WHAT INFLUENCES ACTION VERB NAMING?

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RUNNING HEAD: ACTION VERB NAMING

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ABSTRACT

Persons with aphasia (PWA) frequently experience difficulties in retrieving verbs. Little is known about mechanisms underlying verb retrieval, both in neurologically healthy adults and PWA. The present study investigated two questions pertaining to action verb naming: 1) if any properties of a verb influence naming efficiency, particularly, somatotopy (bodypart used for the action), and 2) if somatotopic and phonemic primes facilitate action verb naming. Neurologically healthy adults and eight PWA named action videos performed by hand, leg or face under three conditions: neutral, phonemic or somatotopic (same body part) prime. Both groups named hand verbs the fastest and leg verbs the slowest. Somatotopic primes speeded naming for healthy adults, while phonemic facilitation was found for both groups. A multiple regression analysis identified verb frequency, name agreement and somatotopic association rating as significant predictors of verb naming in healthy participants. The findings elucidate the dynamics of verb retrieval and its impairment in aphasia.

Key words: aphasia, embodied cognition, naming, priming, semantics, somatotopy, verbs

The most frequent difficulty experienced by persons with post-stroke aphasia is retrieving words. Persons with aphasia (PWA) often substitute target words with semantically similar words (*cat* for *tiger*), make sound errors (*diker* for *tiger*), or use descriptors and generic phrases. While most prior research has focused on noun retrieval difficulties, verb naming is impaired in a significantly larger proportion of persons with aphasia (Mätzig, Druks, Masterson & Vigliocco, 2009; Luzzatti, Raggi, Zonca, Pistarini, Contardi, and Pinna, 2002). Relatively little is known about the underlying source of verb retrieval deficits in PWA and this gap in knowledge hinders development of effective interventions for verb retrieval. In fact, compared to nouns, relatively little is known about the psycholinguistic mechanisms of verb retrieval in neurologically healthy adults because most influential research focused on noun retrieval (Glaser and Dungelhoff, 1984; Levelt, Roelofs & Meyer, 1999). The aim of the research reported here is to elucidate the nature of verb retrieval in neurologically healthy persons and PWA. Given the growing literature on action concepts, this study specifically examines action verb retrieval. In the following sections, current understanding of verb representations and factors influencing verb retrieval are briefly outlined.

Architecture of the Verb Lexicon

Oral naming of verbs takes longer compared to nouns, especially in picture naming tasks even when the two word classes have comparable frequency of occurrence (Szekely et al., 2005). Several authors have noted the variety of conceptual and linguistic parameters that may contribute to more complex representation and

retrieval of verbs compared to nouns (Black & Chiat, 2003; Conroy, Sage & Lambon-Ralph, 2006; Gentner, 1982). These include a looser concept, generally lower imageability, more complex grammatical morphology and more detailed syntactic representations which include argument structure information. However, effects of all these variables have not been empirically investigated. It is generally assumed that the mental representation of verbs is based on semantic features, akin to nouns (Almor et al., 2009; Bird, Howard and Franklin, 2000; Kemmerer, Castillo, Talavage, Patterson & Wiley, 2008). In such a feature-based framework, conceptual knowledge is represented by connections between features and concepts, such as *motion* or *action* for concepts like *running* and *eating* (Bird et al., 2000). Two concepts might share some features but not other features (for example, *eating* involves a resultant *change of state* while *running* does not).

Empirical evidence for feature-based representations comes from paradigms such as speeded reading times, semantic judgments and primed lexical decision for the following semantic features: durativity of the verb (which can be ongoing as in *running* or have a distinct endpoint as in *breaking*), instrumentality (use of an instrument or tool), manipulability (use of arm/hand), mental versus physical, manner of motion, somatotopy (body part association), transitivity, animacy, and thematic associations such as nouns and locations (Ahrens 2003; Almor, Kempler, Anderson, & MacDonald, 2005; Almor et al., 2009; Arevalo et al., 2007; Bergen, Lau, Narayan, Stojanovic & Wheeler, 2010; Bonnotte, 2008; Kemmerer et al., 2008; McRae, Hare, Elman & Ferretti, 2005; Parris & Weekes, 2001; Pulvermuller et al., 2001). Moreover, semantically more

specific verbs are more successfully produced than generic verbs (*scrub* versus *clean*) even though specific verbs tend to be less frequent than generic verbs (Ashenfelter & Eberhard, 2007).

Increasing evidence shows that the sensorimotor features of verbs are inherently included in their semantic representations (Barsalou, 1999; Glenberg & Kaschak, 2002). For example, exposure to a verb such as *close* (as in *Close the drawer*) speeds up the motor act of moving one's arm away from the body (Glenberg & Kaschak, 2002). Brain imaging data indicate that verbs not only recruit language specific brain regions, but also modality specific sensorimotor systems, and these sensorimotor systems are automatically active during semantic processing (see reviews by Barsalou, 2010; Bedny & Caramazza, 2011; Binder & Desai, 2011; Chatterjee, 2010; Kiefer & Pulvermuller, 2011). Hence a verb like *chop* is found to activate neural regions involved in hand/arm use in the premotor and motor cortices, tool use, and motion representations (Kemmerer et al., 2008). This connection between language and sensorimotor systems is referred as Embodied Cognition and is used as the theoretical framework for the present research. One finding germane to the present study is a difference in processing speed of action verbs based on their somatotopic association: face verbs (*licking*) were processed faster than leg verbs (*kicking*) and hand/arm verbs (*picking*) fell in between (Pulvermuller, Harle & Hummel, 2001).

Verb representations in Aphasia

Although there is severely limited research on the nature of verb representations in PWA, the general pattern of findings so far is sensitivity to some variables that

influence verb naming in neurologically healthy adults. This includes argument structure hierarchy (Kim & Thompson, 2000; Thompson, Lange, Schneider & Shapiro, 1997), semantic specificity (Barde, Schwartz, & Boronat, 2006; Breedin, Saffran, Schwartz, 1998; Kim & Thompson, 2004; Kiss, 2000), somatotopic features (Faroqi-Shah, Wood & Gassert, 2010) and lexical frequency (Kemmerer & Tranel, 2000a). Except for lexical frequency, sensitivity to the other three variables listed above was studied in persons with an agrammatic language profile. However, considerably more research is needed before we can better understand how verb representations are impacted in PWA.

Using the feature-based framework of mental representations, one explanation of the verb deficit in PWA is a difficulty with specific semantic features. Bird et al. (2000) found that three “verb deficient” PWA were more impaired in naming concepts that relied on functional features (verbs and inanimate nouns) compared to concepts that had detailed visual representations (animate nouns). The authors concluded that the verb deficit can be reduced to a deficit along the functional-sensory dimension. Another study of 21 PWA investigated the semantic feature of manipulability, that is, whether an arm/hand is used for the action or object (Arevalo et al., 2007). While neurologically healthy adults showed a slight manipulability advantage for naming objects and actions, persons with Broca’s and Wernicke’s aphasia showed a disadvantage for manipulable objects and actions. Jonkers and Bastiaanse (2007) reported a similar disadvantage for instrumentality in persons with Broca’s and Wernicke’s aphasia. In contrast, Kemmerer & Tranel (2000a) found no effect of body part (hand versus body) in 53 PWA. Hence a

handful of studies report impaired semantic features, but there are exceptions to this finding.

Given that disintegration of semantic features may not be an all-or-none phenomenon, Faroqi-Shah et al. (2010) examined the time course of activation of semantic features. They used a primed lexical decision paradigm and manipulated the duration between a somatotopically related prime and a verb target. At a 200ms stimulus onset asynchrony (SOA), PWA and neurologically healthy adults showed an interference effect when the prime and target verbs overlapped in body part (*kissing*→*licking* versus *kissing*→*walking*), suggesting that the body part feature activated by the prime (face/mouth) interfered with activation of the same body part feature for the target verb. While neurologically healthy adults continued to show this interference at a later SOA of 700ms, PWA did not. This suggests abnormally rapid decay of activated semantic features in PWA. It can be hypothesized that when semantic representations decay rapidly, the neural activation may not sufficiently spread to the phonological networks, leading to unsuccessful retrieval of the verb's phonological representations. It remains to be seen if this rapid decay of semantic representations can be circumvented by providing an activation boost from semantic or phonological features.

In summary, two key points emerge from the small number of studies that examined verbs in PWA. First, there is possibly disintegration of semantic features of verbs in PWA who have a verb deficit, but not all data are consistent with this account (Barde et al., 2006; Kemmerer & Tranel, 2000a; Kim & Thompson, 2004). There are at

least two contributing factors for different findings across studies. A variety of semantic (or syntactic) variables have been examined with different experimental paradigms, obscuring the ability to compare findings. And some studies recruit a homogenous group of persons with Broca's or agrammatic aphasia (Faroqi-Shah et al., 2010, Kim & Thompson, 2000, 2004) while others recruit larger numbers of participants with diverse language profiles (Kemmerer & Tranel, 2000a, 2000b, Kemmerer et al., 2012; Luzzatti et al., 2002). The second point that can be drawn from prior studies is the possibility of impaired time course of activation of semantic representations.

