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Processing Distinct Linguistic Information Types in Working Memory in Aphasia

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ABSTRACT

Background: Recent investigations have suggested that adults with aphasia present with a working memory deficit which may contribute to their language processing difficulties. Working memory capacity has been conceptualized as a single "resource" pool for attentional, linguistic, and other executive processing; alternatively, it has been suggested that there may be separate working memory abilities for different types of linguistic information. A challenge in this line of research is developing an appropriate measure of working memory ability in adults with aphasia. One candidate measure of working memory ability that may be appropriate for this population is the *n*-back task. By manipulating stimulus type, the *n*-back task may be appropriate for tapping linguistic-specific working memory abilities.

Aims: he purposes of this study were (a) to measure working memory ability in adults with aphasia for processing specific types of linguistic information and (b) to examine whether a relationship exists between participants' performance on working memory and auditory comprehension measures.

Method & Procedures: Ten adults with aphasia participated in the study. Participants completed three *n*-back tasks, each tapping different types of linguistic information. They included the *PhonoBack* (phonological level), *SemBack* (semantic level), and *SynBack* (syntactic level). For all tasks, two *n*-back levels were administered: a 1-back and 2-back. Each level contained 20 target items; accuracy was recorded by stimulus presentation software. The *Subject-relative, Object-relative, Active, Passive Test of Syntactic Complexity* (SOAP) was the syntactic sentence comprehension task administered to all participants.

Outcomes & Results: Participants' performance declined as *n*-back task difficulty increased. Overall, participants overall performed better on the *SemBack* than *PhonoBack* and *SynBack* tasks, but the differences were not statistically significant. Finally, participants who performed poorly on the *SynBack* also had more difficulty comprehending syntactically complex sentence structures (i.e., passive & object-relative sentences).

Conclusions: Results indicate that working memory ability for different types of linguistic information can be measured in adults with aphasia. Further, our results add to the growing literature that favors the separate working memory abilities for different types of linguistic information view.

Recent investigations have suggested that adults with aphasia present with a working memory deficit (e.g., Caspari, Parkinson, LaPointe, & Katz, 1998, Friedmann & Gvion, 2003; Downey, Wright, Schwartz, Newhoff, Love, & Shapiro, 2004; Yasuda & Nakamura, 2000) and this deficit may contribute to the language processing difficulties found in these individuals (Caspari et al., 1998; Friedman & Gvion, 2003; Wright & Shisler, 2005). Working memory capacity has been conceptualized as a single “resource” pool for attentional, linguistic, and other executive processing (e.g., Just & Carpenter, 1992). It has also been suggested that there may be separate working memory abilities for different types of linguistic information (e.g., Caplan & Waters, 1999; Friedmann & Gvion, 2003; 2006). Moreover, individuals with aphasia may exhibit differential difficulty processing distinct types of linguistic information, such as phonological, semantic, and syntactic (Angrilli, Elbert, Cusumano, Stegagno, & Rockstroh, 2003; Martin, Wu, Freedman, Jackson, & Lesch, 2003; Vallar, Corno, & Basso, 1992; Waters & Caplan, 1996; 1999) which may contribute to their overall difficulties with language. Friedmann and Gvion (2003) suggested that the effect of a verbal working memory deficit on sentence comprehension is dependent on the type of processing (i.e., semantic, syntactic, phonological) required in the sentence.

A challenge in investigating working memory in aphasia is developing an appropriate measure. This has met with mixed success. Historically, adaptations of Daneman and Carpenter’s Reading Span test (1980) have been administered to individuals with aphasia in an effort to measure working memory capacity. Such tasks require participants to process multiple types of information (i.e., phonological, semantic, syntactic) simultaneously, while also remembering sentence-final words for later recall or recognition. Not surprisingly, many individuals perform poorly on such tasks (Caspari et al., 1998; Tompkins, Bloise, Timko, &

Baumgaertner, 1994; Wright, Newhoff, Downey, & Austermann, 2003). Yet, due to the conflation of distinct linguistic information types involved in such a task, it is impossible to determine where breakdowns occur.

