to those referring to non-manipulable objects (bridge). If sensorimotor associations do not affect word production performance within categories, it would seem untenable that they could account for dissociations across categories, which in turn would suggest that noun-verb differences in nfvPPA are attributable either to some grammatical factor or to a semantic factor not related to motor knowledge.

In this study we used an oral picture naming task to examine the effects of motor associations on verb production in patients with nfvPPA. The oral picture naming task included stimuli that represented manipulable objects, non-manipulable objects, actions involving manipulable objects, and actions not involving manipulable objects. This was designed to determine whether there are separate effects of manipulability and category (noun or verb) on confrontation naming in nfvPPA.

METHODS

Participants

Participants were recruited from the Memory and Aging Center at the University of California, San Francisco (UCSF). We included twelve patients with nfvPPA (6 male, 10 right-handed, age 69.1±8.56 years, education 16.1±2.68 years), all of whom met current diagnostic criteria for this disorder (Gorno-Tempini et al., 2011). Nine healthy subjects with similar demographic characteristics were included in the control group (6 male, 8 right-handed, age 66.38±4.69 years, education 17.44±1.42 years).

All participants were native speakers of North American English and had normal or corrected-to-normal visual and auditory acuity. Control subjects had no history of neurological or psychiatric illness or substance abuse. Table 1 summarizes the demographic and clinical characteristics of the study participants.

(Table 1 about here)

Stimuli

The stimuli for the oral picture naming task were 32 black and white two-dimensional line drawings. These consisted of 16 pictures of actions (eliciting verbs) and 16 pictures of objects (eliciting nouns). Within each set of pictures (actions or objects), half of the stimulus items involved manipulable objects/actions, while the other half did not. There were also 4 practice items for each category; performance for these items was not scored.

All of the pictures and their target names were selected from a larger corpus of 795 stimuli available through the Center for Research in Language International Picture Naming Project (CRL-IPNP) (Bates et al., 2000). The action and object picture names were matched for difficulty (production latency), frequency, visual complexity, age of acquisition, length (syllables and characters), and familiarity (Appendices A, B and C). The valency of each verb depicted by action pictures is also presented in appendix B. Word frequency, visual complexity, age of acquisition, and length data were derived from the CRL-IPNP corpus, while familiarity data were derived from the MRC Psycholinguistic Database (Wilson, 1988). Difficulty and manipulability values were derived from a previous study using pictures from the same corpus (Arévalo et al., 2007). In that study, pictures were named by healthy participants and response latencies were measured. Items with mean response latencies of two or more standard deviations above the mean were classified as “hard,” and those with latencies of two or more standard deviations below the mean were classified as “easy” (Arévalo et al., 2007). Manipulability was determined by asking participants to “do the first thing that comes to mind” (e.g., make a movement or adopt a pose) when presented with a given word (Arévalo et al., 2007; Arévalo, Butler, Perani, Cappa, & Bates, 2004). An item was considered “manipulable” if at least 70% of participants produced obvious fine-grained movements of the fingers.

In order to verify that the pictures had high name agreement, the picture naming task was performed by 10 local and self-reported as healthy participants (none of whom subsequently participated in the experiment). All pictures had at least 90% name agreement (that is, at least 9/10 participants named each picture using the same word), which was considered appropriate; there was no need to replace any of the pictures.

Procedure

In the oral picture naming task, participants were instructed to name the action pictures by saying what was happening in the picture or what the person was doing, and to name the object pictures by saying the name of the object. For each picture, they were asked to respond using only one word. Sets of action and object pictures were presented separately. Prior to each set of 16 experimental items, subjects were presented with 4 practice items of the same category.

The final scores were the number of pictures named correctly (with the target names) for each set of pictures. Any grammatical form of a verb was considered correct (e.g. *squeeze, squeezing*, *squeezes, squeezed*).

Statistical Analysis of Behavioral Data

The data were analyzed using Statistical Package for Social Sciences (SPSS) software, version 18. Because of the small group sizes, we analyzed behavioral data using nonparametric tests. For intergroup comparisons of continuous variables we used the Mann-Whitney U test, and for categorical variables we used the Chi-Square test. To compare differences in naming performance within groups we used the Wilcoxon and

Friedman tests. An additional exploratory analysis was performed to investigate the influence of verb arguments on verb naming performance by means of calculating relative risk. All analyses were considered significant at the level $\alpha = 0.05$.