The present research aims to enhance our understanding of verb retrieval by investigating two questions. First, the extent to which verb naming is influenced by specific semantic and lexical properties of the action. Second, the extent to which verb naming is influenced by preceding cues which presumably alter the activation level of semantic and phonological representations. In this study, only action verbs are examined in the context of somatotopic features. We chose action verbs and their somatotopic features because (1) the neural and cognitive representation of action concepts, action verbs, and body part associations has been investigated considerably in the past few years, mostly in the context of Embodied Cognition (for example, Bedny & Caramazza, 2011; Bergen et al., 2010; Tettamanti et al., 2005); (2) our prior work on the time course of somatotopic representations used action verbs, allowing us to better compare prior research with current findings (Faroqi-Shah et al., 2010). Before presenting the methods and findings of the current study, previous findings on verb facilitation in aphasia are briefly reviewed.

Facilitation of Verb Retrieval in Aphasia

Priming refers to the observation that speakers' choice of words and sentences is influenced (*primed*) by the preceding linguistic context (Bock, 1986; Schriefers et al., 1990). Like neurologically healthy persons, PWA's productions can be primed by various types of cues (Hartsuiker & Kolk, 1998; Howard, Patterson, Franklin, Orchard-Wise & Moton, 1985). Investigating short term facilitation effects via priming enables us to make better predictions about what kinds of interventions will produce successful outcomes in PWA (Howard et al., 1985). Two studies investigated priming of verb retrieval in aphasia, one of these studies used a sentence context for priming (Fink, Martin, Schwartz, Saffran & Myers, 1992) and the other study used a single word priming paradigm (Lee & Thompson, 2011). In order boost the activation of the lexical-phonological representation of a verb, Fink et al. (1992) used repetition priming, in which their participant repeated a verb embedded in a sentence context, followed by a picture description prompt. Verb retrieval accuracy improved for four out of five verbs following repetition priming. Lee and Thompson (2011) presented phonologically related words prior to presentation of noun and verb pictures (*belt*→*bed*). Persons with agrammatic aphasia (N=15) were facilitated by phonological cues for verb retrieval, showing faster response latencies. In contrast, verb naming was not facilitated for persons with anomic aphasia (N=9) although noun retrieval latencies improved. Neither of these studies focused on action verbs. And, to our knowledge, the effect of semantic primes on verb retrieval in PWA has not been examined.

Other than the above two studies of short term facilitation, studies of verb facilitation have involved long-term intervention paradigms. This has included treatments based on semantics, phonology, argument structure, gesture enactment and action imagery (for example, Boo & Rose, 2010; Edmonds, Nadeau, & Kiran, 2009; Faroqi-Shah & Graham, 2011; Marangolo, Cipollari, Fiori, Razzano & Caltagirone, 2012; Schneider & Thompson, 2003; Wambaugh, Cameron, Kalinyak-Fliszar, 2004). Overall, these intervention studies have found moderate improvements in retrieval of trained verbs, but limited generalization to untrained verbs. Only a handful of these studies have used action verbs as stimuli (Boo & Rose, 2010; Faroqi-Shah & Graham, 2010; Marangolo et al., 2012). To summarize, little is known about how production of action verbs can be facilitated (or interfered with) in PWA.

The present study

As mentioned earlier, this study addressed two research questions in neurologically healthy adults and persons with aphasia: the extent to which verb naming is influenced by specific semantic and lexical properties of the verb, and the extent to which verb naming can be facilitated by semantic and phonological primes. For the first research question, the effect of somatotopy was examined given Pulvermuller et al.'s (2001) finding of somatotopic effects on lexical decision latencies in healthy adults: faster responses to hand verbs compared to leg verbs. The effects of how closely a verb was associated with an effector, name agreement, lexical frequency, argument structure, polysemy and word length were also examined.

To address the second research question, this study investigated the effect of two priming contexts on action verb naming: somatotopic and phonemic. Somatotopic primes were action verbs that involved the same effector as the target verb (for example, *waving* and *chopping*). As per embodied cognition, the rationale for somatotopic primes was that activation of sensorimotor networks caused by exposure to the prime would spread to another verb that shares the same sensorimotor network. This sensorimotor activation could either lower the threshold of activation of the target verb (a recency effect), or interfere with its retrieval (due to a refractory period). The rationale for phonemic primes was spreading of activation to the phonological code of the target verb, a facilitatory effect that has been reported in prior studies (Howard et al., 1985; Lee & Thompson, 2011; Levelt et al., 1999).

Methods

Participants

There were three groups of participants: neurologically healthy college-aged persons (young normal, N=60, 39 female, age range = 18.6 to 23 years, $M = 19.9$ years; $SD = 1.8$; 52 right-handed), neurologically healthy adults matched in age with PWA (age-matched normal, N=20, 16 females, age range = 40 to 78 years, $M = 56.55$ years; $SD = 10.2$; sixteen right-handed) and PWA with a verb impairment (N=8, three females; age range = 52 to 70 years; $M = 61.7$; $SD = 7.4$; all were pre-morbidly right handed). All participants were native speakers of English with at least high school education. According to their self-reported history, none of the neurologically healthy participants

had a history of psychiatric, neurological, degenerative, cognitive, visual, hearing, or speech-language deficits.

All PWA had experienced a single left hemisphere lesion following a cerebrovascular accident at least one year prior to participation. Radiologic reports indicated fronto-temporo-parietal lesions in the middle cerebral artery territory. All participants passed a pure tone audiometric screening at 1kHz, 2kHz and 4kHz at 40dB HL and a vision screen with a score of at least 20/40 on the Snellen chart (with or without corrective lenses). Six out of eight PWA (except A2 and A5) had persistent right arm and leg hemiparesis. All eight participants passed a test of limb praxis using their nonparetic left side and a brief visuo-spatial cognitive screen (Western Aphasia Battery-Revised, Kertesz, 2006). Identification of any concomitant apraxia of speech was considered important because naming latency was a dependent variable which could be significantly affected by apraxia. Using the checklist of the Apraxia Battery for Adults- 2nd edition (ABA-2; Dabul, 2000), we made an apriori decision to exclude participants who had more than four features characteristic of apraxia of speech. Demographic information and scores on language and cognitive tests for the aphasic participants are given in Table 1.

Language background of PWA

As per the Western Aphasia Battery (WAB-R; Kertesz, 2006), all participants had an overall auditory comprehension score of five or higher, overall naming score of three or higher, and repetition score of four or higher. Seven out of eight participants (except A3) had a profile of Broca's aphasia (WAB-R). Their narrative speech was characterized

by impoverished sentence structure and decreased fluency (see Table 1). Additionally, all participants demonstrated a verb retrieval deficit, operationally defined as a score of less than 70% on verb naming (An Object and Action Naming Battery, Druks & Masterson, 2000). A majority of verb errors across all eight participants were noun substitutions (*beggar* for *begging*; *water* for *pouring*) followed by phrasal descriptive responses. In order to determine access to semantic information conveyed by verbs, two tests were used: the Kissing and Dancing Test (Bak and Hodges, 2003) and a 20-item single word identification test for actions developed using items from the Object and Action Naming Battery. The latter test required participants to match an auditorily presented verb with one of four pictures: the target picture, a semantic distractor, a visual distractor, and an unrelated verb. In general, all PWA performed well above chance on both measures of verb semantics (accuracy > 48/52 and 18/24 for Kissing and Dancing Test and comprehension version of An Object and Action Naming Battery respectively). Based on the high performance on semantic measures, preponderance of noun substitutions and circumlocutions in their verb naming performance, most participants likely had access to semantic representations, and word form (phonological) access was the most likely source of difficulty.

Stimuli

Ninety-eight verbs were initially selected based on the following criteria: (1) higher verb than noun usage frequency as per the CELEX frequency counts (Baayen, Piepenbrok, & VanRijn, 1993, written lemma frequency) in order to limit homophones with a stronger noun usage, (2) association with one of the three effectors (face/mouth

($n=27$), arm/hand ($n=44$) and foot/leg ($n=27$)), (3) imageability and ease of filmability, and (4) relatively even distribution of transitive and intransitive verbs. Actions depicting these verbs were video filmed in which a female actress performed the actions. In all videos, the agent/actor of the action wore a green shirt in order to minimize confusion between verbs that differ only in perspective (for example, *throw* and *catch*). These videos were an average of three seconds long. None of the videos had any accompanying audio cues. It was important to achieve a high degree of name agreement because naming speed is known to be influenced by the degree of name agreement (Barry, Morrison & Ellis, 1997; Lachman, Shaffer, & Hennrikus, 1974; Vitkovitch & Tyrell, 1995).

Norming of action videos

Name agreement data for the videos were obtained by asking twenty six unimpaired native speakers of English (university students, 15 females, age range = 18-23 years, $M = 19.6$, $SD = 2.1$) to name each of these videos. They were also asked to rate the association between the action in the video with a specific effector (face/mouth, arm/hand and foot/leg) on a seven-point scale (1=no association, 7=highly associated). Verbs whose naming accuracy exceeded 80% and whose mean rating for association with an effector exceeded 4.5 were included as stimuli. This resulted in a total of 68 verbs (20 face/mouth, 31 arm/hand and 17 foot/leg verbs). The verbs are listed in the Appendix.

