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The Nonverbal Processing of Actions Is an Area of Relative Strength in the Semantic Variant of Primary Progressive Aphasia

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Purpose: Better performance for actions compared to objects has been reported in the semantic variant of primary progressive aphasia (svPPA). This study investigated the influence of the assessment task (naming, semantic picture matching) over the dissociation between objects and actions.
Method: Ten individuals with svPPA and 17 matched controls completed object and action naming tests, and object and action semantic picture matching tests. Performance was compared between the svPPA and control groups, within the svPPA group, and for each participant with svPPA versus the control group individually.
Results: Compared to controls, participants with svPPA were impaired on object and action naming, and object and action semantic picture matching. As a group, participants with svPPA had an advantage for actions over objects and for semantic picture matching tests over naming tests. Eight participants had a better performance for actions compared to objects in naming, with three showing a significant difference. Nine participants had a better performance for actions compared to objects in semantic picture matching, with six showing a significant difference. For objects, semantic picture matching was better than naming in nine participants, with five showing a significant difference. For actions, semantic picture matching was better than naming in all 10 participants, with nine showing a significant difference.
Conclusion: The nonverbal processing of actions, as assessed with a semantic picture matching test, is an area of relative strength in svPPA. Clinical implications for assessment planning and interpretation and theoretical implications for current models of semantic cognition are discussed.

The semantic variant of primary progressive aphasia (svPPA; also known as semantic dementia) is a severe impairment of semantic cognition that affects various aspects of behavior, most strikingly language (Gorno-Tempini et al., 2011; Lambon Ralph et al., 2017). Severe confrontation naming and single-word comprehension deficits are at the core of the clinical profile (Gorno-Tempini et al., 2011). However, according to some authors, the processing of specific categories of content, including digits, body parts, and actions, would be relatively spared in svPPA (Cappelletti et al., 2005; Coslett et al., 2002; Silveri et al., 2017).

An advantage for the semantic processing of actions compared to the semantic processing of objects has been reported in a number of studies of individuals with svPPA (Hillis et al., 2006, 2004; Silveri et al., 2017; Silveri & Ciccarelli, 2007, 2009; Silveri et al., 2003; Thompson et al., 2012; but see Cotelli et al., 2006; Marcotte et al., 2014; Pulvermüller et al., 2009). Words used to describe actions typically belong to the category of verbs, whereas words

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used to describe objects typically belong to the category of nouns. While some studies interpreted the difference in terms of an advantage for the grammatical category of verbs (Silveri & Ciccarelli, 2007; Silveri et al., 2003), more recent studies interpreted this difference based on these content's dissimilar reliance on specific sets of semantic features (Pulvermüller et al., 2009).

Actions would be defined chiefly in terms of motor features, which would be responsible for representing their specific properties: sequence, body parts involved, and so forth. On the contrary, objects would be defined mostly in terms of perceptual features: color, sound, smell, and so forth. (Pulvermüller, 2005, 2017; Pulvermüller et al., 2009, 2005). The representation of these different features would be ensured by specific regions of the brain involved in the planning and execution of movements and in sensory perception, respectively (Lambon Ralph et al., 2017; Patterson et al., 2007). While there is broad consensus about this idea (Barsalou, 2008; Binder & Desai, 2011; Binder et al., 2009; Kiefer & Pulvermüller, 2012; Martin & Chao, 2001; Patterson et al., 2007), the necessity to define an area responsible for tying together all those different features into coherent concepts is more controversial (Meteyard et al., 2012).

svPPA is consistently associated with marked atrophy of the anterior temporal lobe (ATL; Gorno-Tempini et al., 2011; Lambon Ralph et al., 2017). Atrophy is bilateral, although asymmetric, and tends to progress to lateral regions of the temporal lobe and to the frontal lobe as the disease progresses (Macoir et al., 2017; Montembeault et al., 2018). Considering that svPPA is consistently associated with ATL atrophy and that it is characterized by profound semantic impairment, the ATL has been identified as a "semantic hub," an area that would be essential to make coherent concepts out of individual features, as well as to categorize and compare concepts (Lambon Ralph et al., 2017; Patterson et al., 2007).

The coexistence of several feature-specific areas with one dedicated semantic area has been summarized in the "hub-and-spoke" model of semantic cognition (Patterson et al., 2007) and integrated in the revised controlled semantic cognition framework (Lambon Ralph et al., 2017). In the case of svPPA, the model predicts generalized semantic impairment, affecting all categories of content. While this seems a priori incompatible with the dissociations between objects and actions reported in previous studies, the bilateral distribution of semantic processing in the brain and dispersion of the different spokes helps reconcile those findings with the hub-and-spoke model.

Objects and actions can be contrasted based on their different reliance on specific sets of semantic features, namely, perceptual features and motor features, which are supported by different brain areas (Lambon Ralph et al., 2017; Patterson et al., 2007; Pulvermüller et al., 2009). Perceptual features are represented in different portions of the temporal lobes, for example, the superior temporal gyrus (sounds) and the inferior temporal gyrus (shapes; Lambon Ralph et al., 2017; Patterson et al., 2007; Pulvermüller et al., 2009). The location and relative importance of areas that subtend the representation of motor features important for action words remain controversial (Watson et al., 2013). Several areas have been associated with their processing, such as the motor and premotor cortex (Kiefer & Pulvermüller, 2012; Pulvermüller, 2005; Pulvermüller et al., 2009, 2005) and supplementary motor area and presupplementary motor area (Courson et al., 2017; Postle et al., 2008). All of these areas share the characteristic of being located at a greater distance from the ATL than areas responsible for perceptual features. The importance of the relative distance of spokes from the hub is coherent with the proposition of a "graded hub," centered on the ventrolateral ATL (Lambon Ralph et al., 2017). Subregions of the ATL closest to each sensory input (e.g., visual, auditory) would become specialized in processing that type of information, whereas the ventrolateral region would remain equally involved in the processing of all input types (Lambon Ralph et al., 2017). In svPPA, not only the area responsible for general semantic processing will be impaired but also areas most specialized in the processing of perceptual features. Areas responsible for motor features would be relatively spared and less likely to be affected even as disease progresses. This idea was supported by a study of individuals with svPPA (Pulvermüller et al., 2009) in which performance for actions involving face movements and speech acts (subtended by the inferior portion of the posterior frontal lobe) was worse than for actions involving the hands and arms (dorsolateral posterior frontal lobe). In summary, objects, which depend highly on perceptual features represented in areas close to the hub, would be more impaired than actions, which depend highly on motor features represented in areas located at a greater distance from the hub.

However, results regarding the dissociation between objects and actions have been inconsistent, and studies have reported equivalent performance for the two categories (Cotelli et al., 2006; Marcotte et al., 2014; Pulvermüller et al., 2009). While svPPA constitutes a generalized semantic impairment affecting all tasks and types of material, it is possible that tasks involving words, and more particularly naming tests, are more difficult in svPPA. Therefore, they may be less useful to reveal differences between categories. Naming tests require the participant to process a visual stimulus, access its specific semantic features, combine them to identify a concept, and produce its related phonological word form. When using a picture matching test instead of a naming test, all the previously mentioned steps are involved, except the production of a phonological word form. This difference is important because the temporal areas and structures responsible for encoding the word form and connecting it to the semantic hub are close to, or overlap with, the area of maximal atrophy in svPPA (Bajada et al., 2015; Lambon Ralph et al., 2017; Pulvermüller et al., 2009). Critically, in contrast to other processes described above, accessing the word form depends strongly on the left hemisphere, while other processes are distributed bilaterally. However, the right ATL plays an important role in visual processing, and right-lateralized atrophy is associated with semantic impairments in the visual modality (e.g., prosopagnosia; Lambon Ralph et al., 2017; Snowden et al., 2018). Accessing specific word forms from different categories of content is difficult in svPPA, especially in individuals with left-lateralized atrophy. Tasks that do not require the production of a word form would be relatively easier, a finding that has been reported in the past (Lambon Ralph et al., 2017; Mion et al., 2010; Snowden et al., 2018).