Imaging Data Acquisition and Analysis

All participants underwent structural brain magnetic resonance imaging (MRI). Whole-brain T1-weighted images were acquired on a 3T Siemens TrioTim Syngo scanner equipped with an eight-channel transmit and receive head coil using a magnetization-prepared rapid gradient echo (MP-RAGE) sequence (160 sagittal slices; matrix = 240 x 256; voxel size = 1.0 mm3; repetition time= 2300 ms; echo time = 3 ms; inversion time = 900 ms; flip angle = 9°). Image processing and statistical analysis were performed with Statistical Parametric Mapping (SPM8) software (Wellcome Trust Center for Neuroimaging, London, UK). The images were segmented into gray matter (GM), white matter (WM) and cerebrospinal fluid and spatially normalized to the Montreal Neurological Institute (MNI) stereotactic template with the diffeomorphic exponentiated lie algebra (DARTEL) registration toolbox (Ashburner, 2007) and using volume-preserving Jacobian modulation. Finally, images were smoothed with an 8 mm full-width half-maximum Gaussian kernel. Gray matter volumes were compared between nfvPPA and control participants using the general linear regression model in SPM8. The statistical analysis was performed by covarying out age, gender, handedness, and total intracranial volume. Statistical threshold was set at $p<0.001$ uncorrected. We present the overlap of all nfvPPA to characterize the brain atrophy of our sample (see Figure 1).

(Figure 1 about here)

RESULTS

We compared naming performance on noun (object) pictures and verb (action) pictures between patients with nfvPPA and control participants. Compared to control participants, the nfvPPA group was significantly impaired for both noun naming ($p < 0.01$) and verb naming ($p < 0.005$). Across categories, the nfvPPA group was also significantly impaired at naming both manipulable pictures and non-manipulable pictures ($p < 0.05$). When effects of manipulability were examined within categories, the only subset for which nfvPPA patients did not show impaired performance compared to controls was that of manipulable objects (Table 2).

(Table 2 about here)

Within the group of nfvPPA patients, performance was significantly worse in naming verbs than nouns ($p < 0.01$). This was true for both manipulable words ($p < 0.05$) and non-manipulable words ($p < 0.05$). By contrast, control subjects did not show noun-verb differences in naming either manipulable words or non-manipulable words (Figure 2). When nouns and verbs were combined, we did not observe differences in naming performance related to manipulability for either nfvPPA patients or controls (Figure 3).

(Figures 2 and 3 about here)

We performed an additional exploratory analysis to investigate whether a verb's valency (number of arguments) influenced verb naming performance[1]. Of 16 action pictures depicting verbs, 4 represented verbs with 1 argument, 10 verbs with 2 arguments, and 2 verbs with 3 arguments. Because of the low number of verbs of each type (especially 3-argument verbs), the variable of valency behaves more as categorical than as continuous, rendering a regression analysis inappropriate. We therefore dichotomized naming performance for each verb type as low accuracy (< 70%) or high accuracy (≥ 70%) for each participant, and calculated the relative risk of low accuracy for each type among participants who performed poorly at verb naming in general (< 14 total correct) versus participants who performed well (≥ 14 total correct). We used 14 as cut-off for total verb naming performance because this was the lowest score among control participants. The relative risks were not significantly different between the 3 valency categories, but there was a trend toward increasingly poor performance with verbs of as a function of valency: the relative risk of low accuracy was 3.8 (95% CI 1.79-8.06) for 1-argument verbs, 8 (95% CI 2.19-29.25) for 2-argument verbs, and 15 (95% CI 2.26-99.64) for 3-argument verbs.

DISCUSSION

[1] We thank an anonymous reviewer for this suggestion.

The aim of this study was to explore the basis of the noun-verb difference in nfvPPA by examining the effect of manipulability on picture naming performance. The motor hypothesis predicts that a relative impairment for verbs (action names) should be associated with greater difficulty for more manipulable items. By contrast, a dissociation between effects of category and manipulability would imply that the verb naming deficit cannot be explained solely as a function of impaired access to motor semantic features.

We found that patients with nfvPPA were indeed more impaired at producing verbs than nouns in an oral picture naming task, even with stimulus items controlled for a number of lexical variables including frequency, age of acquisition, length, familiarity, and visual complexity. This finding is consistent with prior studies showing that verbs are more impaired than nouns in naming, verbal fluency, and connected speech tasks in patients with nfvPPA (Cotelli et al., 2006; Hillis, Oh, & Ken, 2004; Hillis, Tuffiash, & Caramazza, 2002; Silveri & Ciccarelli, 2007; Davis et al., 2010; Wilson, et al., 2010; Thompson, Lukic, King, Mesulam, & Weintraub, 2012).

The effect of manipulability in word production has been investigated in prior studies of patients with nfvPPA, but with some limitations. The first study that examined the effect of manipulability in action and object naming was that of conducted by Cotelli et al. (2006). They found an effect of manipulability in patients with corticobasal degeneration (CBD), but not in nfvPPA. However, the interpretation of these results is not straightforward, as the manipulable and nonmanipulable items were not matched for linguistic features, and only two nfvPPA patients were included in the experiment.

One previous study has examined effects of manipulability on object naming in patients with nfvPPA, by way of comparing the naming performance of manufactured artifacts relative to natural kinds (Reilly, Rodriguez, Peelle, & Grossman, 2011). Patients were worse overall in naming manufactured artifacts than natural kinds. However, the participants showed no reliable correlation between the classical symptoms of posterior inferior frontal lobe damage and artifact naming, which would be inconsistent with a strict version of the motor hypothesis that posits that motor schemata are a necessary component of the representation of artifacts.