Verb names produced by this group of raters were later used as a reference for accuracy scoring of PWA and neurologically healthy adult participants' responses

(described further under Data Analysis). For example, *weeping* and *crying* were both scored as correct for the target *crying*, and the response *skateboarding* for *skating* was also scored as correct.

Given that a variety of stimulus properties can influence word retrieval, we noted the following variables for each verb and compared these across the three effector groups: effector association ratings as described earlier, lemma frequency using CELEX, syllable and phoneme number, polysemy count (number of semantic senses) from WordNet (Fellbaum, 1998) and argument structure from VerbNet (Kipper-Schuler, 2006). These psycholinguistic characteristics are summarized in Table 2. The three effector categories of verbs did not differ in lemma frequency and syllable number (analysis of variance, $p > 0.05$), but differed significantly in effector association rating, phoneme number and argument structure ($p < 0.05$; Table 2).

Prime –Target pairings

The progressive verb form was used for all stimuli (targets and primes) in order to avoid ambiguity with noun homophones. Each verb in the final list of stimuli was paired with three prime types: unrelated, somatotopic and phonemic. *Unrelated* primes consisted of frequency-matched unrelated nouns that had no thematic or associative relation with the verb (for example, marriage [prime] >> limping [target]). *Somatotopic* primes were verbs that used the same effector as the target verb (e.g., chasing [prime] >> limping [target]). Verbs selected as somatotopic primes were at least as strongly associated with the effector as the target (procedure for verb-effector association ratings obtained from 26 unimpaired individuals described earlier). Some verbs were

used more than once as primes ($n=10$). Given that transitivity can have a facilitatory priming effect (Bonnotte, 2008), somatotopic primes were chosen so that these did not match the target verb in transitivity (transitive [prime] >> intransitive [target] and vice versa). Care was taken to avoid overlap in other semantic aspects such as manner of action (as in *sip* and *suck*) or resultant state (as in *cut* and *break*) as these factors could produce confounding priming effects. The somatotopic and unrelated primes did not differ in frequency of occurrence (CELEX count, Baayen et al., 1993). Phonemic primes consisted of the initial bigraph (consonant + vowel or vowel + consonant; li [prime] >> limping [target]). All primes were digitally audio-recorded by a native female speaker of English.

Procedure

The study was performed in accordance with the ethical guidelines of the University of Maryland's Institutional Review Board and participants provided written consent. Participants were tested individually in a quiet room. The experiment was presented via Superlab Pro v.8. Each trial began with a fixation cross for 750 ms, followed by a blank screen for 350ms, followed by a prime (which was presented auditorily and orthographically) and then the target action video. The stimulus onset asynchrony (time duration between prime and action video) was 600 ms for somatotopic (and neutral) primes and 200 ms for phonemic primes. These SOAs were based on what is known about the effects of phonological and semantic facilitation for noun naming (Levelt et al., 1999). An auditory signal (100ms beep) coinciding with the

onset of the video was used to enable latency analysis (described under Data Analysis).

The order of presentation of trials was randomized.

Participants were instructed to pay attention to the prime, but not respond to it. They were asked to name the action depicted in the video as quickly and accurately as they could. Participants were encouraged to name verbs in the *progressive* in order to avoid potential ambiguity with noun homophone responses. Participants were given ten practice trials with non-target verbs. Participants were given a maximum of 8000 milliseconds to respond for each verb name. Responses were noted during the session by the experimenter. In order to determine naming latency and reliability of transcription and scoring, the entire experiment was audiorecorded, with additional videorecording for PWA.

Separate groups of 20 neurologically healthy young participants each named the action videos in neutral, phonemic and somatotopic prime conditions (total 60 participants). In addition, twenty age-matched neurologically healthy participants named action videos in the neutral condition to examine any effects of age on verb naming. Separate sessions, spaced at least two weeks apart, were used for the eight PWA to name the action videos in neutral, phonemic and somatotopic prime conditions. The sequence of prime conditions was randomized across PWA so that each participant received the conditions in a different order of presentation.

Data Analysis

The dependent variables were accuracy and speech onset latencies (SOL). Transcribed responses were scored as correct if the intended verb name was produced unambiguously. Close semantic associates were scored as correct if the same effector was involved and if it had also been noted during the name agreement phase of the stimulus development (for example, *biking* for *pedaling*). Speech onset latencies were defined as the time in milliseconds that elapsed between the onset of the video and the onset of the participants' correct naming response without any intervening utterances. Responses with intervening utterances such as false starts or fillers (e.g., *um...la...le...limping; cutting....no....sew....sewing*) were excluded from latency analysis because these are not accurate measures of verb retrieval per se. This criterion excluded 1.2% and 12.3% of all responses from neurologically healthy and PWA respectively. SOLs were manually computed by tracking the sound wave in Audacity (<http://audacity.sourceforge.net/>). Latency measures were repeated for 30% of all responses to determine inter- and intra-rater reliability. Both reliability measures exceeded 93%. SOLs of correct responses were trimmed for outliers using the criteria of 2.5 standard deviations above the participant's mean.

To investigate which factors influenced verb retrieval, two analyses were conducted. First, the influence of effector was analyzed by comparing SOLs (with neutral primes) for the three effectors (face/mouth, arm/hand, leg) for three groups of participants (young, age-matched and aphasia). Second, linear multiple regression analysis was used to predict SOL from the following variables: effector, lemma frequency (CELEX), syllable number, argument structure (VerbNet), polysemy

(WordNet), and name agreement. A measure of name agreement that accounts for the proportion of respondents producing each alternative verb label was used (H-statistic, Bates et al., 2003; Snodgrass and Vanderwart, 1980). H statistic was calculated using the formula

$H = \sum_i^k p_i \log_2(1/p_i)$ where k is the number of different names given to each picture, p_i is the proportion of respondents giving each name¹. Perfect name agreement will yield a H statistic of zero, and higher values indicate lower name agreement. Due to the low accuracies and individual variability in SOLs of PWA, a separate binary logistic regression was performed on accuracy for each PWA.

To investigate the effect of primes on verb retrieval, accuracies and speech onset latencies were compared in separate analyses for neurotypical group (between group analysis) and PWA (repeated measures) for the three priming conditions: neutral, phonemic and somatotopic.

Results

Factors influencing action verb naming

Accuracy. Accuracy scores were converted in rationalized arcsine units (Studebaker, 1985) and compared between groups and effectors using linear mixed effects model. Participant group (young, age-matched, aphasia) and effector

¹ Hence if 19 out of 20 ($p_i=0.95$) respondents named a video *scratching* and one respondent used *itching* ($p_i = 0.05$), the H statistic is $0.95(\log_2 1/0.95) + 0.05(\log_2 1/0.05) = 0.286$.

(face/mouth, hand/arm and leg) were the fixed factors, and participant identity was entered as random factor. There was a significant main effect of group $F(2,45) = 113.2, p < .001$, no main effect of effector $F(2,90) = .89, p > .05$ and no group-by-effector interaction $F(4,90) = .18, p > .05$. Bonferroni pairwise comparisons revealed accuracy of PWA was significantly lower than young and age-matched participants (PWA versus young: Mean difference = 63.1, $SE = 4.5$; PWA versus age-matched: Mean difference = 62.9, $SE = 4.5$). Young and age-matched participants did not differ in accuracy (Mean difference = .33, $SE = 3.4$).

Speech onset latency (SOL). The group-by-effector latencies are plotted in Figure 1. Linear mixed effects models were used to analyze log transformed SOLs. Participant group (young, age-matched, aphasia) and effector (face/mouth, hand/arm and leg) were the fixed factors, and participants and items were entered as random effects. There was a main effect of group, $F(2,45.9) = 12.3, p < .001$, and effector, $F(2,72.2) = 3.5, p < .05$, and a significant interaction between group and effector, $F(4, 2661.5) = 4.6, p < .01$. Pairwise comparisons with Bonferroni tests showed that SOLs of persons with aphasia were significantly longer than those of young and age-matched adults ($p < .001$; young versus aphasia: Mean difference = -.4, $SE = .09$, 95% $CI = -.63$ to $-.17$; age-matched versus aphasia: Mean difference = -.46, $SE = .09$, 95% $CI = -.7$ to $-.23$), while young and age-matched groups did not differ from each other ($p > .05$, Mean difference = .06, $SE = .05$). SOLs for Arm/hand verbs were significantly faster than those of Leg verbs ($p < .01$, Mean difference = -.156, $SE = .06$, 95% $CI = -.31$ to $-.004$) while Face/mouth versus Leg and Face/mouth versus Arm/hand SOLs did not differ from each other ($p > .05$;

Face/mouth versus Leg: Mean difference = $-.05$, $SE = .06$; Face/mouth versus Arm/hand: Mean difference = $.1$, $SE = .05$). The faster SOLs for Arm/hand verbs compared to Leg verbs were significant for the young and age-matched groups ($p < .01$; young: Mean difference = $-.16$, $SE = .05$; age-matched: Mean difference = $-.18$, $SE = .04$) and approached significance for persons with aphasia ($p = .055$; Mean difference = $-.12$, $SE = .08$).