A better understanding of the implications of using a naming versus a semantic picture matching task could improve the clinical utility of comparing objects to actions in svPPA. Studies that compared the performance of different PPA groups show that patterns differ across variants. While patients with svPPA show an advantage for actions over objects, the opposite pattern is observed in the nonfluent/agrammatic variant of PPA (nfaPPA; Cotelli et al., 2006; Hillis et al., 2006, 2004; Silveri & Ciccarelli, 2007; Thompson et al., 2012). Since nfaPPA is characterized by word-finding difficulties, but not with semantic impairment, this difference is usually observed in naming (oral and written; Hillis et al., 2006, 2004; Silveri & Ciccarelli, 2007) but not in other tasks, such as single-word comprehension (Cotelli et al., 2006; Thompson et al., 2012). Importantly, patients with nfaPPA perform near or at ceiling in semantic picture matching tasks, whether they target objects or actions (Hillis et al., 2006). Participants with the logopenic variant of PPA show no difference between objects and actions in naming and no comprehension difficulties (Thompson et al., 2012), which is coherent with the impairment of phonological/lexical processing and the preservation of semantic processing in this variant. Therefore, an advantage for actions over objects in semantic picture matching could be specifically associated with svPPA.

This study aimed to investigate the dissociation between the processing of objects and the processing of actions in svPPA and how this dissociation is influenced by the task used to assess these categories of content. To account for variability across participants, the analysis of general differences at the group level was complemented by a detailed analysis of differences between pairs of tests in individual participants. The results have several clinical implications for assessment planning and result interpretation in svPPA. Theoretical implications are discussed in relation to current neurobiological models of semantic cognition.

Method

Participants

Ten individuals (three women, seven men) with a clinical diagnosis of svPPA (semantic dementia) based on the Gorno-Tempini et al. (2011) criteria were recruited in 2013 and 2014 to participate in a study on inflectional and derivational morphology (Auclair-Ouellet, Fossard, et al., 2016; Auclair-Ouellet, Macoir, et al., 2016). This study was approved by the research ethics board at the Centre de Recherche de l'Institut Universitaire en Santé Mentale de Québec, the Centre Hospitalier Universitaire de Québec, and the Centre de Recherche de l'Institut Universitaire de Gériatrie de Montréal. It was conducted according to the principles of the Declaration of Helsinki, and all participants provided informed consent in writing to participate.

All participants with svPPA were native speakers of Québec French, were aged between 53 and 78 years (M = 66.2, SD = 7.55), and had between 10 and 24 years of education (M = 15.3, SD = 4.3). On anatomical brain imaging, all participants showed signs of bilateral ATL atrophy. Five participants had more prominent atrophy in the left hemisphere, two participants had more prominent atrophy in the right hemisphere, and three participants had similar atrophy in both hemispheres. Anatomical magnetic resonance imaging scans from six participants were available and are presented in Figure 1. All scans were collected for clinical purposes on 1.5-T scanners.

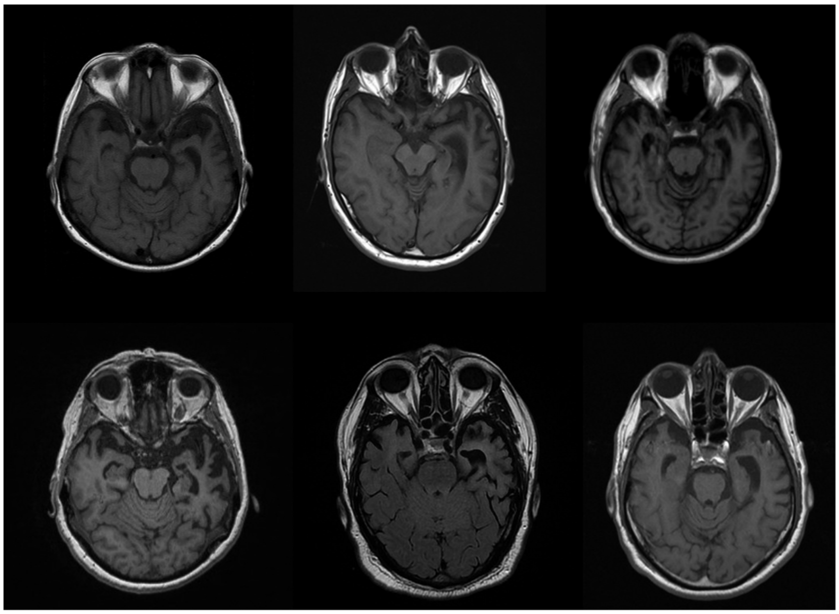
For each individual with svPPA, two healthy participants matched for age, sex, and education were recruited to form the control group, for a total of 20 participants (six women, 14 men). Participants provided comparison data for the experimental tasks included in the original study, as well as for tests for which there are no norms in the same population. The composition of the neuropsychological battery is detailed in the next section. One healthy participant had a low score on the experimental action naming test (83% correct). His performance on the pseudoword reading test was also very low (6/15), which raised concerns about his overall language capacities.

The distribution of control group scores on the experimental action naming test was examined in order to determine statistically if the performance of this participant was within the range of typical control performance. To this end, we calculated the standardized deviation of each observation from a robust measure of location and compared them to a predetermined cutoff value (3.5). We used a procedure based on deviations from the median of the raw values standardized by the Sn estimator (Maronna et al., 2006; Rousseuw & Croux, 1993). This approach is more robust to distribution asymmetry than the usual approach based on the median absolute deviation estimator (Leys et al., 2013). The procedure was performed using the robustbase package in R (Maechler et al., 2019). The deviation of the observation in question was 3.8 (> 3.5), whereas the deviations from the other control participants ranged from 0.14 to 1.82.

Controls usually obtain high scores in naming tests (Strauss et al., 2006). Based on this participant's low result in naming and pseudoword reading and on the result of the statistical procedure described above, this participant's profile was not considered representative of normal control performance and he was excluded from further analyses.

Two other participants did not complete the Pyramids and Palm Trees Test (PPTT; Howard & Patterson, 1992) due to lack of time. Because of the small sample size, it was judged preferable not to replace missing values using imputation methods. Furthermore, the Bayesian inference method used to investigate the difference between pairs of tests required sample sizes to be equal, so only complete observations

Figure 1. Anatomical brain scans. Top row, from left to right: P1, P2, and P3. Bottom row, from left to right: P4, P5, and P6. Montreal Neurological Institute coordinates (spatial normalization, 12 degrees of freedom), P1: $z = -26$; P2: $z = -25$; P3: $z = -25$; P4: $z = -26$; P5: $z = -12$; P6: $z = -11$.



were included in the analysis. Therefore, analyses were completed with the remaining sample of 17 control participants.

Participants in the control group were aged between 52 and 80 years (*M* = 66.06, *SD* = 6.74) and had between 11 and 20 years of education (*M* = 15.76, *SD* = 2.82). Control participants had scores within the normal range on global cognition screening tests (Montreal Cognitive Assessment [MoCA], Mini-Mental State Examination) and did not report any cognitive change or complaint. The groups were well matched for age (svPPA: *Mdn* = 68; control: *Mdn* = 67; Mann–Whitney *U* = 82.5, *p* = .9) and education (svPPA: *Mdn* = 14.5; control: *Mdn* = 17; Mann–Whitney *U* = 74, *p* = .577).