Reilly et al. (2014) investigated the effect of manipulability in nfvPPA using a name generation test in nfvPPA, and found no differences in behavioral performance between these two categories. As in their previous experiment, however, all target words were nouns, and these results therefore do not directly address the question of whether noun-verb differences might be attributable to differences in manipulability. Our study, by contrast, investigates the effect of manipulability on both action and object naming with matched sets of stimuli, allowing us to begin to distinguish the effects of semantics of objects and actions from effects of grammatical category.

In this experiment, patients with nfvPPA did not show differences in picture naming based on the manipulability of stimulus items across categories, suggesting that a specific impairment in motor knowledge cannot account for the noun-verb difference. If anything, nfvPPA patients seemed to have *less* impairment in naming nouns that depicted manipulable objects than in naming verbs that depicted manipulable actions. The absence of a selective effect of manipulability does not exclude the possibility that motor brain areas are involved in lexical and semantic representations. They do, however, show that in this group of patients, there is no apparent effect of motor-related features on word production.

Although patients performed poorly on object naming overall, manipulability did not predict poorer performance. Our results are consistent with this finding and add information with regards to the absence of manipulability effect on action naming as well.

Overall, these data suggest that poor naming performance in nfvPPA may be more influenced by grammatical or non-motor semantic features of words than by association with action knowledge, despite a pattern of brain atrophy that predominantly involves prefrontal cortical regions. Thus, verb deficits in nfvPPA may be primarily grammatical in nature, with lesser contributions of other aspects of verb representation.

The results of our study and of the study by Reilly et al. (2011) in patients with nfvPPA seem to diverge from a study of patients with aphasia after stroke, in which the investigators found that patients with frontal lesions tended to have greater difficulties naming both verbs and manipulable items (in contrast to healthy controls, who had more difficulty naming non-manipulable items) (Arévalo et al., 2007). However, the distribution of lesions in this study was much broader than the pattern of atrophy in our patients, suggesting that the effect of manipulability may emerge from damage to different, if perhaps adjacent brain areas.

In one fMRI study in which manipulability was examined specifically, activation of a left posterior/inferior frontal network was observed in reading verbs irrespective of whether the stimuli referred to actions involving a manipulable object (Yang, Shu et al., 2011). Manipulability was more strongly correlated with activation in a network that was largely unaffected in our population, including the left middle frontal gyrus as well as the superior parietal lobule and the posterior middle temporal gyrus (Yang, Shu, Bi, Liu, & Wang, 2011). Likewise, in a study of patients with nonfluent aphasia due to vascular lesions, (Reilly et al., 2014) showed that damage in motor and premotor regions did not predict deficits in producing words with high motor salience. Manipulability was associated with lesions in the posterior middle temporal gyrus and angular gyrus.

Controversially, a previous study has investigated the effect of actionality (defined as the degree of fine motor planning of hand movements underlying the action denoted by each of the verbs) in verb-impaired patients with post-stroke aphasia (Aggujaro, Crepaldi, Pistarini, Taricco & Luzzatti, 2006). Two of four patients with left posterior temporal and inferior parietal lesions were not able to retrieve any of the high or low actionality verbs. However, the other two were more impaired for low-actionality verbs than for high-actionality verbs. The authors argue that these findings suggest a critical role of the temporo-parietal area when retrieving verbs, irrespective of their degree of actionality. Manipulability might be somewhat associated with actionality, but the findings of the study of Aggujaro et al. (2006) must be interpreted with caution, since the sample size is quite small.

A number of factors not directly related to motor semantics may contribute to verb naming impairments in patients with nfvPPA and others with similar lesions. Compared to nouns, verbs are acquired later, less imageable, less frequent, and morphologically and syntactically more complex (Garbin, Collina, & Tabossi, 2012; Mätzig et al., 2009;

Szekely et al., 2005; Tomasello, Akhtar, Dodson, & Rekau, 1997; Vigliocco, Vinson, Druks, Barber, & Cappa, 2011). Among all these features, some are easily controlled across grammatical categories, like the word frequency. On the other hand, imageability is more difficult to match between these grammatical classes; even concrete verbs are systematically rated lower in imageability than concrete nouns (Mätzig et al., 2009). Furthermore, although we attempted to control for many of differences in lexical properties, we could not control for differences in morphological and syntactic dimensions, which may play a crucial role in processing the distinction between grammatical categories and seem to depend particularly on brain regions within the left prefrontal cortex. This observation is corroborated by neuroimaging studies in neurologically unimpaired individuals, which have demonstrated activation of the same areas in the production of verbs compared to nouns (Palti, Ben Shachar, Hendler, & Hadar, 2007; Shapiro, Moo, & Caramazza, 2006, 2012). Interestingly, this activation is found regardless of whether verbs refer to concrete actions or abstract states, and it is even found when pseudo-words are produced as verbs rather than nouns (Shapiro et al., 2006, 2012).