Regression analyses. Descriptive statistics and regression coefficients of the linear multiple regression analyses are shown in Table 3. The model was able to account for 36% of the variance in SOL for the young group, $F(6,61) = 5.8$, $p < .001$, $R^2 = .36$, and for 33.5% of the variance for the age-matched group $F(7,60) = 4.3$, $p < .001$, $R^2 = .33$. For both young and age-matched adults, H-statistic and number of phonemes had significant ($p < .05$) zero-order correlation with SOL. Additionally, young adults' SOL correlated with effector association rating while age-matched adults' SOL correlated with argument structure. Significant partial effects in the full model were obtained for effector association rating (young adults: $t = -2.6$, $p < .01$, $\beta = -.32$; age-matched adults: $t = -2.1$, $p < .05$, $\beta = -.24$), lemma frequency (young adults: $t = 2.1$, $p < .05$, $\beta = .26$; age-matched adults: $t = 2.4$, $p < .05$, $\beta = .31$), and H-statistic (young adults: $t = 3.7$, $p < .001$, $\beta = .4$; age-matched adults: $t = 3.1$, $p < .01$, $\beta = .35$). In other words, three variables significantly predicted faster verb naming latencies for both speaker groups: higher effector association rating, high lemma frequency and low H statistic.

None of the individual PWA's logistic regression models reached statistical significance ($p > .05$) with the following variables entered into the equation: effector

association rating, lemma frequency, number of phonemes, argument structure, polysemy and H statistic of age-matched adults. For five out of eight participants, the age-matched adult group's H statistic was significantly associated with naming accuracy (A1, A2, A4, A7, A8, see Table 4). Better naming accuracy was associated with lower H statistic (that is, higher name agreement). One PWA's accuracy was associated with higher number of argument structures (A3) and two other PWA's accuracy was not associated with any variable that was entered into the regression analysis (A5 and A6).

Post-hoc analysis of effector verbs. Given the significant predictive effect of H-statistic, we conducted a follow up analysis of H-statistic differences to delineate if the significant SOL difference between leg and arm/hand verbs could be attributed to H-statistic (note: Table 2 already shows that leg verbs *do not* differ from arm/hand verbs in effector association rating and frequency). Linear mixed effects analysis revealed a significant difference between leg and arm/hand verbs on H-statistic young and age-matched adults (young: $F(6,65) = 3.4, p < .05$; Mean difference = $-.51, SE = .19$; age-matched: $F(6,65) = 3.6, p < .05$; Mean difference = $-.52, SE = .19$). For both groups, the mean H-statistic for leg verbs was *higher*, indicating poorer name agreement and therefore biasing towards longer SOLs. The mean H-statistics by effector are given in Table 5.

Priming of action verb naming

Accuracy. Young healthy participants' verb naming accuracies converted to rationalized arcsine units (Studebaker, 1985) and compared for prime type and effector using mixed effects models. There were no significant effects of prime type or effector

(all $F_s < 1$ and $p > .05$). All accuracies exceeded 93%. Although PWA group's percent accuracy was higher for phonemic and somatotopic primes compared to neutral primes, the effect of prime type was not significant (Friedman's two-way analysis of variance for related samples, $p > .05$; neutral: $M = 44.7\%$, $SE = 5.4$, phonemic: $M = 49.5\%$, $SE = 7.2$ and somatotopic: $M = 50.1\%$, $SE = 7.3$). Effector type was not entered as a factor for PWA because of the overall low number of correct responses and this analysis was not an *a priori* research question.

Speech onset latency (SOL). SOLs for each prime condition for the young healthy group and PWA are plotted in Figure 2. Individual PWA latencies are also plotted to illustrate individual response to primes. For young healthy participants, mixed model analysis of variance with prime (neutral, phonemic and somatotopic) and effector as fixed factors and participants and items as random factors showed significant main effects of prime type $F(2, 56.3) = 3.2$, $p < .05$ and effector $F(2, 64.9) = 5.8$, $p < .01$, but no interaction between prime and effector $F(4, 3681) = .75$, $p > .05$. Bonferroni pairwise comparisons showed that SOLs for both phonemic and somatotopic primes were significantly faster than neutral primes ($p < .05$; neutral versus phonemic: Mean difference = 180.1, $SE = 62.4$; neutral versus somatotopic: Mean difference = 188.1, $SE = 60.8$) and there was no difference between SOLs for phonemic and somatotopic primes (Mean difference = 17.1, $SE = 72.1$, $p > .05$). Bonferroni pairwise comparisons for effector type showed that SOLs for arm/hand verbs were faster than for leg and face/mouth verbs (arm/hand versus leg: Mean difference = -216.2, $SE = 78.4$; arm/hand versus face/mouth: Mean difference = -216.2, $SE = 74.4$). In sum, both phonemic and

somatotopic primes facilitated verb naming relative to neutral primes, and SOLs differed by effector type, fastest to slowest were arm/hand, face/mouth and leg.

Repeated measures analysis of variance (linear mixed model) for PWA on log transformed SOLs revealed a main effect of prime type $F(2, 548.5) = 11, p < .01$. Pairwise comparisons showed that latencies of phonemic primes were significantly faster than neutral ($p < .01$, Mean difference of logRT = $-.075$, $SE = .01$) and somatotopic primes ($p < .05$, Mean difference of logRT = $-.055$, $SE = .01$). Although somatotopic primes showed a trend to be faster than neutral condition SOLs, this contrast was not significant ($p > .05$, Mean difference of logRT = $-.02$, $SE = .01$). To summarize, both participant groups showed SOL facilitation with phonemic primes, healthy adults additionally showed a similar magnitude of facilitation with somatotopic primes, while PWA's SOLs differed between phonemic and somatotopic conditions.

Discussion

This study investigated two questions pertaining action verb retrieval: 1) influence of select semantic, lexical, syntactic and phonological properties, and 2) influence of somatotopic and phonemic primes. To our knowledge, this is the first study to investigate the effect of somatotopy on action verb naming (prior studies have addressed comprehension) and to conduct a regression analysis of these specific combination of semantic, lexical, syntactic and phonological properties on verb naming (most other studies have investigated nouns). The findings can be summarized into four main points. First, neurologically healthy participants named arm/hand verbs significantly faster than leg verbs. Verb-impaired PWA did not show a significant effect

of somatotopy on naming latencies (Figure 1). Second, verb naming latency was significantly predicted by three variables in healthy adults: higher effector association rating, high lemma frequency and low H statistic, and this model accounted for approximately one-third of the variance in naming latencies. Argument structure and number of phonemes failed to account for naming speed even though these variables differed significantly across effector groups. In PWA, age-matched adult's H statistic was significantly associated with verb naming accuracy in five participants. Third, both phonemic and somatotopic primes facilitated verb naming latencies in neurologically healthy adults. Finally, PWA were also facilitated by phonemic primes, while response to somatotopic primes not significant. Individual data in Figure 2 show that, numerically, all eight PWA had faster SOLs for phonemic and somatotopic primes although there is relatively high intrasubject variance (indicated by error bars) and moderate intersubject variability. The implications of these findings will be discussed in the following sections.

Variables that influence action verb naming

Neurologically healthy adults. The finding of faster latencies for arm/hand and face/mouth verbs and slow leg verbs is consistent with Pulvermuller et al.'s (2001) results for a lexical decision task. Hence this somatotopic effect is found in both input and output response modes for very distinct kinds of stimuli: action videos in the current study and written words in Pulvermuller et al.'s research. Before this cross domain difference in response speed for different effector verbs can be interpreted further, it is important to examine if this is an artifact of stimulus properties. Frequency, which is known to consistently influence naming speeds (e.g., Oldfield & Wingfield,

1965), did not differ across the three verb effector groups (Table 2). We used action videos in this study in order to minimize imageability differences across effector groups. We also obtained extensive naming norms to eliminate ambiguous stimuli, and collected effector association ratings to determine how closely each verb was associated with a single body part. Table 2 shows that leg verbs had one variable in favor of faster retrieval compared to arm/hand verbs (fewer argument structures) and one variable posing a production disadvantage (longer overall phoneme length). The regression analysis failed to identify either of these as significant predictors of SOLs and so these stimulus differences could not account for longer leg verb SOLs.

The linear regression analysis of neurologically healthy adults' speech onset latencies identified three predictors: H-statistic, frequency and effector association rating. Given that the three effector verb groups were already matched on frequency and effector association rating, a post-hoc comparison of H statistic across the three effector groups was conducted. This post-hoc analysis showed that leg verbs did have higher H statistic values (Table 5), which means that people used a wider variety of alternative names to describe leg actions compared to arm/hand actions (e.g., stomping was also named as stamping, stepping, hopping). It has been proposed that the different alternative names of a stimulus compete for lexical selection, slowing lexical retrieval of the target word. The strong association between response latencies and H statistic (or other name agreement measures) is consistent with other studies in the literature for noun naming (Barry et al., 1997; Bates et al., 2003; Lachman, et al., 1974; Snodgrass & Vanderwart, 1980; Vitkovitch & Tyrell, 1995). Hence the slower SOLs for leg verbs

compared to arm/hand verbs can be attributed, at least in part, to greater lexical competition arising from alternative names. The implications of this finding for semantics of somatotopy and embodied cognition will be discussed later.