Neuropsychological and Language Testing

The participants completed a comprehensive neuropsychological battery that assessed global cognition (MoCA; Larouche et al., 2016; Nasreddine et al., 2005), visuoconstructional skills and visual memory (Rey–Osterrieth Complex Figure [ROCF]; Meyers & Meyers, 1995; Tremblay et al., 2015), visual discrimination and visual knowledge for objects (Birmingham Object Recognition Battery [BORB]; Humphreys & Riddoch, 1993; St-Hilaire, Blackburn, et al., 2018), verbal short-term and working memory (Digit Span; Wechsler et al., 2008), processing speed and inhibition (Trail Making Test [TMT]; Reitan, 1955; St-Hilaire, Parent, et al., 2018), execution of gestures (praxis; Joanette et al., 1995), verbal fluency (Joanette et al., 2004), and reading.

Participants also completed the Test de Dénomination de Québec, 60 items (TDQ-60; Macoir et al., 2018), an object naming test that consists of 60 colorized pictures showing everyday objects (fruits, vegetable, tools, animals, etc.; cherry, onion, knife, cow, etc.); an experimental action naming task (hereafter ANT; Routhier et al., 2015) that consists of 100 short videos (5 s) showing people performing actions (done with the hands, the feet, or the mouth; to fold, to step on, to chew, etc.); the PPTT (Callahan et al., 2010; Howard & Patterson, 1992), a test that consists of 52 triplets of pictures representing objects that need to be matched based on semantic association; and the Kissing and Dancing Test (KDT; Bak & Hodges, 2003), a test that was developed off the PPTT and that includes 52 triplets of pictures representing actions that need to be matched based on semantic association. TDQ-60 and ANT target words were not different in terms of spoken (TDQ-60: *M* = 36.56, *SD* = 70.21; ANT: *M* = 28.05, *SD* = 39.27) Welch test, *F*(1, 81.52) = 0.705, *p* = .403, and written (TDQ-60: *M* = 61.15, *SD* = 171.84; ANT: *M* = 44.41, *SD* = 48.99), Welch test, *F*(1, 64.81) = 0.543, *p* = .464, lemma frequency (Lexique; New et al., 2001). Each svPPA participant's results, atrophy lateralization, and sociodemographic characteristics are reported in Table 1.

Statistical Analysis

Between-group difference on the TDQ-60, the ANT, the PPTT, and the KDT was tested using a nonparametrical test for independent samples (Mann–Whitney *U* test, α = .05). Within-group difference for participants with svPPA on the TDQ-60 versus the ANT, the PPTT versus the KDT, the TDQ-60 versus the PPTT, and the ANT versus the KDT was tested using a nonparametrical test for paired samples (Wilcoxon signed-ranks test, α = .05).

Table 1. Individual scores on the neuropsychological battery and language tests.

Variable	1	2	3	4	5	6	7	8	9	10	Impairment Threshold
Sex	F	M	M	F	M	M	M	F	M	M	
Age	72	53	78	69	61	73	61	68	68	59	
Education (years)	12	13	16	12	24	12	19	18	17	10	
Manual dominance	R	R	R	R	R	R	R	R	R	R	
Anterior temporal lobe atrophy	L > R	L > R	=	=	L > R	L > R	=	R > L	L > R	R > L	
MoCA (30)	24	19[a]	20[a]	13[a]	21[a]	15[a]	15[a]	18[a]	19[a]	20[a]	Larouche et al., 2016
ROCF											Tremblay et al., 2015[b]
ROCF - Copy (36)	32	32	29.5	32	34	29.5	29.5	36	30	31.5	
ROCF - Short-term Recall (3 min) (36)	5.5	13	12.5	0[a]	2[a]	10	10	9	27	13	
ROCF - Delayed Recall (20 min) (36)	NA	NA	NA	NA	2[a]	15	8	11	27	13	
BORB											
BORB - Line Length Judgment (30)	21[a]	25	28	27	27	28	26	25	27	26	Control Group (< 23.44)
BORB - Object Decision, List A (32)	20[a]	25	18[a]	15[a]	23	21	15[a]	18[a]	25	21[a]	St-Hilaire, Blackburn, et al., 2018
Gestures											Joanette et al., 1995
Meaningless Gestures (35)	28	29[a]	30	23[a]	33	32	30	32	27[a]	30	
Meaningful Gestures (35)	26[a]	20[a]	28	0[a]	35	15[a]	14[a]	29	30	22[a]	
DS											Wechsler et al., 2008
DS Forward, Longest Span	6	7	5	6	6	7	5	6	6	7	
DS Backward, Longest Span	6	6	4	5	5	4	4	4	2	5	
DSF-LS/DSB-LS	0	1	1	1	1	3	1	2	4	2	
TMT											St-Hilaire, Parent, et al., 2018
TMT-A (s)	36	23	58	102[a]	45	80[a]	53	50	52	52	
TMT-B (s)	99	41	90	250[a]	97	137	104	96	134	233[a]	
Fluency											Joanette et al., 2004
Verbal fluency - free, 150 s	40[c]	29[c]	24[c]	2[c]	38[c]	15[c]	19[c]	31[c]	18[c]	26[c]	
Verbal fluency - letter “p”, 120 s	9[c]	6[c]	14[c]	3[c]	11[c]	9[c]	7[c]	9[c]	11[c]	4[c]	
Semantic fluency - clothes, 120 s	16[c]	6[c]	6[c]	0[c]	4[c]	1[c]	8[c]	14[c]	3[c]	7[c]	
Word reading (24)	24	23	24	14[d]	21[d]	18[d]	21[d]	24	24	17[d]	Control Group[d] (< 21.6)
Non-word reading (15)	11	8[a]	9	9	11	9	12	12	11	7[a]	Control Group (< 8.77)
TDQ-60 (60)	38[a]	29[a]	37[a]	3[a]	25[a]	4[a]	16[a]	31[a]	38[a]	32[a]	Macoir et al., 2018
ANT (100)	66[a]	66[a]	72[a]	7[a]	64[a]	34[a]	24[a]	57[a]	40[a]	46[a]	Control Group (< 90.32)
PPTT (52)	42[a]	37[a]	37[a]	30[a]	40[a]	7[a]	29[a]	22[a]	39[a]	35[a]	Callahan et al., 2010
KDT (52)	38[a]	42[a]	37[a]	24[a]	44[a]	35[a]	40[a]	37[a]	47	30[a]	Control Group (< 44.88)

Note. F = female; M = male; R = right, L = left; MoCA = Montreal Cognitive Assessment; ROCF = Rey–Osterrieth Complex Figure; BORB = Birmingham Object Recognition Battery; DS = Digit Span; DSF-LS = Digit Span Forward–Longest Span; DSB-LS = Digit Span Backward–Longest Span; TMT = Trail Making Test; TDQ-60 = Test de Dénomination de Québec, 60 items; ANT = Action Naming Task; PPTT = Pyramids and Palm Trees Test; KDT = Kissing and Dancing Test.

[a] z score < −2 corrected for sex and/or age and/or education where appropriate. [b] Copy time was not available, which prevented the use of formulas correcting for sex, age, and education. Means and standard deviations reported in Tremblay et al. (see Table 2) with a threshold of $z = -2$ were used. [c] Raw score at the point of alert or lower (10th percentile). [d] All participants of the control group had a score of 24/24. Scores were lower than 90% accuracy.

The presence of a dissociation between object and action tests (in naming and semantic picture matching) and naming and semantic picture matching tests (for objects and for actions) in each participant with svPPA was tested using a single-subject Bayesian dissociation test (DissocsBayes_ES; Crawford & Garthwaite, 2007; Crawford et al., 2010). In cognitive neuropsychology, dissociations have traditionally been identified when a patient had an impairment on a Task X and preserved performance on a Task Y (Coltheart, 2001). However, this conclusion relies on a test for the null hypothesis (i.e., the absence of difference between the patient and the control group on Task Y), and it could be spurious if both scores are close to the normality threshold (Crawford & Garthwaite, 2007; Crawford et al., 2010). Crawford and colleagues (Crawford & Garthwaite, 2007; Crawford et al., 2010) have developed frequentist (i.e., traditional statistics) and Bayesian methods to test the difference between two scores from the same case directly. The methods also include tests to determine the presence of a dissociation following the traditional approach of cognitive neuropsychology.