The "argument structure complexity hypothesis" offers one explanation for the increased difficulty of verb naming based on their greater syntactic complexity, even when other psycholinguistic features are controlled (Thompson, 2003). This hypothesis holds that verbs with more complex argument structures are more difficult for agrammatic aphasic individuals to produce, where "complexity" is determined both by the number of arguments (valency) and the syntactic consequences of particular argument structures (e.g., whether they trigger movement operations). Although our study was not designed to test this hypothesis directly, we performed an exploratory *post hoc* relative risk analysis to test the effects of valency on verb naming performance. Indeed, we found that increased valency was associated with a higher relative risk of low naming accuracy, consistent with the argument structure complexity hypothesis, although the confidence intervals overlapped considerably and thus the trend did not reach statistical significance. Future studies could be designed to test this hypothesis more robustly by including more verbs of each valency type and examining the effects of implied movement operations.

The main finding of this study was that the naming deficit in nfvPPA does not seem to be sensitive to the manipulability of target words, and thus that motor salience is not sufficient to account for these patients' relative impairment in producing verbs compared to nouns. The findings add information relevant to understanding the role of access to semantic and grammatical knowledge in word production. The results also provide insights into the cognitive profile of nfvPPA, which can contribute to the clinical diagnosis. Overall, these results are consistent with a lexical-grammatical, rather than motor semantic, explanation of the naming deficit in patients with nfvPPA.

Finally, it is important to point out the limitations of our study. Our sample size is relatively small, which is a frequent problem in studies of primary progressive aphasia, a relatively rare neurologic disease. Because of the small sample size, we applied nonparametric statistical tests. However, nonparametric tests do not allow correction for multiple comparisons; as a consequence, the investigation of the variability found in the performance of the nfvPPA group was limited. For the same reason, we were unable to investigate the effects of speech apraxia and agrammatism on naming performance. It may be that these co-occurring disorders differentially interact with effects of manipulability on naming. Furthermore, because we strictly matched lexical features between different types of stimuli, the overall number of items included in the naming test was relatively small. We felt that it was more crucial to match stimuli rigorously for lexical features than to include a larger set of stimuli, partly to exclude potential linguistic confounds and partly to avoid fatiguing our participants by requiring them to name a greater number of items.

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Table 1. Demographic, clinical and general cognitive data of the participants of the study.

Variable	nfvPPA	Control Group	p-value
N	12	9	-
Sex (% male)	50%	66.7%	0.445[b]
Age	68.25(±8.01)	66.38 (±4.69)	0.851[a]
Education (years)	15.75(±2.56)	17.44(±1.42)	0.111[a]
Handedness (% right)	83.3%	88.9%	0.719[b]
MMSE (30)	23.85(±6.36)	-	-
CDR (%)			
Normal	25%	-	-
Very mild dementia	58.3%	-	-
Mild dementia	16.7%	-	-
AOS rating (MSE, 7)	3.67 (±1.94)	-	-

AOS = apraxia of speech; MSE = motor speech evaluation; [a] Mann-Whitney U test; [b] Chi-Square test

Table 2 - Intergroup comparison of noun naming and verb naming and its subtests split according the semantic criteria of manipulability

Variable	**nfvPPA Group (n=12)**		**Control Group (n=9)**		**p-value**
	Mean (SD)	Median	Mean (SD)	Median	
Noun Naming (NN)	12.83 (3.93)	14.00	15.67 (0.71)	16.00	0.006*
Manipulable NN	6.58 (2.15)	7.50	7.78 (0.44)	8.00	0.193
Non-manipulable NN	6.25 (1.86)	7	7.89 (0.33)	8.00	0.002*
Verb Naming (VN)	10.75 (4.49)	11.50	15.22 (0.67)	15.00	0.002*
Manipulable VN	5.33 (2.71)	6	7.67 (0.50)	8.00	0.023*
Non-manipulable VN	5.42 2.15)	6	7.56 0.53)	8.00	0.002*
All Manipulable pictures	11.92 (4.66)	12.5	15.44 (0.53)	15.00	0.049*
All Non-manipulable pictures	12.25 (4.97)	14.00	15.44 (0.53)	15.00	0.003*

*p<0.05 Mann-Whitney U test

Figure 1 – Overlap of all nfvPPA showing the atrophic brain areas. Images are in neurological view (left = left).