The second predictor variable, effector association rating, pertains specifically to verbs of human action and refers to how strongly any verb was associated with a specific body part. For example, *smiling* may be rated more strongly as a face verb than *eating* or *sneezing* (which also involve hands to some extent). This study identifies the predictive importance of effector association, a variable that has not been well examined in past research on somatotopic effects on verb processing. The influence of effector association on speaking latencies is open to interpretation. The most intuitive explanation is that actions associated with multiple effectors (hence lower effector association rating) activate a larger set of sensorimotor representations compared to single effector actions. This more complex sensorimotor activation could potentially delay retrieval of a specific verb label, leading to longer SOLs. This account would predict an influence of effector association on processing tasks as well, such as lexical decision latencies. This account needs to be confirmed with future work because, to date, studies on effector verbs have only categorized verbs, and not considered the complexity of effector representations (Aziz-Zadeh, Wilson, Rizzolatti & Iacoboni, 2006; Hauk & Pulvermuller, 2004; Pulvermuller et al., 2001; Saccuman, Perani, Bates, Danna & Cappa, 2003).

Lemma frequency emerged as the third significant predictor of healthy adults' SOLs, showing that actions that could be labeled with higher frequency verb labels were

produced faster than lower frequency verbs. This finding is consistent with a robust body of prior research on frequency effects in a variety of other experimental paradigms such as picture naming, reading and lexical decision (Almeida, Knobel, Finkbeiner & Caramazza, 2007; Colombo & Burani, 2002; Jescheniak & Levelt, 1994; Oldfield & Wingfield, 1965). The present study extends frequency effects to action videos and verb naming.

Persons with aphasia. Individual logistic regression analyses found that PWA accuracy was not predicted by the semantic, lexical, phonological and syntactic variables examined in this study. The only similarity between neurologically healthy adults and PWA was that five out of eight participants' accuracies were predicted by H statistic obtained from the age-matched healthy group (Table 4). Kemmerer and Tranel (2000a) also found that name agreement was a significant predictor of verb naming. As discussed earlier, the H statistic could be considered a measure of lexical competition (Bates et al., 2003). Prior research with nouns has indicated that persons with Broca's aphasia may experience excessive difficulty in resolving lexical competition (Milberg, Blumstein, Katz, Gershberg & Brown, 1995; Schnur, Schwartz, Brecher & Hodgson, 2006).

The present study failed to find an effect of lexical frequency on any PWA. This finding is consistent with numerous other studies that found no frequency effects in PWA (Crutch & Warrington, 2005; Hoffman, Rogers & Lambon Ralph, 2011; Marshall, Pring, Chiat, & Robson, 2001; Warrington & Shallice, 1979) and studies that found frequency effects (Kemmerer and Tranel, 2000a; Kittredge, Dell, Verkuilen & Schwartz,

2008; Knobel, Finkbeiner & Caramazza, 2008; Luzzatti et al., 2002). Although the exact locus of frequency effects is debated (e.g., Allen et al., 2005), Hoffman et al. (2011) proposed that high frequency words may actually be more difficult for PWA because these words are typically more semantically diverse (polysemy) and therefore the nontarget senses of the high frequency word have to be inhibited. Hoffman et al. confirmed this frequency by polysemy interaction in a group of PWA who had a severe semantic deficit. The PWA group in the present study was relatively unimpaired in verb semantics, as indicated by ceiling performance in two tasks, Kissing and Dancing Test and verb comprehension adaptation from An Object and Action Naming Battery (Table 1). Hence Hoffman et al.'s account may not be applicable here. It has also been proposed that persons with lexical and phonological impairments will show (sometimes exaggerated) frequency effects (Kittredge et al., 2008; Knobel et al., 2008). Although the PWA group of this study likely had a lexical phonological locus of verb impairment, a frequency effect was not found. The lack of a straightforward account for the frequency effect is an attestation to the complex nature of verb retrieval impairment in PWA.

Another finding was an absence of an argument structure complexity effect, which is consistent with our findings for neurologically healthy adults and another large group study of aphasia (Kemmerer & Tranel, 2000a), but inconsistent with verb naming on agrammatic aphasia (Collina, Marangolo, Tabossi, 2001; Kim & Thompson, 2000, 2004; Thompson, Lange, Schneider & Shapiro, 1997). There are two possible interpretations of the argument structure findings: first, argument structure is an unimportant factor for the action verbs used in the present study, hence neither of the

three participant groups showed sensitivity. Second, methodological differences between the present study and past research could play a role. This study elicited verbs from action videos while pictures or narrative speech were used in past studies to elicit heterogeneous verbs (Collina et al., 2001; Kim & Thompson, 2000, 2004; Thompson et al., 1997). When heterogeneous verbs are used, argument structure complexity could get conflated with other variables such as semantic features, visual complexity, and, more importantly, *name agreement*. The present study highlights the significance of name agreement in successful verb retrieval (also Kemmerer & Tranel, 2000a).

To summarize, the key finding of this study is that the variables that predict action verb naming in neurologically healthy adults do not influence PWA, with a slight exception for name agreement. This PWA's insensitivity to critical variables suggests that the mechanisms underlying action verb retrieval are significantly degraded in this group.

Effect of Primes on Verb Naming

The assumption underlying priming methodology is that the prime stimulus will increase the activation level of semantic feature(s) or sound segment(s) that overlap with the target word, thereby increasing the probability of their selection for the target word within a network of possible semantic features or phonemes. Previous research with nouns has shown that the timing of prime presentation is crucial in determining whether the prime facilitates or interferes with naming of the target word (Carter, Hough, Stuart and Rastatter, 2011; Levelt et al., 1991; Schriefers, et al. 1990). Typically, in picture naming with nouns, semantic primes are facilitative at very early SOAs and

interfering at SOAs of 150 to 100ms before target, while facilitation by phonological primes appears later during the time course of lexical retrieval. Therefore, in the present study, semantic (somatotopic) and phonemic primes were presented at -600ms and -200ms SOA respectively. Both primes resulted in comparable facilitation effects of nearly 180ms in neurologically healthy adults. While only one past study has examined phonemic priming for verbs in PWA (Lee & Thompson, 2011), the novel aspects examined by the present study are: effects of phonemic priming on verb naming in neurologically healthy adults, somatotopic priming in healthy adults and PWA and elicitation of priming effects with videos, which, unlike pictures or visually presented words, unfold over time.

Somatotopic primes were carefully selected to avoid overlap in action/motion features or argument structure (e.g., cutting >>> waving), hence we can be confident that the priming effect was due to overlap in body part between the prime and target. This study adds verb production to the body of evidence on activation of effector information during action verb processing (Bergen et al., 2010; Faroqi-Shah et al., 2010; Glenberg & Kaschak, 2002; Hauk & Pulvermuller, 2004; Pulvermuller et al., 2001). Further, it shows that information about the effector is a semantic feature in the verb lexicon, akin to features such as +animal or +furniture for nouns (Bird et al., 2000; Vinson & Vigliocco, 2008; Warrington & Shallice, 1984). While numerous studies of brain imaging of action and action verb processing have reported activation of sensorimotor regions, the implications of this activation for mental representation of verbs has been debated (for critical reviews, see Aziz-Zadeh & Damasio, 2008; de Zubicaray, Postle,

McMahon, Meredith, & Ashton, 2010; Mahon & Caramazza, 2008). The crucial question for neuroimaging studies is whether activation of sensorimotor regions is an intrinsic semantic attribute that is a pre-requisite for verb processing, or is a post-semantic associative activation. The current finding of facilitative priming effect with effector overlap favors the view that effector information is an inherent feature of verb representations.

In this study, PWA's verb production was not effectively facilitated by somatotopic primes. There multiple potential reasons for this result. First, it is likely that somatotopic information is already available for this group of PWA given their ceiling performance on tasks of verb semantics. Hence the additional activation of somatotopic networks may not have addressed the verb retrieval impairment. Conversely, the activated somatotopic network may have dissipated by the presentation of the action video to named. This explanation is consistent with Faroqi-Shah et al. (2010) who found that a verb impaired group of participants² showed robust activation of somatotopic information in a primed lexical decision task. In that study, somatotopically overlapping primes interfered with the target at 200ms SOA, but not at 700ms SOA. The authors interpreted this finding as rapid decay of activation by 700ms because neurologically healthy adults showed interference effects at both SOAs. A third possible explanation is that activation boost of a single semantic feature may be insufficient to aid verb selection. A fourth explanation for the absence of semantic facilitation is that, as mentioned earlier, the most likely locus of verb impairment in this PWA group was

² A7 and A8 from this study also participated in the Faroqi-Shah et al. (2010) study.

(post-semantic) lexical retrieval or phonological encoding. And so phonemic primes, rather than somatotopic primes, may target the level of deficit.

In this study, PWA responded positively to phonemic primes, a finding that is consistent with Lee and Thompson (2011) for verb-impaired persons with agrammatic aphasia. All other prior work on phonemic facilitation in PWA used nouns, but the general finding is improvement in word retrieval when the prime type matches the type of deficit (phonological or semantic) (Howard, Patterson, Franklin & Morton, 1985; Martin, Fink, Laine & Ayala, 2004).