In this study, the Bayesian approach was chosen to conclude to the presence of a dissociation. The advantage of using Bayesian inference over frequentist statistics has been described in Crawford and Garthwaite (2007). Importantly, the Bayesian approach is better suited to account for uncertainty when patients obtain scores that depart largely from normality (i.e., which are several standard deviations below the mean of the control group, which is the case of scores obtained by individuals with svPPA in naming and semantic matching tests). Furthermore, the Bayesian test provides point estimates of the abnormality of the difference between the two scores, which correspond to the percentage of the control population that would exhibit a more extreme difference between the two tests. Thus, Bayesian inference provides a useful and accessible interpretation of the difference between two tests for a single case.

The steps involved in DissocsBayes_ES are briefly described below (see Crawford & Garthwaite, 2007, for a tutorial and complete example). First, the difference between each individual with svPPA and the control group for each of the two tests was tested using a frequentist test (Crawford & Howell, 1998). Crawford and Garthwaite (2007) explain that the frequentist Crawford and Howell (1998) test is used for computational convenience, having established that the frequentist and Bayesian methods give equivalent results when testing for the difference between a case and the control group, while they are not equivalent when testing the dissociation between two tests for the same case. Then, the Bayesian Standardized Difference Test is used to test whether the difference between the patient's standardized score (*z* score) on each of the two tests is large enough to reject the null hypothesis that the difference belongs to the control group's distribution of differences (Crawford & Garthwaite, 2007; Crawford et al., 2010). The significance threshold used at each step is $\alpha = .05$ (i.e., a difference that is not observed by chance 95% of the time for frequentist tests and a difference that is more extreme than 95% of differences in the control group for Bayesian inference). Following the analysis, two types of dissociations can be observed (Crawford & Garthwaite, 2007; Crawford et al., 2010). A "putatively classical" dissociation is observed when the patient is impaired on only one of the tests and the difference between each test's standardized score is abnormal. A "strong dissociation" is observed when the patient is impaired on both tests and the difference between each test's standardized score is abnormal.

Results

Neuropsychological Tests

Table 1 provides a comparison of each svPPA participant's score to published norms from samples of the same population, when possible, and to this study's control group when norms were not available. Group averages have been reported elsewhere (Auclair-Ouellet, Fossard, et al., 2016; Auclair-Ouellet, Macoir, et al., 2016).

All scores on the MoCA were below the suggested cutoff of 26 (Nasreddine et al., 2005). However, P1's score was within the normal range ($z = -0.83$) when compared to a normative sample from the same population (Larouche et al., 2016). All participants with svPPA had good visuoconstructional skills on the ROCF copy (Tremblay et al., 2015). Only one participant, P1, had a low visual discrimination score compared to the control group on the Line Length Judgement subtest of the BORB. Two participants (P4 and P5) had a visual memory deficit on the ROCF recall after 3 min, and of those who completed the long delay (20 min) recall condition, one participant (P5) had a deficit (Tremblay et al., 2015). Six participants had impaired visual object knowledge on the BORB Object Decision subtest, List A (St-Hilaire, Blackburn, et al., 2018).

Three participants had deficits imitating meaningless gestures, whereas six were impaired at executing meaningful gestures following a verbal command (e.g., do the gesture of looking through binoculars; Joanette et al., 1995). All participants had normal verbal short-term and working memory on the Digit Span test, shown by normal forward and backward longest spans, and normal difference between the two conditions (Wechsler et al., 2008). Two participants had processing speed deficits (TMT-A), and two participants had flexibility deficits (TMT-B; St-Hilaire, Parent, et al., 2018). All participants were impaired in unconstrained (free) and letter verbal fluency (Joanette et al., 2004). All participants were also impaired in semantic verbal fluency, although P1's score could be considered as borderline (at the 10th percentile). Five participants had low word reading accuracy, and two had difficulties with nonword reading compared to the control group.

Except for P9 whose score on the KDT was within the normal range compared to the control group, all participants were impaired on object naming (Macoir et al., 2018), action naming (compared to the control group), object picture semantic matching (Callahan et al., 2010), and action picture semantic matching (compared to the control group).

Naming and Semantic Matching Tests

Each group's average performance expressed as percentage of correct answers and standard scores (*z* scores) on the TDQ-60, ANT, PPTT, and KDT is reported in Table 2. Participants with svPPA had lower scores than control participants on all four tests (all ps $< .001$). When using the percentage of correct answers on each task, within-group comparisons of the participants with svPPA on the TDQ-60 versus the ANT and on the PPTT versus the KDT revealed no difference (all ps $> .05$). However, the comparison of standard scores showed that performance on the TDQ-60 was lower than on the ANT ($p < .05$) and performance on the PPTT was lower than on the KDT ($p < .01$). Comparisons of standard scores also showed that performance was lower on the naming task than on the picture matching task for the category of objects (TDQ-60 < PPTT, $p < .01$) and the category of actions (ANT < KDT, $p < .01$).

Difference Between Objects and Actions

Dissociation tests compared the TDQ-60 to the ANT, and the PPTT to the KDT, respectively. Each individual with svPPA's score expressed as percentage of correct response and standardized score (*z* score) on the TDQ-60 and the ANT are reported in Table 3. Results for the PPTT and KDT are reported in Table 4. The *z* score for each

Table 2. Performance on object and action naming as well as object and action semantic picture matching in the semantic variant of primary progressive aphasia (svPPA) group and the control group.

	svPPA (*n* = 10)								
	Percentage correct			**Standard score**			**Control (*n* = 17)**		
Test	***M***	***SD***	**Range**	***M***	***SD***	**Range**	***M***	***SD***	**Range**
TDQ-60	42.17*	22.14	5 to 63.33	−20.00	8.11	−33.61 to −12.25	96.76	2.73	91.67 to 100
ANT	47.60*	21.29	7 to 72	−16.06	6.99	−29.39 to −8.04	96.47	3.04	90 to 100
PPTT	61.15*	20.37	13.46 to 80.77	−12.06	6.86	−28.13 to −5.45	96.95	2.97	90.38 to 100
KDT	71.92*	12.89	46.15 to 90.38	−5.75	3.36	−12.47 to −0.94	94	3.84	86.54 to 100

Note. TDQ-60 = Test de Dénomination de Québec, 60 items; ANT = Action Naming Task; PPTT = Pyramids and Palm Trees Test; KDT = Kissing and Dancing Test.

*Significant difference compared to the control group, $p < .05$.

testcan be interpreted as the effect size of the difference between the case and control groups on that test. The difference in z scores between the TDQ-60 and the ANT and between the PPTT and KDT is also reported (Δz), along with the Bayesian point estimate of significance for the difference between z scores. When multiplied by 100, this value can be interpreted as the percentage of controls who would exhibit a larger difference in any direction. As suggested by Crawford and Garthwaite (2007) and coherent with the standard approach of rejecting the null hypothesis when $p < .05$, a difference was considered "significant" (i.e., unexpected based on the distribution of differences in controls or "abnormal" for short; Crawford & Garthwaite, 2007; Crawford et al., 2010) when a more extreme difference would be observed in less than 5% of controls. The estimated percentage of controls who would obtain a more extreme difference in the same direction as the participant with svPPA is given in column %CMED (controls with more extreme difference), along with the 95% credible interval for the abnormality of the difference. The interpretation of credible intervals in the Bayesian approach differs from the traditional frequentist interpretation of confidence intervals (see Crawford & Garthwaite, 2007; Crawford et al., 2010). When interpreting Bayesian credible intervals, it is possible to state that there is a 95% probability that the case's true level of abnormality falls within the interval.