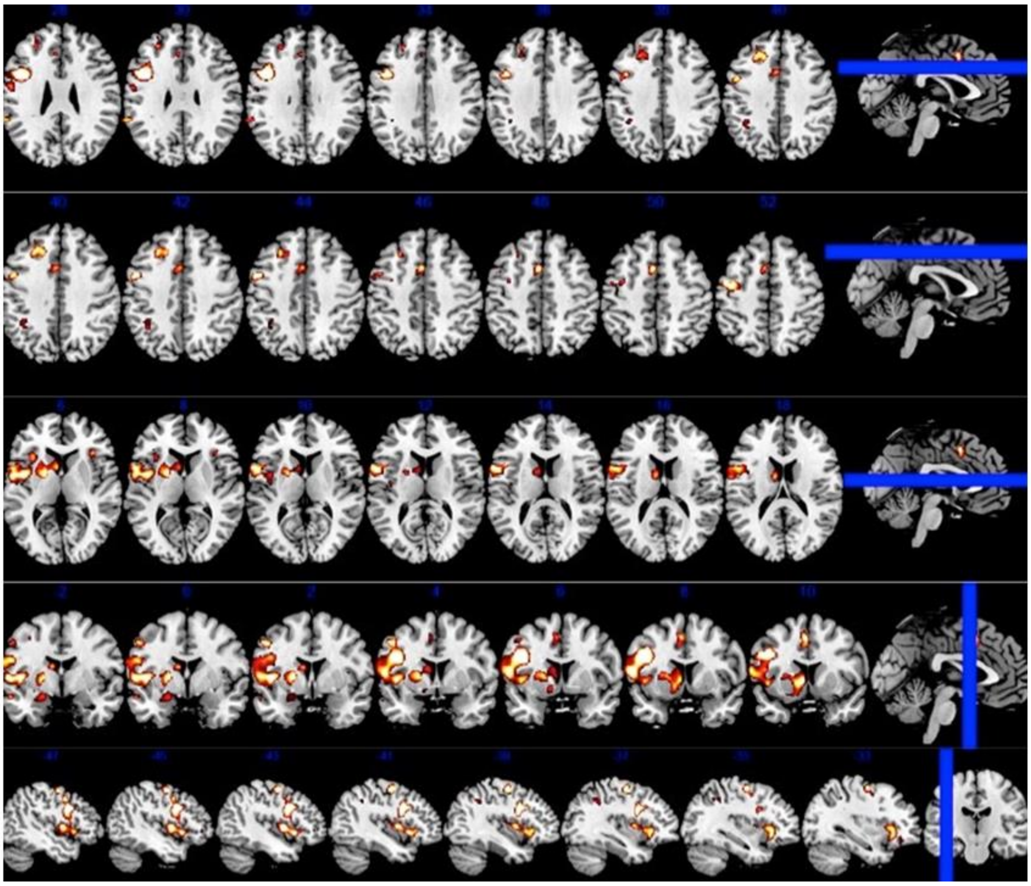
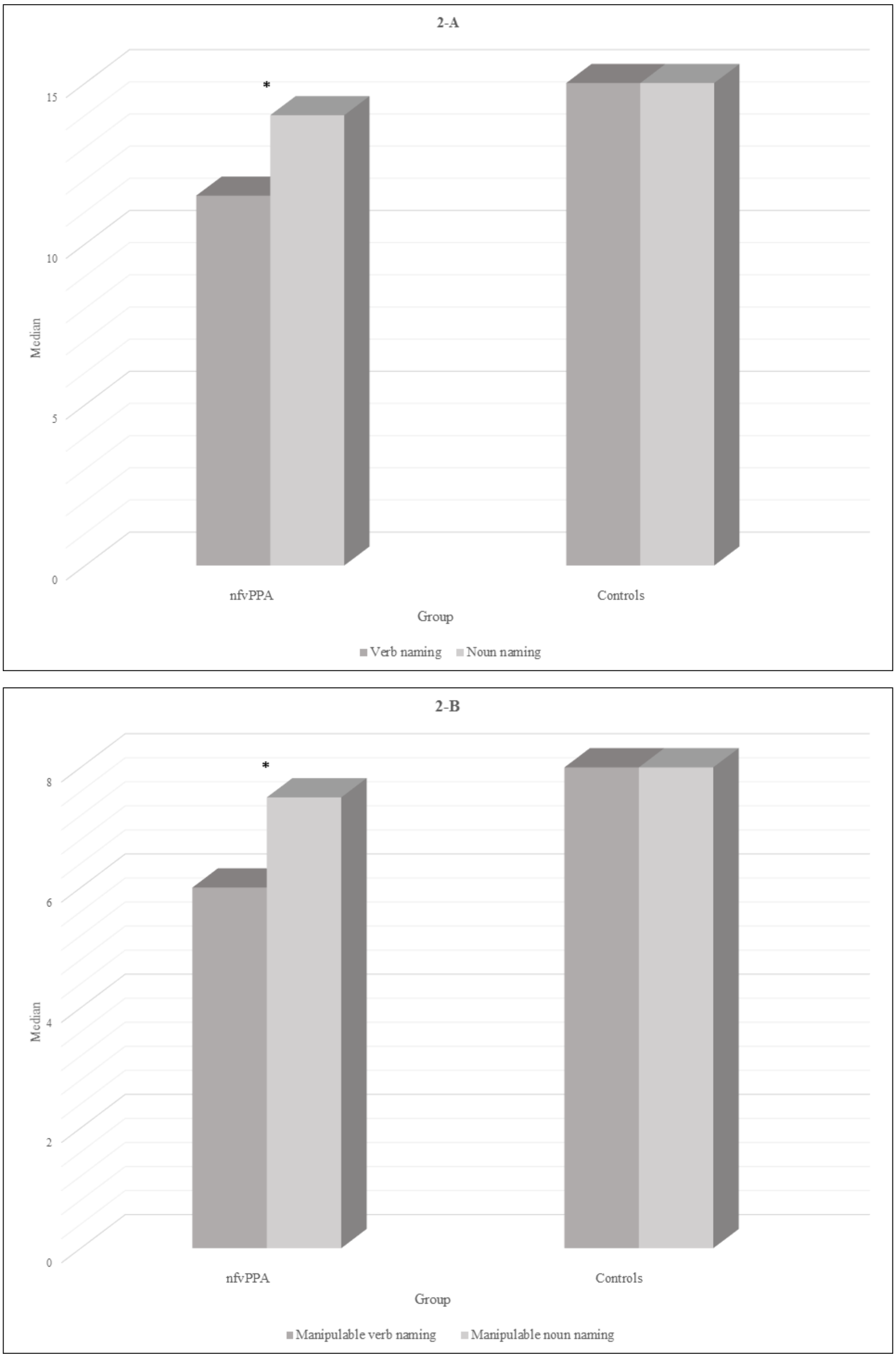