To summarize, the results of the priming manipulation illustrate that pre-activation of semantic and phonological segments improves speed of action verb naming in neurologically healthy adults. PWA with a post-semantic verb-impairment benefit from phonological priming, but not from semantic priming.

Theoretical and Clinical Implications

There are two main theoretical implications of the present research: mental representation of verbs and language embodiment. It should be noted that the use of action verbs in this study limits the generality of the findings to the entire class of verbs, but allows one to address a very specific set of predictions about verb representations. Facilitation by somatotopic primes indicates that effector information is a tangible attribute of an action verb's mental representation. However, there is little evidence to support that somatotopically different verb groups differ in processing complexity that is independent of other factors: slower naming of leg verbs is mostly likely the

consequence of lower name agreement for this effector group. This conclusion is in contrast with the proposal that, because the somatotopic representation of leg verbs is farther away from language cortices than hand/arm verbs, leg verbs have a wider neurocognitive network that takes longer to get activated (Pulvermuller et al., 2001). The confound between somatotopy and name agreement (and possibly effector association) provides a cautionary note to the numerous recent studies in which action verbs have been investigated in a variety of clinical populations with motor impairments such as Parkinson's Disease and semantic deficits semantic dementia (Kemmerer, Miller, MacPherson, Humber & Tranel, 2013; Pulvermuller et al., 2009).

This study found that verb impaired PWA's verb representations are degraded to an extent that verb retrieval was not governed by the typical predictors of verb naming (frequency and effector association) were unreliable. Name agreement had a partial effect for individual PWAs. The findings of this study also have implications for verb retrieval intervention in PWA: somatotopic primes (at least in the manner of presentation used in the present study) less likely to be effective than phonemic primes. Future research can confirm these clinical predictions.

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APPENDIX

List of verbs used in the study, their psychometric properties and name agreement values (H statistic). The effector ratings were obtained from native English speakers using a 7 point scale (7=hand/arm/face is totally used for this action). Lemma frequencies are per million for the printed word, phonemes were calculated for the progressive verb form. H statistics was separately calculated for young and age-matched adults based on their responses (see text for calculation details).

Verb	Body Part	Effector Rating	Lemma Frequency (CELEX)	Phonemes	Polysemy (WordNet)	Argument Structure (VerbNet)	H Statistic (YN)	H Statistic (AN)
biting	Face	5.27	27	5	4	2	0.998	1.469
blinking	Face	6.23	14	7	3	1	0.723	1.292
blowing	Face	5.54	84	5	23	3	0	0
chewing	Face	6.35	20	4	1	2	0	0.569
crying	Face	5.04	120	5	7	1	1.28	1.419
kissing	Face	5.35	59	5	2	2	0	0.286
laughing	Face	5.96	170	5	1	1	0.276	0.848
licking	Face	5.42	11	5	4	2	0.276	0.569
nodding	Face	6.2	79	5	5	1	0	0
singing	Face	5.35	78	5	7	2	0.276	0.286
smiling	Face	6.62	173	6	2	1	0	0.569
sneezing	Face	4.77	3	6	1	1	0.454	0.881
spitting	Face	5.12	11	6	4	2	0	0.286
staring	Face	6.5	130	6	2	2	0.857	2.071
sucking	Face	4.67	36	5	7	2	0.549	1.054
talking	Face	5.73	471	6	6	1	0.792	1.392
whispering	Face	4.68	43	7	1	1	0	0.286
whistling	Face	4.62	13	6	6	2	0.276	1.885
winking	Face	6.44	9	6	4	1	0.276	0
yawning	Face	4.73	8	5	2	1	0	0
catching	Hand	6.29	193	5	29	2	1.845	1.504
clapping	Hand	6.58	12	6	7	3	0	0
closing	Hand	4.96	120	6	17	2	0.592	0.469
cutting	Hand	6.12	190	5	41	2	0	0
dialing	Hand	6.36	8	5	2	2	1.221	2.602

digging	Hand	6.08	40	5	8	2	1.206	0.469
drawing	Hand	6.68	215	5	36	2	0	0
erasing	Hand	6.5	4	6	3	2	0	0.569
folding	Hand	6.42	38	6	5	3	0	0
juggling	Hand	5.85	2	6	5	2	0.276	0
knocking	Hand	6.23	54	5	6	2	0	0
opening	Hand	5.35	230	6	11	3	0	0.286
painting	Hand	6	72	6	4	2	0	0.439
peeling	Hand	6.27	10	5	3	2	0.276	0
pinching	Hand	5.83	9	6	5	2	0	0
poking	Hand	6.12	14	5	5	2	0.723	1.319
pouring	Hand	6.23	79	5	6	3	0.276	0
pushing	Hand	6.12	125	5	10	2	0.276	0.469
sawing	Hand	6.08	3	4	1	2	0.276	0.569
scratching	Hand	5.62	24	7	7	2	0.592	0.286
sewing	Hand	6.42	11	4	2	2	0.549	0.569
snapping	Hand	6.35	28	6	13	3	0	0.569
stirring	Hand	6.31	41	6	8	3	0.454	0
swiping	Hand	6.04	1	6	2	2	0.454	1.885
tickling	Hand	5.65	4	6	3	2	0	0
tying	Hand	6.38	61	4	9	2	0	0
typing	Hand	6.46	17	5	2	1	0	0
washing	Hand	5.16	93	5	13	2	0.549	0
waving	Hand	6.23	45	5	5	3	0	0
wiping	Hand	6.24	37	5	1	2	0.893	1.579
writing	Hand	6.69	464	5	8	2	0.276	0.748
climbing	Leg	6	92	6	6	2	1.877	1.671
dancing	Leg	5.5	66	6	3	1	0.818	0.286
jogging	Leg	6.13	5	5	6	1	0.959	0.993
jumping	Leg	6.36	67	6	15	1	0	0.88
kicking	Leg	6.5	42	5	8	2	0	0
kneeling	Leg	6.35	23	5	1	1	0.549	0.286
limping	Leg	6.67	7	6	2	1	1.375	1.98
pedaling	Leg	6.33	3	7	2	2	1.736	2.039
running	Leg	6.33	441	5	40	3	0.549	0
skating	Leg	5.56	3	6	1	1	1.049	0.884
skipping	Leg	6.35	9	6	6	1	0.276	0.992
squatting	Leg	6.29	5	6	3	1	0.276	1.022
standing	Leg	6.19	467	7	12	1	0.276	0.884
stomping	Leg	6.5	17	7	1	2	0.276	1.154
tiptoeing	Leg	5.87	4	7	1	1	0.549	1.501
tripping	Leg	5.92	7	6	5	3	1.363	1.395
walking	Leg	6.5	309	6	10	1	0	0.61

REFERENCES

- Ahrens, K., & Swinney, D. (1995). Participant roles and the processing of verbs during sentence comprehension. *Journal of Psycholinguistic Research*, 24, 533-547.
- Almeida, J., Knobel, M., Finkbeiner, M., & Caramazza, A. (2007). The locus of the frequency effect in picture naming: When recognizing is not enough. *Psychonomic Bulletin & Review*, 14, 1177-1182.
- Almor, A., Aronoff, J. M., MacDonald, M. C., Gonnerman, L. M., Kempler, D., Hintiryan, H., . . . , & Andersen, E. S. (2009). A common mechanism in verb and noun naming deficits in Alzheimer's patients. *Brain and Language*, 111, 8-19.
- Almor, A., Kempler, D., Andersen, E. S., & MacDonald, M. C. (2005). Frequency and semantic effects on verb reading in aging and dementia. *Brain and Language - Special Abstract Issue Academy of Aphasia*, 95, 147.
- Arévalo, A., Perani, D., Cappa, S. F., Butler, A., Bates, E., & Dronkers, N. (2007). Action and object processing in aphasia: From nouns and verbs to the effect of manipulability. *Brain and Language*, 100(1), 79-94.
- Ashenfelter, K. T., & Eberhard, K. M. (2007). Effects of verb complexity on speech errors. *Memory and Cognition*, 35(7), 1527-1541.
- Aziz-Zadeh, L., & Damasio, A. (2008). "Embodied semantics for actions: Findings from functional brain imaging." *Journal of Physiology – Paris*, 102, 35-39.

- Aziz-Zadeh, L., Wilson, S. M., Rizzolatti, G., & Iacoboni, M. (2006). Congruent embodied representations for visually presented actions and linguistic phrases describing actions. *Current Biology*, 16, 1818-1823.
- Baayen, R., Piepenbrock, R., & van Rijn, H. (1993). The celex lexical database (release 1) [cd-rom]. Philadelphia, Linguistic Data Consortium: University of Pennsylvania [Distributer].
- Bak, T. H., & Hodges, J. R. (2003). Kissing and dancing--a test to distinguish the lexical and conceptual contributions to noun/verb and action/object dissociation. Preliminary results in patients with frontotemporal dementia. *Journal of Neurolinguistics*, 16, 169-181.
- Barde, L. H. F., Schwartz, M. F., & Boronat, C. B. (2006). Semantic weight and verb retrieval in aphasia. *Brain and Language*, 97, 266-278.
- Barry, C., Morrison, C. M., Ellis, A. W. (1997). Naming the Snodgrass and Vanderwart pictures: effects of age of acquisition, frequency, and name agreement. *Quarterly journal of Experimental Psychology*, 50A, 560-585.
- Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral & Brain Sciences*, 22, 577-609.
- Barsalou, L. W. (2010). Grounded cognition: Past, present, and future. *Topics in Cognitive Science*, 2, 716-724.
- Bates, E., D'Amico, S., Jacobsen, T., Szekely, A., Andonova, E., Devescovi, A., . . . Tzeng, O. (2003). Timed picture naming in seven languages. *Psychonomic Bulletin & Review*, 10, 340-380.