All participants with svPPA were impaired on the TDQ-60 and the ANT compared to this study's control group using the Crawford and Howell (1998) test (all *p*s < .001). The correlation between these tests in controls was $r = .521$, $p < .05$. Eight participants with svPPA out of 10 (P1–P8) had a lower standardized score on the TDQ-60 compared to the ANT. The difference between the tests' standardized score was abnormal in three out of eight participants (P2, P5, and P6). Since they were impaired on both tests, this difference can be interpreted as a "strong dissociation" (Crawford & Garthwaite, 2007). The percentage of control participants who would show a more extreme

Table 3. Individual percentage of correct answers, standardized scores, and differences in object and action naming in semantic variant of primary progressive aphasia.

	TDQ-60				**ANT**				**Difference**				
Participant	**%**	***z* (ES)**	**95% CI L**	**95% CI H**	**%**	***z* (ES)**	**95% CI L**	**95% CI H**	**Δ*z***	**PE (*p*)**	**% CMED**	**95% CI L**	**95% CI H**
1	63.33*	−12.25	−16.47	−8.02	66*	−10.01	−13.47	−6.54	−2.24	.381	19.05	0.00	99.17
2	48.33*	−17.74	−23.84	−11.94	66*	−10.01	−13.47	−6.54	−7.73	**.015**	0.74	0.00	3.70
3	61.67*	−12.86	−17.28	−8.42	72*	−8.04	−10.83	−5.24	−4.82	.051	2.53	0.00	34.32
4	5*	−33.61	−45.14	−22.08	7*	−29.39	−39.48	−19.30	−4.22	.529	26.44	0.00	100.00
5	41.67*	−20.18	−27.11	−13.24	64*	−10.67	−14.35	−6.98	−9.51	**.007**	0.33	0.00	0.23
6	6.67*	−33.00	−44.32	−21.67	34*	−20.52	−27.57	−13.47	−12.48	**.032**	1.57	0.00	11.12
7	26.67*	−25.68	−34.49	−16.86	24*	−23.81	−31.98	−15.63	−1.87	.724	36.20	0.00	100.00
8	51.67*	−16.52	−22.20	−10.83	57*	−12.97	−17.43	−8.49	−3.55	.278	13.91	0.00	99.49
9	63.33*	−12.25	−16.47	−8.02	40*	−18.55	−24.93	−12.17	6.30	.067	3.34	0.00	55.69
10	53.33*	−15.91	−21.38	−10.43	46*	−16.58	−22.28	−10.87	0.67	.851	42.54	0.00	100.00

Note. Abnormal differences between z scores are shown in bold. TDQ-60 = Test de Dénomination de Québec, 60 items; ANT = Action Naming Task; z (ES) = z score and effect size for the difference with the control group; 95% CI L = 95% credible interval, lower bound; 95% CI H = 95% credible interval, higher bound; Δz = difference between z scores (TDQ-60 − ANT); PE (p) = point estimate of the abnormality of difference between z scores; %CMED = percentage of control participants with a more extreme difference in the same direction as the participant with the semantic variant of primary progressive aphasia.

*Significant difference compared to controls, $p < .05$.

Table 4. Individual percentage of correct answers, standardized scores, and differences in object and action semantic picture matching in semantic variant of primary progressive aphasia.

	PPTT				KDT				Difference				
Participant	%	*z* (ES)	95% CI L	95% CI H	%	*z* (ES)	95% CI L	95% CI H	Δ*z*	PE (*p*)	% CMED	95% CI L	95% CI H
1	80.77*	–5.45	–7.37	–3.52	73.08*	–5.45	–7.37	–3.52	0.00	.999	49.99	2.04	97.93
2	71.15*	–8.69	–11.71	–5.67	80.77*	–3.45	–4.71	–2.17	–5.24	**.012**	0.62	0.00	6.24
3	71.15*	–8.69	–11.71	–5.67	71.15*	–5.95	–8.04	–3.85	–2.74	.228	11.39	0.00	72.76
4	57.69*	–13.23	–17.78	–8.66	46.15*	–12.47	–16.76	–8.16	–0.76	.824	41.21	0.00	99.99
5	76.92*	–6.75	–9.10	–4.38	84.62*	–2.45	–3.40	–1.47	–4.30	**.019**	1.00	0.03	7.07
6	13.46*	–28.13	–37.78	–18.47	67.31*	–6.95	–9.38	–4.52	–21.18	**< .001**	< 0.001	0.00	0.00
7	55.77*	–13.87	–18.65	–9.09	76.92*	–4.45	–6.04	–2.85	–9.42	**< .001**	0.03	0.00	0.22
8	42.31*	–18.41	–24.73	–12.08	71.15*	–5.95	–8.04	–3.85	–12.46	**< .001**	0.01	0.00	0.01
9	75*	–7.39	–9.97	–4.81	90.38	–0.94	–1.51	–0.36	–6.45	**< .001**	0.04	0.00	0.29
10	67.31*	–9.99	–13.44	–6.53	57.69*	–9.46	–12.73	–6.18	–0.53	.848	42.40	0.00	99.92

Note. Abnormal differences between *z* scores are shown in bold. PPTT = Pyramids and Palm Trees Test; KDT = Kissing and Dancing Test; *z* (ES) = *z* score and effect size for the difference with the control group; 95% CI L = 95% credible interval, lower bound; 95% CI H = 95% credible interval, higher bound; Δ*z* = difference between *z* scores (PPTT – KDT); PE (*p*) = point estimate of the abnormality of difference between *z* scores; %CMED = percentage of control participants with a more extreme difference in the same direction as the participant with the semantic variant of primary progressive aphasia.

*Significant difference compared to controls, $p < .05$.

difference in the same direction as those three participants ranged from 0.33% to 1.57%. For one additional individual, P3, the difference between *z* scores when considering differences in any direction for the control group was close to the threshold of abnormality ($p = .051$). When looking only at differences in the same direction as the one shown by P3, 2.53% (< 5%) of controls would obtain a more extreme difference. It is worth noting that, based on the 95% credible interval of abnormality, up to 34.32% of controls could show a similar difference between those two scores. Two out of 10 participants (P9 and P10) showed the opposite pattern of dissociation and had a lower standardized score on the ANT compared to the TDQ-60. The difference between *z* scores when considering differences in any direction for the control group was close to significance for P9 ($p = .067$). When looking only at differences in the same direction, 3.34% (< 5%) of controls would obtain a more extreme difference. However, based on the credible interval, up to 55.69% of controls could show a similar difference.

All participants with svPPA were impaired on the PPTT and the KDT compared to this study's control group using the Crawford and Howell (1998) test (PPTT: all $ps < .001$; KDT: all $ps < .05$), except P9, whose score on the KDT was within the normal range. The correlation between these tests in controls was $r = .118$, $p = .652$. Nine participants with svPPA out of 10 (P2–P10) had a lower standardized score on the PPTT compared to the KDT. The difference between the tests' *z* score was abnormal for six out of these nine participants (P2, P5, P6, P7, P8, and P9). The difference shown by P9, who was only impaired on the PPTT but not on the KDT, can be considered as a "putatively classical dissociation," whereas the other five participants' difference fit the criteria for a "strong dissociation" (Crawford & Garthwaite, 2007). The percentage of control participants who would show a more extreme difference in the same direction as those six participants ranged from less than 0.001% to 1%. P1's standardized scores on the PPTT and the KDT were practically identical, and therefore, no dissociation was observed.