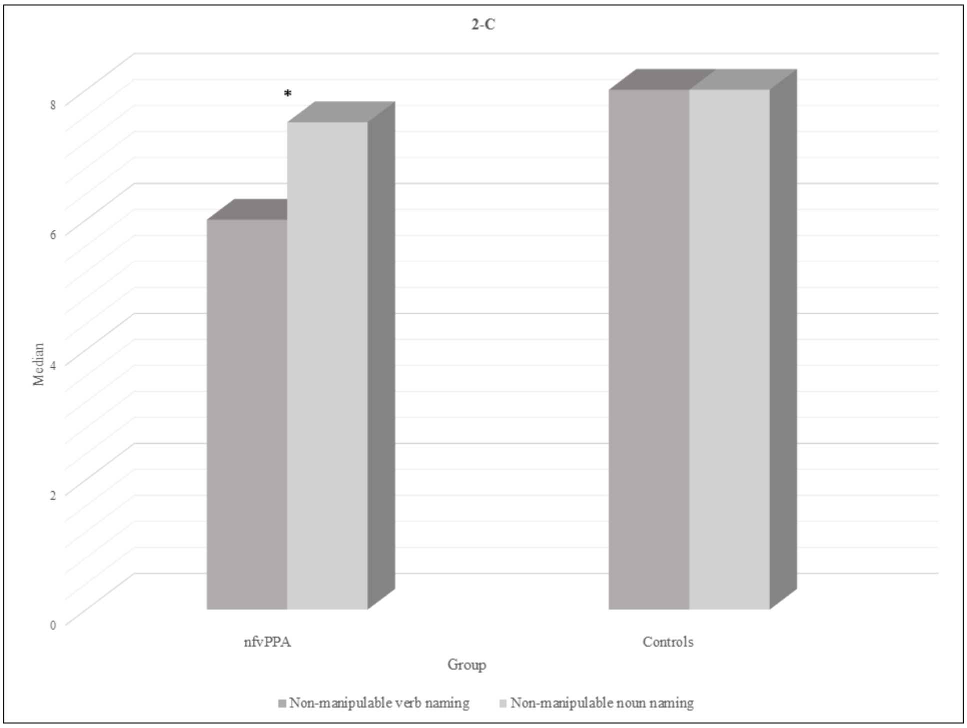