- Bedny, M., & Caramazza, A. (2011). Perception, action, and word meanings in the human brain: the case from action verbs. *Annals of the New York Academy of Sciences*, 1224, 81-95.
- Bergen, B., Lau, A., Narayan, S., Stojanovic, D., & Wheeler, K. (2010). Body part representations in verbal semantics. *Memory and Cognition*, 38, 969-981.
- Binder, J. & Desai, R. (2011). The neurobiology of semantic memory. *Trends in Cognitive Sciences*, 15, 527-536.
- Bird, H., Howard, D., & Franklin, S. (2000). Why Is a Verb Like an Inanimate Object? Grammatical Category and Semantic Category Deficits. *Brain and Language*, 72, 246-309.
- Black, M., & Chiat, S. (2003). Noun-verb dissociations: a multi-faceted phenomenon. *Journal of Neurolinguistics*, 16, 231-250.
- Bock, K. (1986). Syntactic persistence in language production. *Cognitive Psychology*, 18, 355-387.
- Bonnotte, I. (2008). The role of semantic features in verb processing. *Journal of Psycholinguistic Research*, 37, 199-217.
- Boo, M., & Rose, M. (2010). The efficacy of repetition, semantic, and gesture treatments for verb retrieval and use in Broca's aphasia. *Aphasiology*, 25, 17-37.
- Breedin, S. D., Saffran, E. M., & Schwartz, M. F. (1998). Semantic factors in verb retrieval: an effect of complexity. *Brain and Language*, 63, 1-31.
- Chatterjee, A. (2010). Disembodying cognition. *Language & Cognition*, 2(1), 79-116.

- Collina, S., Marangolo, P., & Tabossi, P. (2001). The role of argument structure in the production of nouns and verbs. *Neuropsychologia*, 39, 1125-1139.
- Colombo, L., & Burani, C. (2002). The influence of age of acquisition, root frequency, and context availability in processing nouns and verbs. *Brain and Language*, 81, 398-411.
- Conroy, P., Sage, K., & Lambon Ralph, M. (2006). Towards theory-driven therapies for aphasic verb impairments: A review of current theory and practice. *Aphasiology*, 20, 1159-1185.
- Crutch, S. J., & Warrington, E. K. (2005). Abstract and concrete concepts have structurally different representational frameworks. *Brain*, 128, 615-627.
- Dabul, B. (2000). Apraxia Battery for Adults-Second Edition (ABA-2). Austin, TX: Pro-ed.
- de Zubicaray, G., et al. (2008). Mirror neurons, the representation of word meaning, and the foot of the third left frontal convolution. *Brain and Language*, 112, 77-84.
- Druks, J., & Masterson, J. (2000). *An object and action naming battery*. Philadelphia, PA: Taylor & Francis.
- Druks, J., & Masterson, J. (2000). *An object and action naming battery*. Philadelphia, PA: Taylor & Francis.
- Edmonds, L. A., Nadeau, S. E., & Kiran, S. (2009). Effect of Verb Network Strengthening Treatment (VNeST) on Lexical Retrieval of Content Words in Sentences in Persons with Aphasia. *Aphasiology*, 23, 402-424.

- Faroqi-Shah, Y., & Graham, L. E. (2011). Treatment of semantic verb classes in aphasia: acquisition and generalization effects. *Clinical Linguistics & Phonetics*, 25, 399-418.
- Faroqi-Shah, Y., Wood, E., & Gassert, J. (2010). Verb impairment in aphasia: a priming study of body part overlap. *Aphasiology*, 24(11), 1377-1388.
- Fink, R. B., Martin, N., Schwartz, M. F., Saffron, E. M., & Myers, J. L. (1992). Facilitation of verb retrieval skills in aphasia: a comparison of two approaches. *Clinical Aphasiology*, 21, 263-272.
- Gentner, D. (1982). Why nouns are learned before verbs: linguistic relativity versus natural partitioning. In Kuczaj, S. (Ed.) (1982). *Language Development*. Hillsdale, N.J.: Lawrence Erlbaum.
- Glaser, W. R., & Duengelhoff, F.J. (1984). The time course of picture-word interference. *Journal of Experimental Psychology: Human Perception & Performance*, 10, 640-654.
- Glenberg, A. M., & Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bulletin & Review*, 9(3), 558-565.
- Hartsuiker, R. J., & Kolk, H. H. J. (1998). Syntactic facilitation in agrammatic sentence production. *Brain & Language*, 62, 221-254.
- Hoffman, P., et al. (2011). Semantic Diversity Accounts for the “Missing” Word Frequency Effect in Stroke Aphasia: Insights Using a Novel Method to Quantify Contextual Variability in Meaning. *Journal of Cognitive Neuroscience*, 23: 2432–2446.

- Howard, D., Patterson, K. E., Franklin, S., Orchard-Wise, V., & Morton, J. (1985). The facilitation of picture naming in aphasia. *Cognitive Neuropsychology*, 2, 49-65.
- Jescheniak, J.-D., & Levelt, W. J. M. (1994). Word frequency effects in speech production: Retrieval of syntactic information and of phonological form. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, 20, 824-843.
- Jonkers, R., & Bastiaanse, R. (2007). Action naming in anomic aphasic speakers: Effects of instrumentality and name relation. *Brain and Language*, 102, 262-272.
- Kemmerer, D., & Tranel, D. (2000a). Verb Retrieval in Brain-Damaged Subjects: 1. Analysis of Stimulus, Lexical, and Conceptual Factors. 73, 347-392.
- Kemmerer, D., & Tranel, D. (2000b). Verb Retrieval in Brain-Damaged Subjects: 2. Analysis of Errors. *Brain and Language*, 73, 393-420.
- Kemmerer, D., Castillo, J. G., Talavage, T., Patterson, S., & Wiley, C. (2008). Neuroanatomical distribution of five semantic components of verbs: Evidence from FMRI. *Brain and Language*, doi:10.1016/j.bandl.2007.09.003.
- Kemmerer, D., Rudrauf, D., Manzel, K., & Tranel, D. (2012). Behavioral patterns and lesion sites associated with impaired processing of lexical and conceptual knowledge of actions. *Cortex*, 48, 826-848.
- Kertesz, A. (2006). Western aphasia battery-Revised. Grune Stratton. New York.
- Kiefer, M., & Pulvermüller, F. (2011). Conceptual representations in mind and brain: Theoretical developments, current evidence and future directions. *Cortex*, 48, 805-25.

- Kipper-Schuler. (2005). *VerbNet: A broad-coverage, comprehensive verb lexicon*. (PhD), University of Pennsylvania. Retrieved from <http://verbs.colorado.edu/verb-index/>
- Kim, M. & Thompson, C. K. (2000). Patterns of comprehension and production of nouns and verbs in agrammatism: Implications for lexical organization. *Brain and Language*, 74, 1-25.
- Kim, M., & Thompson, C. K. (2004). Verb deficits in Alzheimer's disease and agrammatism: Implications for lexical organization. *Brain and Language*, 88, 1-20.
- Kiss, K. (2000). Effects of verb complexity on agrammatic aphasic's sentence production. In R. Bastiaanse & Y. Grodzinsky (Eds.), *Grammatical disorders in aphasia* (123-151). London: Whurr Publishers.
- Kittredge, A. K., et al. (2008). Where is the effect of frequency in word production? Insights from aphasic picture-naming errors. *Cognitive Neuropsychology*, 25, 463-492.
- Knobel, M., et al. (2008). The many places of frequency: Evidence for a novel locus of the lexical frequency effect in word production. *Cognitive Neuropsychology*, 25, 256-286.
- Lachman, R., Shaffer, J. P., & Hennrikus, D. (1974). Language and cognition: effects of stimulus codability, name-word frequency, and age of acquisition on lexical reaction time. *Journal of verbal learning and verbal behavior*, 13, 613-625.