Three participants showed dissociations in both types of tests (P2, P5, and P6), where object processing was more impaired than action processing in both naming and semantic picture matching tests. Three participants showed a dissociation for only one type of tests (P7, P8, and P9). For all three participants, the dissociation was found in semantic picture matching only (objects more impaired than actions), although P9 showed a trend for a dissociation in the opposite direction in naming (actions more impaired than objects). In fact, P9 was the only participant who showed a "putatively classical" dissociation, having a score within the normal range in action semantic picture matching. Four participants showed no dissociation between objects and actions in naming and semantic picture matching (P1, P3, P4, and P10).

Difference Between Naming and Semantic Picture Matching Tests

Dissociations tests were also used to clarify the difference between naming and semantic picture matching tests for the same category of content. Performance on the TDQ-60 was compared to performance on the PPTT (correlation in the control group: $r = .163$, $p = .532$), and performance on the ANT was compared to performance on the KDT (correlation in the control group: $r = .452$, $p = .069$). Table 5 shows that all participants except P8 had a lower score on the TDQ-60 than on the PPTT. The difference between the tests' *z* score was abnormal for five out of the nine participants (P1, P2, P4, P5, and P7) and fit the criteria for a strong dissociation. Less than 1% of controls would show a more extreme difference in the same

Table 5. Individual percentage of correct answers, standardized scores, and differences in object processing tests in semantic variant of primary progressive aphasia.

	TDQ-60				PPTT				Difference				
Participant	**%**	***z* (ES)**	**95% CI L**	**95% CI H**	**%**	***z* (ES)**	**95% CI L**	**95% CI H**	**Δ*z***	**PE (*p*)**	**% CMED**	**95% CI L**	**95% CI H**
1	63.33*	−12.25	−16.47	−8.02	80.77*	−5.45	−7.37	−3.52	−6.80	**.009**	0.44	0.00	3.72
2	48.33*	−17.74	−23.84	−11.94	71.15*	−8.69	−11.71	−5.67	−9.05	**.010**	0.51	0.00	2.62
3	61.67*	−12.86	−17.28	−8.42	71.15*	−8.69	−11.71	−5.67	−4.16	.159	7.94	0.00	77.35
4	5*	−33.61	−45.14	−22.08	57.69*	−13.23	−17.78	−8.66	−20.39	**< .001**	0.03	0.00	0.00
5	41.67*	−20.18	−27.11	−13.24	76.92*	−6.75	−9.10	−4.38	−13.43	**< .001**	0.01	0.00	0.00
6	6.67*	−33.00	−44.32	−21.67	13.46*	−28.13	−37.78	−18.47	−4.87	.519	25.93	0.00	100.00
7	26.67*	−25.68	−34.49	−16.86	55.77*	−13.87	−18.65	−9.09	−11.80	**.019**	0.93	0.00	4.49
8	51.67*	−16.52	−22.20	−10.83	42.31*	−18.41	−24.73	−12.08	1.89	.671	33.55	0.00	100.00
9	63.33*	−12.25	−16.47	−8.02	75*	−7.39	−9.97	−4.81	−4.85	.079	3.94	0.00	46.25
10	53.33*	−15.91	−21.38	−10.43	67.31*	−9.99	−13.44	−6.53	−5.93	.085	4.25	0.00	58.14

Note. Abnormal differences between *z* scores are shown in bold. TDQ-60 = Test de Dénomination de Québec, 60 items; PPTT = Pyramids and Palm Trees Test; *z* (ES) = *z* score and effect size for the difference with the control group; 95% CI L = 95% credible interval, lower bound; 95% CI H = 95% credible interval, higher bound; Δ*z* = difference between *z* scores (TDQ-60 − PPTT); PE (*p*) = point estimate of the abnormality of difference between *z* scores; %CMED = percentage of control participants with a more extreme difference in the same direction as the participant with the semantic variant of primary progressive aphasia.

*Significant difference compared to controls, $p < .05$.

direction as those five participants. The difference was close to the threshold of abnormality for P9 and P10.

Table 6 shows that all participants except P3 had a lower performance on the ANT than on the KDT. The difference was abnormal for nine participants. P9's difference fit the criteria for a "putatively classical dissociation," whereas the others can be considered as "strong dissociations." The percentage of control participants who would show a more extreme difference in the same direction as those nine participants ranged from less than 0.001% to 1.37%.

Five participants showed a dissociation between naming and picture matching tasks for both objects and actions (P1, P2, P4, P5, and P7). Four participants showed an abnormal difference only in tests using actions (P6, P8, P9, and P10). P3 did not show any abnormal difference.

Discussion

As expected, all participants with svPPA in this study had pervasive semantic language impairments while showing spared performance in other domains of cognition. When compared to tests' norms or to this study's control participants, they all showed below-normal performance in object and action naming and in object and action semantic picture matching, with the exception of P9 whose performance in action semantic picture matching was within the

Table 6. Individual percentage of correct answers, standardized scores, and differences in action processing tests in semantic variant of primary progressive aphasia.

	ANT				KDT				Difference				
Participant	**%**	***z* (ES)**	**95% CI L**	**95% CI H**	**%**	***z* (ES)**	**95% CI L**	**95% CI H**	**Δ*z***	**PE (*p*)**	**% CMED**	**95% CI L**	**95% CI H**
1	66*	−10.01	−13.47	−6.54	73.08*	−5.45	−7.37	−3.52	−4.56	**.027**	1.37	0.00	15.53
2	66*	−10.01	−13.47	−6.54	80.77*	−3.45	−4.71	−2.17	−6.56	**< .001**	0.04	0.00	0.14
3	72*	−8.04	−10.83	−5.24	71.15*	−5.95	−8.04	−3.85	−2.09	.269	13.45	0.00	81.95
4	7*	−29.39	−39.48	−19.30	46.15*	−12.47	−16.76	−8.16	−16.93	**< .001**	0.03	0.00	0.00
5	64*	−10.67	−14.35	−6.98	84.62*	−2.45	−3.40	−1.47	−8.22	**< .001**	0.002	0.00	0.00
6	34*	−20.52	−27.57	−13.47	67.31*	−6.95	−9.38	−4.52	−13.57	**< .001**	0.003	0.00	0.00
7	24*	−23.81	−31.98	−15.63	76.92*	−4.45	−6.04	−2.85	−19.36	**< .001**	< 0.001	0.00	0.00
8	57*	−12.97	−17.43	−8.49	71.15*	−5.95	−8.04	−3.85	−7.01	**.004**	0.20	0.00	0.69
9	40*	−18.55	−24.93	−12.17	90.38	−0.94	−1.51	−0.36	−17.61	**< .001**	< 0.001	0.00	0.00
10	46*	−16.58	−22.28	−10.87	57.69*	−9.46	−12.73	−6.18	−7.12	**.022**	1.12	0.00	10.29

Note. Abnormal differences between *z* scores are shown in bold. ANT = Action Naming Task; KDT = Kissing and Dancing Test; *z* (ES) = *z* score and effect size for the difference with the control group; 95% CI L = 95% credible interval, lower bound; 95% CI H = 95% credible interval, higher bound; Δ*z* = difference between *z* scores (ANT − KDT); PE (*p*) = point estimate of the abnormality of difference between *z* scores; %CMED = percentage of control participants with a more extreme difference in the same direction as the participant with the semantic variant of primary progressive aphasia.

*Significant difference compared to controls, $p < .05$.

normal range. Unsurprisingly, as a group, participants with svPPA were impaired on all four measures of object and action processing compared to the control group. Their performance for objects was lower than their performance for actions, and their performance in naming was lower than their performance in picture matching.