Figure 2 – Comparison between verb and noun naming tests and subsets in each group. * = p<0.05 Wilcoxon test.





2-C
*
Median
0
2
4
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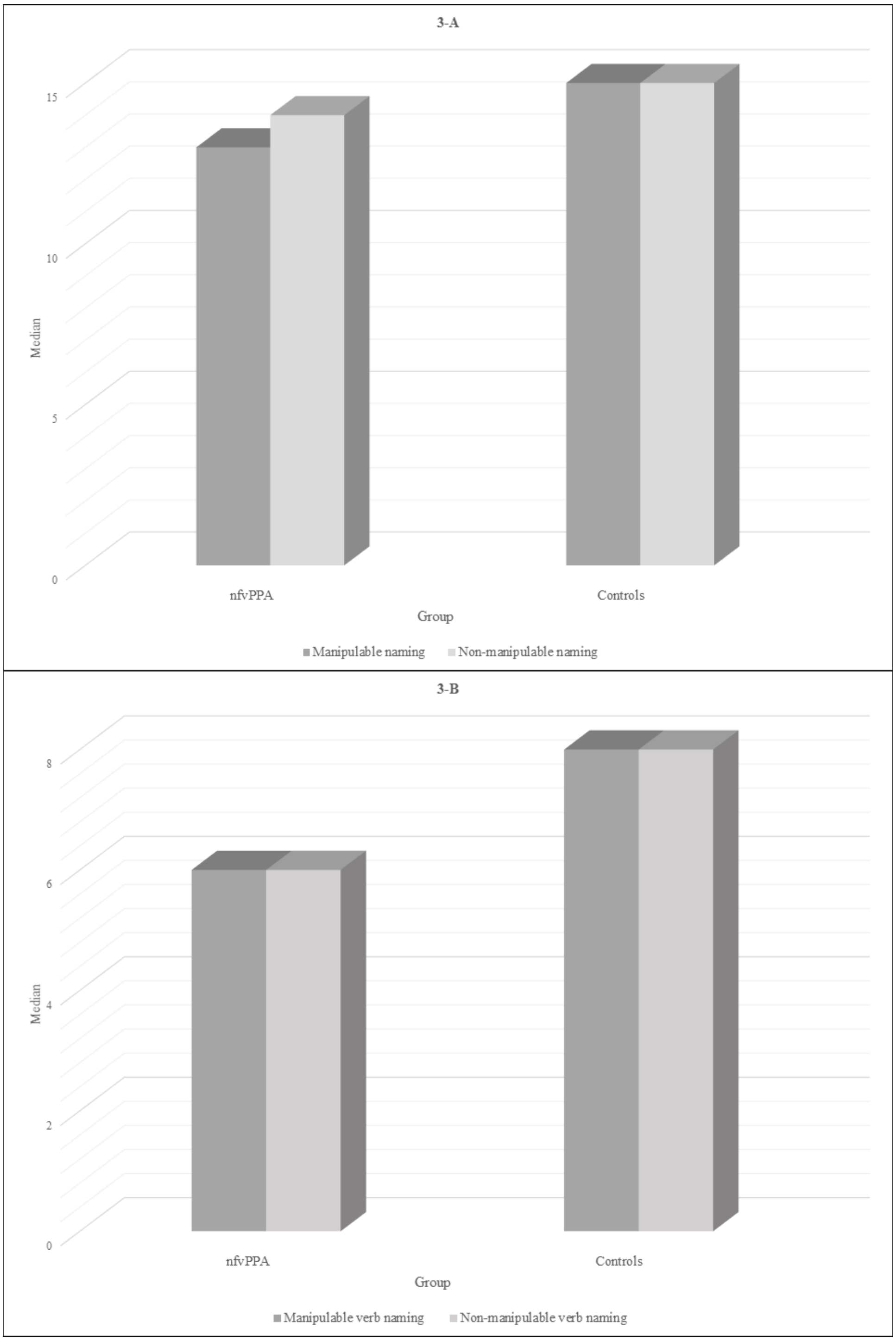
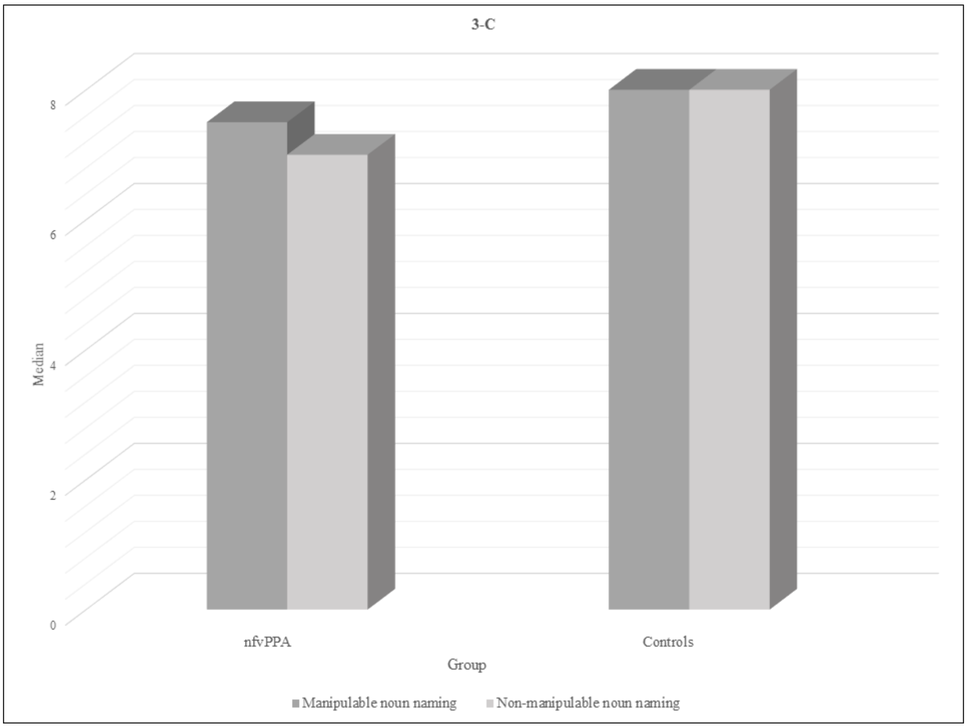
8
nfvPPA
Controls
Group
Non-manipulable verb naming
Non-manipulable noun naming