- Lee, J., & Thompson, C. (2011). Phonological facilitation effects during noun and verb naming in agrammatic and anomic aphasia. *Procedia-Social and Behavioral Sciences*, 23, 180-181.
- Levelt, W. J. M., Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech production. *Behavioural and Brain Sciences*, 22, 1-75.
- Luzzatti, C., Raggi, R., Zonca, G., Pistarini, C., Contardi, A., & Pinna, G-D. (2002). Verb-noun double dissociation in aphasic lexical impairments: The role of word frequency and imageability. *Brain and Language*, 81, 432-444.
- Mahon, B. Z. and A. Caramazza (2008). A critical look at the embodied cognition hypothesis and a new proposal for grounding conceptual content. *Journal of Physiology – Paris*, 102, 59-70.
- Marangolo, P., Cipollari, S., Fiori, V., Razzano, C., & Caltagirone, C. (2012). Walking but Not Barking Improves Verb Recovery: Implications for Action Observation Treatment in Aphasia Rehabilitation. *PLoS ONE*, 7(6), 1-7.
- Marshall, J., Pring, T., Chiat, S., & Robson, J. (2001). When ottoman is easier than chair: An inverse frequency effect in jargon aphasia. *Cortex*, 37, 33–53.
- Martin, N., Fink, R., Laine, M. & Ayala, J. (2004). Immediate and short-term effects of contextual priming on word retrieval in aphasia. *Aphasiology*, 18, 867-898.
- Matzig, S., Druks, J., Masterson, J., & Vigliocco, G. (2009). Noun and verb differences in picture naming: Past studies and new evidence. *Cortex*, 65(6), 738-758.
- McRae, K., Hare, M.L., Elman, J.E., and Ferretti, T. (2005). A basis for generating expectancies for verbs from nouns. *Memory and Cognition*, 33, 1174-1184.

Memory and Cognition, 35(7), 1527-1541.

Oldfield, R. C., & Wingfield, A. (1965). Response latencies in naming objects. *Quarterly Journal of Experimental Psychology*, 17, 273-281.

Parris, B., & Weekes, B. (2001). Action naming in dementia. *Neurocase*, 7, 459-471.

Pulvermüller, F., et al. (2009). The Word Processing Deficit in Semantic Dementia: All Categories Are Equal, but Some Categories Are More Equal than Others. *Journal of Cognitive Neuroscience*, 21, 2027-2041.

Pulvermüller, F., Härle, M., & Hummel, F. (2001). Walking or talking? Behavioral and neurophysiological correlates of action verb processing. *Brain and Language*, 78, 143-160.

Schneider, S. L., & Thompson, C. K. (2003). Verb production in agrammatic aphasia: The influence of semantic class and argument structure properties on generalisation. *Aphasiology*, 17, 213-241.

Schnur, T. T., Schwartz, M. F., Brecher, A., & Hodgson, C. (2006). Semantic interference during blocked-cyclic naming: Evidence from aphasia. *Journal of Memory and Language*, 54, 199-227.

Schriefers, H., Meyer, A. S., & Levelt, W. J. M. (1990). Exploring the time course of lexical access in speech production: Results from picture-word interference experiments. *Journal of Memory and Language*, 29, 86-102.

Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: Norms for name agreement, familiarity and visual complexity. *Journal of Experimental Psychology: Human Learning & Memory*, 6, 174-215.

- Studebaker, G. A. (1985). A "Rationalized" Arcsine Transform. *Journal of Speech Hearing Research, 28*, 455-462.
- Szekely, A., D'Amico, S., Devescovi, A., Federmeier, K., Herron, D., Iyer, G., . . ., Bates, E. (2005). Timed Action and Object Naming. *Cortex, 41*, 7-25.
- Tettamanti, M., Buccino, G., Saccuman, M. C., Gallese, V., Danna, M., Scifo, P., et al. (2005). Listening to action-related sentences activates fronto-parietal motor circuits. *Journal of Cognitive Neuroscience, 17*, 273–281.
- Thompson, C. K., Lange, K. L., Schneider, S. L., & Shapiro, L. P. (1997). Agrammatic and non-brain-damaged subjects' verb and verb argument structure production. *Aphasiology, 11*, 473-490.
- Vinson, D. P., & Vigliocco, G. (2008). Semantic feature production normals for a large set of objects and events. *Behavior Research Methods, 40*, 183-190.
- Vitkovitch, M., & Tyrell, L. (1995). Sources of disagreement in object naming. *Quarterly journal of Experimental Psychology, 48A*, 822-848.
- Wambaugh, J. L., Cameron, R., Kalinyak-Fliszar, M., Nessler, C., & Wright, S. (2004). Retrieval of action names in aphasia: Effects of two cueing treatments. *Aphasiology, 18(11)*, 979-1004.
- Warrington, E. K., & Shallice, T. (1979). Semantic access dyslexia. *Brain, 102*, 43–63.
- Warrington, E. K., & Shallice, T. (1984). Category specific semantic impairments. *Brain, 107*, 829-853.
- WordNet: An Electronic Lexical Database*. (1998). C. Fellbaum (Ed.) Retrieved from <http://wordnet.princeton.edu/wordnet/citing-wordnet/>

Table 1.

Demographic details and language scores of participants with aphasia.

Participant	Age & Gender	Yrs Educ	MPO	Prior Occupation	WAB-R					OANB		KDT	Narratives	
					Aphasia Quotient	Fluency	Compr	Naming	Repetition	Object /Action	Verb Comp*		WPM	Prop. Gram
A1	63/F	16	79	<u>Max. Score→</u> Nurse	<u>100</u> 64.8	<u>10</u> 4	<u>10</u> 5.6	<u>10</u> 6	<u>10</u> 7.8	<u>50/50</u> 45/32	<u>24</u> 23	<u>52</u> 48 50.	13.2	0
A2	62/M	12	60	Clerk Program	80.3	5	9.05	8.5	8.6	46/35	24	5	47.8	0.2
A3	52/F	16	71	analyst	87.6	6	9.7	9.2	9.2	48/35	24	51	56.7	0.35
A4	70/M	21	66	Attorney Telecom	78.8	6	7.5	8.5	7.4	33/29	24	50	44.8	0.15
A5	63/M	18	22	Engineer	55.3	4	5.65	4.7	5.3	30/24	22	50	82.5	0.33
A6	74/M	25+	52	Professor	59.7	3	7.8	6.2	3.4	25/9	23	51	45.8	0.19
A7	45/M	16	160	Police Officer	80	4	9	9	9	39/25	24	49	34.9	0.1
A8	47/M	16	86	Elect. Engineer	75.6	5	9.2	7.9	6.7	42/18	24	51	29	0

KDT: Kissing and Dancing Test; MPO: months post onset, Prop Gram: proportion of grammatical utterances; WAB-R: Western Aphasia Battery- Revised, WPM: words per minute

Table 2.

Properties of the three effector groups of verbs used in this study, mean and standard deviations. Statistically significant differences between verb groups are indicated.

	Face/mouth	Arm/hand	Leg
Number of verbs	20	31	17
Lemma Frequency per million (CELEX)	77.9 (107.2)	72.4 (98.7)	92. 2 (154.8)
Effector Association **	5.5 (.7)	6.1 (.41)	6.2 (.33)
Syllable length	2.05 (.22)	2.03 (.18)	2.11 (.33)
Phoneme length *	5.5 (.76)	5.35 (.71)	6.0 (.7)
Argument Structure**	1.55 (.6)	2.2 (.47)	1.5 (.71)

* = $p < .05$; ** = $p < .01$

Table 3.

Results of linear multiple regression on speech onset latencies of neurologically healthy participants. The table represents correlations between variables, the standardized regression coefficient (β) for each variable. * $p < .05$; ** $p < .01$

Variable	H statistic	Polysemy	Argument structure	Phoneme number	Lemma frequency	Eff. Assoc. Rating	SOL (YN)	SOL (AN)	β (YN)	β (AN)
Zero-Order r										
Effector Association Rating							-0.314*	-0.165*	-0.31**	-0.242*
Lemma frequency						0.14	0.099	0.171	0.256*	0.311*
Phoneme number					-0.003	-0.078	0.227*	0.284*	0.124	0.104
Argument structure				-0.185	-0.023	0.088	-0.192*	-0.243*	-0.037	-0.056
Polysemy			0.302	-0.17	0.503	0.099	-0.156	-0.172	-0.203	-0.199
H statistic (YN)		-0.048	-0.092	0.093	-0.029	-0.016	0.43**		0.408**	
H statistic (AN)		-0.25	-0.22	0.247	-0.036	0.01		0.438**		0.35**
Mean	0.43 (YN) .67 (AN)	4.4	1.82	5.5	78.9	5.9				
SD	0.49 (YN) .67 (AN)	3.6	0.67	0.76	115.8	0.56				

Table 4

Results of binary logistic regression on accuracy in individual persons with aphasia. The significant predictor variable is listed. The overall model was not significant for any participant.

Participant	Predictor Variable	β , SE	Wald χ^2	p
A1	H statistic	-1.1 , .4	5.26	.02
A2	H statistic	-1.25, .4	6.9	.008
A3	Argument Structure	1.01, .4	5.3	.02
A4	H statistic	-1.02, .4	5.3	.02
A5	None			
A6	None			
A7	H statistic	-1.1 , .3	5.8	.01
A8	H statistic	-1.21, .4	6.3	.009

Table 5

Name agreement measure (H statistic) for neurologically healthy adults for the three effector verb sets. Higher H statistic denotes lower name agreement.

	Face/mouth	Arm/hand	Leg
Young adults	.36 (.1)	.34 (.08)	.7 (.11)
Age-matched adults	.76 (.14)	.46 (.11)	.97 (.15)

Figure Captions

Figure 1. Mean speech onset latencies (milliseconds) for each participant group and verb effector group. Positive error bars represent standard error of the mean. * $p < .05$.

Figure 2. Mean speech onset latencies (milliseconds) for neurologically healthy and aphasic participants for each prime condition. Positive error bars represent standard error of the mean. * $p < .05$