Looking at individual performance, eight out of 10 participants showed the expected pattern of a lower score for objects than for actions in naming, whereas the other two showed the opposite pattern. Results show the importance of considering standardized scores instead of raw scores, as considering raw scores can be misleading (e.g., compare P7's raw scores to his standardized scores). Of the eight participants who showed a difference in the expected direction, three fit the criteria for a "strong dissociation," meaning that they were impaired in both object and action naming but more impaired in object naming. While the variability shown by participants justifies testing for differences in both directions, when considering only differences in the same direction as the participant with svPPA, one additional participant (P3) could qualify as showing a trend of more severe difficulties for objects compared to actions. None of the differences showing the opposite pattern fell within the abnormal range, but when considering only one specific direction, one participant (P9) could qualify as showing a trend of more severe difficulties for actions compared to objects. Nine out of 10 participants showed the expected pattern of lower scores for objects than for actions in semantic picture matching, although the difference was very small for two participants. Again, considering only raw scores, one could conclude that P1 had a better score for objects (PPTT) than for actions (KDT), but her *z* scores for those two tests were practically identical, showing only a difference at the third decimal (not displayed in Table 4). Six out of the nine participants with the expected pattern showed an abnormal difference, with five being impaired in both object and action processing, but more severely so for objects, and one being impaired only for objects. According to the traditional definition of a dissociation in cognitive neuropsychology, this participant (P9) would be the only one considered as having a dissociation between object and action processing, a conclusion that would need to be mitigated by the fact that he showed the opposite pattern in naming. P9 presented some specificities that will be discussed in more details below.

Overall, patterns were mixed, but the semantic picture matching task was more consistent in showing dissociations between the two types of semantic contents. Coherent with this result, the object picture matching task was easier than the object naming task for nine out of 10 participants, with five of them showing a difference that can be considered as abnormal. Importantly, the action picture matching task was easier than the ANT for all participants, and the difference was abnormal for nine out of 10 participants.

Taken together, the results suggest that naming tasks are less useful to reveal differences between objects and actions in svPPA. It seems that, when using a naming task, any superior access to one set of semantic features is compromised by impaired access to the word form. All participants with svPPA showed pervasive semantic deficits, but as clearly exemplified by the individual Bayesian dissociation tests, participants also showed considerable variability in their performance. Therefore, it seems preferable to qualify the differences observed between different semantic categories and different tasks as highlighting areas of relative strengths rather than talking about "dissociations."

The overall pattern suggests that the nonverbal processing of actions is a relative strength in svPPA. Tests targeting objects are useful to identify impairments, especially when time is limited and batteries need to be kept short. Tests targeting actions can be included to highlight strengths and could potentially help with differential diagnosis, especially if semantic picture matching tests for objects and actions are compared. Other studies comparing the different variants of PPA would be needed to support this conclusion. The following sections will discuss the difference between assessment tasks and semantic categories in relation to current models of semantic cognition.

The Advantage for Picture Matching Over Naming

Naming requires the production of a phonological word form. Whether it is conceptualized as access to the phonological output lexicon or as access to one of the concept's features (e.g., compare the first version of the "hub-and-spoke" model [Patterson et al., 2007] to the revised controlled semantic cognition framework [Lambon Ralph et al., 2017], which adopts the second perspective more explicitly), this process is bound to be impaired in svPPA. The temporal areas and structures responsible for encoding the word form and connecting it to the semantic hub are affected by brain atrophy (Bajada et al., 2015; Lambon Ralph et al., 2017; Pulvermüller et al., 2009). Therefore, naming will be impaired, no matter the category of content that is targeted in the task (Bird et al., 2000; Macoir et al., 2015; Méligne et al., 2011). This could explain why differences between objects and actions were not observed in studies that used naming tests (Cotelli et al., 2006; Marcotte et al., 2014). In this study, a difference between object naming and action naming was observed in the svPPA group, but only when using standard scores. This suggests that, in order to reveal differences in profiles characterized by pervasive impairments, the degree of difference to the control group needs to be taken into account. Most importantly, the analysis of individual differences was useful to further clarify the difference between naming and semantic picture matching tests. The comparison of naming tests revealed less abnormal differences than the comparison of picture matching tests, and these differences were less "extreme" overall. The results further support that picture matching tests would provide a clearer distinction between different semantic categories in svPPA.

It was possible to predict that the naming task would reveal differences in participants with right-dominant ATL atrophy, as their left-hemisphere hub and its connections to the phonological word form would be relatively spared (Lambon Ralph et al., 2017; Snowden et al., 2018). The results did not confirm that prediction since all participants who had an abnormal difference between object and action naming *z* scores had left-dominant atrophy (all participants were right-handed based on self-report). It is important to note that both tests relied on the processing of visual features, which is supported by both hemispheres but more so by the right (Lambon Ralph et al., 2017). The inclusion of a task that did not use pictures (e.g., semantic judgment of spoken words) would have been useful to further clarify the role of each hemisphere. The contribution of visual features also has several implications for the differences observed between semantic categories.

The Advantage for Actions Over Objects

The processing of objects, whether assessed with a naming or a picture matching test, requires access to areas that subtend the processing of perceptual features. Because tasks used visual material, visual features likely played a major role in participants' performance. However, other types of perceptual features contribute to the identification of concepts (Lambon Ralph et al., 2017; Meteyard et al., 2012; Patterson et al., 2007). For example, music instruments evoke sounds, and foods evoke tastes. svPPA participants' responses on the TDQ-60 support the contribution of other perceptual features in the performance. In response to the picture of a violin, P4 said, "It wants to sing," referring to the sounds this object makes. Impaired visual object knowledge did not completely prevent accurate naming of objects, while having preserved object knowledge did not ensure success in object naming either. For example, P2 had one of the highest scores on the BORB Object Decision, List A (25/32), but named only 48.33% of items correctly on the TDQ-60. To further illustrate the contribution of visual features, in response to the picture of a fox, he said, "An animal. The shape of a dog, not a dog." While visual features helped P2 access a close candidate for naming, they were not sufficient to identify the exact word. Other features, such as the emotional valence associated with a concept, and a host of "encyclopedic" or abstract features also contribute to the representation of concepts (e.g., dogs are generally friendly and are kept as pets; foxes are wild animals and are potentially dangerous; Lambon Ralph et al., 2017; Meteyard et al., 2012; Patterson et al., 2007). Note that the complexity and diversity of semantic features involved in the representation of concepts apply to actions as well. For example, the semantic representation of actions involves highly symbolic information in that they represent events unfolding over time (Vigliocco et al., 2011). As such, both objects and actions would depend to some extent on overlapping sets of features.

The difference between objects and actions does not follow the strict boundaries imposed by grammatical categories. However, it is important to keep in mind that objects targeted in standard tests typically belong to the category of nouns, while actions typically belong to the category of verbs. Verbs have long been considered more difficult to process than nouns because they have complex, highly context-dependent meanings (Druks et al., 2006; Kim & Thompson, 2004; Szekely et al., 2005; Vigliocco et al., 2011). Furthermore, verbs and nouns differ in their morphosyntactic properties. Verbs have different argument structures that determine the number and type of complements they can take and influence their lexical access (Kim & Thompson, 2004; Thompson et al., 2012). They also have different inflected forms that mark grammatical information such as tense, mode, person, and number. Nouns have simpler morphosyntactic properties but can carry grammatical gender information and be inflected for number, for example (Levelt, 1989). Thompson et al. (2012) tested patients with different profiles of aphasia resulting from stroke and PPA variants on noun and verb production and comprehension. Nouns were better preserved than verbs in patients with agrammatic aphasia resulting from stroke and patients with nonfluent/agrammatic PPA. This effect was found in word production but not in word comprehension. They also found a transitivity (argument structure) effect in patients with agrammatic aphasia resulting from stroke and nonfluent/agrammatic PPA who produced one-argument verbs more accurately than two- or three-argument verbs. In comparison, three out of the four patients with svPPA had a better performance for verbs than nouns in both production and comprehension. There was no transitivity effect for verb production or comprehension in svPPA. The study of Thompson et al. shows that the contrast between nouns and verbs (or objects and actions) is best interpreted in the light of the patients' overall language profile. In patients with syntactic and grammatical impairments, the comparison reveals differences in words' morphosyntactic properties. In patients with semantic impairments, differences in the relative importance of various sets of semantic features for the words' representation are highlighted. It is worth noting that, if the effect was driven by the complexity of semantic representations and existence of multiple, context-dependent meanings for actions/verbs, a better preservation of objects/nouns would be expected in svPPA (Druks et al., 2006; Kim & Thompson, 2004). Instead, the pattern reported in this study and others point toward the importance of different semantic features in the representation of these categories of content (Vigliocco et al., 2011).