Figure 3 – Comparison between manipulable and non-manipulable naming tests and subsets in each group




3-C
Median
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nfvPPA
Controls
Group
Manipulable noun naming
Non-manipulable noun naming

APPENDICES

Appendix A - Description of object pictures of the noun naming test

Target Name	Manipul	Difficulty	Freq	Visual Comp	Syllables	Characters	Age of Acq	Familiarity
Comb	M	E	1.79	28324	1	4	1	-
Kite	M	E	1.79	17880	1	4	3	481
Drum	M	E	2.83	39085	1	4	3	506
Purse	M	E	2.4	21948	1	5	3	533
Package	M	D	3.04	29767	2	7	3	497
Faucet	M	D	1.1	17509	2	6	3	-
Shell	M	D	3.85	18590	1	5	3	524
Drill	M	D	2.20	16254	1	5	3	473
Bridge	NM	E	4.20	27543	1	6	3	561
Tent	NM	E	3.81	16963	1	4	3	521
Clock	NM	E	3.69	25639	1	5	1	608
Bed	NM	E	5.14	13761	1	4	1	636
Lizard	NM	D	1.61	12070	2	6	3	483
Vase	NM	D	2.08	20221	1	4	3	452
Waiter	NM	D	3.14	27418	2	6	3	-
Tank	NM	D	3.69	11180	1	4	3	511

M= manipulable; NM= non-manipulable; E=easy; D= difficult

Appendix B - Description of action pictures of the verb naming test

Target Name	Manipul	Difficulty	Freq	Visual Comp	Syllables	Characters	Age of Acq	Familiarity	Arguments
Brush	M	E	3.22	23911	1	5	3	579	2
Squeeze	M	E	3.37	17216	1	7	3	-	2
Iron	M	E	1.79	13323	2	4	3	555	2
Vacuum	M	E	0.69	30285	2	6	3	-	2
Erase	M	D	1.61	23620	2	5	3	-	2
Dip	M	D	2.89	20402	1	3	3	466	3
Mail	M	D	1.61	25541	1	4	3	554	3
Light	M	D	4.01	20907	1	5	3	575	2
Drip	NM	E	2.4	15971	1	4	3	-	1
Dance	NM	E	4.2	30516	1	5	1	550	2
Salute	NM	E	1.39	15575	2	6	3	479	2
Slide	NM	E	3.58	32449	1	5	3	529	1
Sweat	NM	D	2.89	16947	1	5	3	545	1
Wave	NM	D	3.83	15853	1	4	3	518	2
Fall	NM	D	5.69	26229	1	4	1	572	2
Kneel	NM	D	3.18	14002	1	5	3	-	1

M= manipulable; NM= non-manipulable; E=easy; D= difficult

Appendix C - Summary of psycholinguistic features of target words and its matching according word class and semantic category.

	Verb (n=16)		**Noun (n=16)**		
	Mean (SD)	Median	Mean (SD)	Median	p-value
Log Frequency	270.06 (139.72)	293.50	252.56 (149.33)	289.00	0.735[a]
Visual Complexity	21509 (7552)	19405	21421 (6263)	20654	0.972[a]
Length (syllables)	1.25 (0.45)	1.00	1.25 (0.45)	1.00	1.000[b]
Length (characters)	4.94 (1.00)	5.00	4.81 (0.98)	5.00	0.838[b]
Age of acquisition	2.62 (0.81)	3.00	2.75 (0.68)	3.00	0.780[b]
Familiarity	538.36 (37.53)	550.00	522.00 (52.87)	511.00	0.400[a]
	Manipulable (n=16)		**Non-manipulable (n=16)**		
	Mean (SD)	Median	Mean (SD)	Median	p-value
Log Frequency	219.00 (120.21)	199.50	303.62 (154.01)	338.00	0.093[a]
Visual Complexity	22785 (6600)	21427	20146 (6999)	16955	0.291[a]
Length (syllables)	1.31 (0.48)	1.00	1.19 (0.40)	1.00	0.564[b]
Length (characters)	4.94 (1.120)	5.00	4.81 (0.83)	5.00	0.809[b]
Age of acquisition	2.88 (0.5)	3.00	2.50 (0.89)	3.00	0.381[b]
Familiarity	522.09 (40.49)	524.00	535.77 (51.41)	529.00	0.483[a]

[a] t test; [b] Mann-Whitney U test; *p<0.05