It is important to acknowledge that the semantic representation of manipulable objects also depends on motor features to an important extent (Kiefer & Pulvermüller, 2012; Martin & Chao, 2001; Oliveri et al., 2004; Vigliocco et al., 2011). For example, while he was unable to name these items correctly, P2 produced appropriate gestures in response to the pictures of an accordion, a kettle, a hammer, a rolling pin, and a screw driver. Several participants with svPPA were impaired in the execution of meaningful gestures following a verbal command, but the evaluation of praxis was complicated by the important single-word comprehension deficit that is found in svPPA. For example, it is not possible to “do the gesture of looking through binoculars” if the word “binocular” is not understood anymore. Nevertheless, it is possible that motor features supported the processing of manipulable objects to some extent in both the naming and semantic picture matching tasks. However, perceptual features play a major role in the representation of objects, and both tasks included a number of highly perceptual (nonmanipulable) items (e.g., TDQ-60: cloud; PPTT: rain–cloud–sun triplet).

Future studies should directly compare manipulable to nonmanipulable objects, similar to the study of Pulvermüller et al. (2009) that compared subcategories of actions. The degree of object manipulability should be carefully controlled (see Binder et al., 2016). It is also worth noting that information about the manipulation of objects has been associated with the left temporoparietal cortex (Campanella et al., 2010; Kalénine & Buxbaum, 2016; Pobric et al., 2010), which suggests that, although motor in nature, information about gestures related to objects is distinct from information about the performance of actions. Comparing sets of nonmanipulable objects, manipulable objects and action words that are well controlled for their respective semantic properties would clarify the pattern of performance observed in svPPA.

P9’s Profile

P9 presented a different pattern of performance compared to the other participants with svPPA in this study. He had a better performance in object naming than action naming, but the difference did not fall within the abnormal range (although it was close to the abnormality threshold). He also had spared semantic picture matching for actions but impaired semantic matching for objects. After his participation in the study, P9 manifested additional symptoms and was later diagnosed with amyotrophic lateral sclerosis (ALS). ALS is a form of motor neuron disease characterized by atrophy and weakness of muscles, fasciculations, abnormal reflexes, and hypertonia (Kiernan et al., 2011; Swinnen & Robberecht, 2014). Major progress in the understanding of the relationship between frontotemporal lobar degeneration (FTLD; of which svPPA is a form) and ALS has been accomplished in the last 5–10 years (Strong et al., 2017, 2009). Cognitive impairment was long thought to be uncommon in ALS, and spared cognition was even proposed as a condition for its diagnosis (Kiernan et al., 2011; Swinnen & Robberecht, 2014). However, the presence of nonmotor symptoms, including cognitive impairment, has been increasingly recognized. FTLD and ALS are now considered by many as poles on a continuum (Kiernan et al., 2011; Mann & Snowden, 2017; Strong et al., 2017, 2009; Swinnen & Robberecht, 2014). While it was thought that the co-occurrence of ALS in FTLD mostly concerned the behavioral variant of frontotemporal dementia (Kiernan et al., 2011; Swinnen & Robberecht, 2014), ALS has been found in patients presenting with language phenotypes (Tan et al., 2019; Vinceti et al., 2019), and language symptoms have been found in patients with ALS (Taylor et al., 2013). It is not clear at this time if ALS represents an expected comorbidity or progression of svPPA or if FTLD-ALS represents a different entity altogether (Mann & Snowden, 2017; Saxon et al., 2017; Strong et al., 2017, 2009; Tan et al., 2019; Vinceti et al., 2019). However, up to 50% of patients with frontotemporal dementia have some motor neuron involvement, although they may remain unaware of this (Swinnen & Robberecht, 2014). Conversely, when assessed with appropriate neuropsychological tests, between 20% and 50% of patients with ALS fit the consensus criteria for probable or definite frontotemporal dementia (Kiernan et al., 2011). Regarding P9, his overall cognitive profile was consistent with svPPA at the time of the study (Gorno-Tempini et al., 2011). Like patients with isolated svPPA, patients with concurrent ALS and svPPA present with severe ATL atrophy and naming deficits (Vinceti et al., 2019). However, atrophy is more confined to the medial aspect of the temporal lobe, and additional spreading to the orbitofrontal region occurs early along with amnestic, dysexecutive, and behavioral symptoms (Vinceti et al., 2019). P9 did not have processing speed or inhibition deficits, and his performance in the ROCF recall conditions was remarkably good. His better performance for objects compared to actions in naming would be coherent with motor neuron involvement. His spared performance in action semantic matching is more difficult to explain but could be accounted by better visual processing than other participants with svPPA. It is worth noting that, for a number of items on the KDT, the target picture and the stimulus picture present important similarities (e.g., the kissing and dancing pictures that both show a couple). Between-group and within-group comparisons did not change when excluding his results.

Hillis et al. (2006, 2004) compared the performance of patients with frontotemporal dementia and ALS in actions and objects processing. These patients had more difficulty naming actions than objects (Hillis et al., 2006, 2004), a pattern coherent with the one observed in isolated nonfluent/agrammatic PPA. All patients included in the Hillis et al. (2004) study had previously received a diagnosis of nonfluent PPA following the Neary et al. (1998) guidelines, whereas patients in the Hillis et al. (2006) study met the criteria for any FTLD subtype (Neary et al., 1998). More studies on the cognitive profile of patients with ALS and FTLD-ALS would be necessary to further interpret the results.

Limitations

This study has a number of limitations. First, the object naming test used colorized line drawings, whereas the action naming test used videos. This difference could have caused differences in processing because one type of material was more realistic than the other (see den Ouden et al., 2009; Tranel et al., 2008, for a discussion), but this could not explain the difference between the PPTT and the KDT, which use a similar testing material, namely, black-and-white line drawings. The sample size of controls was small, and the object and action processing measures were subject to ceiling effects in controls. However, the method used for the analysis of individual results takes the sample size into account and is robust to the nonnormality of distributions (Crawford & Garthwaite, 2007). The results reported represent one point in time for participants with svPPA, and the differences between objects and actions may not be maintained as disease progresses or when comorbidities emerge. For example, the participant with the most severe semantic language impairment (P4) did not show any difference between objects and actions in naming and semantic picture matching. She had sought medical attention a few months before participating in the study. No widely accepted measure of overall language severity exists for svPPA (but see Sapolsky et al., 2010, 2014), but such measures would be useful to characterize the degree of impairment in different individuals and follow its progression over time.

Conclusion

svPPA constitutes a pervasive impairment of semantic cognition that affects a variety of categories of content. While actions are relatively easier to process than objects in svPPA, individuals with svPPA are impaired in naming and associating actions based on their meaning. Nevertheless, naming places additional difficulty over processing, and tasks that do not require naming are relatively easier and are more consistent in highlighting differences between objects and actions. Overall, the nonverbal processing of actions may be considered as an area of relative preservation in svPPA. When contrasted with tests that target objects, tests that target the nonverbal processing of actions can be used to highlight areas of strength in a disease characterized by pervasive semantic impairment.

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