One candidate measure of working memory ability that may be appropriate for this population is the *n*-back task (task is described in detail in the method section). Downey et al. (2004) suggested that an *n*-back task may be useful in differentiating individuals with aphasia based on working memory ability. To perform the *n*-back task different cognitive processes are required, these include storing *n* information in working memory and continuously updating contents of working memory by dropping the old, unnecessary information and adding the newly presented information (Jonides, Lauber, Awh, Satoshi, & Koeppe, 1997). This task is commonly used to measure working memory ability in functional neuroimaging studies for several reasons. The task does not require an overt verbal response; participants can respond with a button press. Task difficulty can be increased parametrically by increasing the *n* back, thus increasing memory load and taxing the participant's working memory system. Also, by including several levels of the *n*-back (i.e., 0-back, 1-back, 2-back), a baseline task is not needed; rather, comparisons can be made between the different task levels. Finally, by manipulating stimulus type, the *n*-back task may be appropriate for tapping linguistic-specific working memory abilities. For these reasons, the *n*-back task may be an appropriate measure of working memory ability in adults with aphasia and differentiating individuals based on linguistic-specific working memory ability.

The present study is a follow-up to the study by Downey and colleagues (2004). In the initial study, we determined if the *n*-back task, using semantically-related stimuli, was appropriate to use with adults with aphasia and if a relationship existed between performance on the WM measure and performance on a syntactic, auditory comprehension measure. Participants' performance declined as *n*-back task difficulty increased, but no relationship was found between performance on the *n*-back and comprehension measures. However, the two tasks tapped different types of linguistic information (i.e., semantic and syntactic). Friedmann and Gvion (2003) hypothesized that to measure the effect of a working memory limitation on sentence comprehension, the type of reactivation required, the memory load, and the working memory limitation all need to be the same (i.e., phonological, syntactic, etc…) and they demonstrated this with adults with conduction aphasia. Investigating this tripartite relationship in adults with aphasia is a logical next step in unraveling the relationship between sentence comprehension and working memory. The purposes of the current study, then, were (a) to measure working memory ability in adults with aphasia for processing specific types of linguistic information and (b) to examine whether a relationship exists between participants' performance on working memory and auditory comprehension measures.

METHOD

Participants

Ten adults with aphasia participated in the study. Participants included one female and nine males, ages 44 to 80 (Mean = 59.6; SD = 14.0). Years of education completed ranged from eight to 20+ (Mean = 14.0, SD = 3.2). All participants presented with unilateral left hemisphere damage subsequent to cerebrovascular accident (CVA). Clinical criteria for participation included (a) no more than one stroke located in the left hemisphere, (b) at least six months post onset of the stroke, (c) pre-morbid right-handed, and (d) no history of dementia or other neurological illness. In addition to the previously mentioned inclusion criteria, all participants met the following criteria, as well: (a) aided or unaided hearing acuity within normal limits; (b) normal or corrected visual acuity; and (c) sufficient dexterity control to make responses using a computer keyboard or button box. All participants presented with aphasia as confirmed by clinical diagnosis and performance on the *Western Aphasia Battery* (WAB; Kertesz, 1982). Aphasia quotients (AQ) were obtained for each participant who received the WAB. Table 1 presents group demographic and clinical description data.

Table 1 about here

Stimuli and tasks

N-back tasks. We developed three *n*-back tasks, each tapping different types of linguistic information. They included the *PhonoBack*, which tapped the phonological level, *SemBack*, tapping the semantic level, and *SynBack*, which tapped the syntactic level. For all tasks, two *n*-back levels were administered: a 1-back and 2-back, each containing 20 target items used for determining performance. All 1-back tasks were comprised of 4 blocks: one practice block of 10 items containing 2 targets; a second practice block of 12 items, with 3 targets; a third block of 32 items with 10 targets; and a fourth block of 33 items with 10 targets. All 2-back tasks similarly consisted of 4 blocks: 10 practice with 2 targets; 15 practice with 3 targets; 37 experimental with 10 targets; and 39 experimental with 10 targets. Thus, the percentage of tokens that were targets in the 1-back and 2-back was 31% and 27%, respectively. These percentages were selected to be consistent with *n*-back tasks in the literature while also falling within the ability level of the participants to keep the tasks from being frustratingly long. The 1-back level required a response when the current token was the same as the one immediately preceding it (e.g., apple…peach…*peach*…). For the “2-back” level, participants responded to any token that was identical to the item appearing two tokens prior (e.g., plum…apple…*plum…*).

The *PhonoBack* stimuli consisted of 25 CVC words, five ending in each of five frames: -at, -it, -in, -ill, and -ig. The *SemBack* stimuli consisted of five words from each of five different semantic categories: fruits, tools, furniture, animals, and clothing. Stimuli were controlled across categories for length and frequency of occurrence. The *SynBack* stimuli included five-word sentences with either active ("The doctor kissed the banker") or passive ("The banker was kissed by the doctor") sentence structures. Ten nouns and ten verbs were used; length, frequency of occurrence, and role (object/subject) were controlled.

Each *n*-back task also consisted of two levels of processing; <u>Identity</u> and <u>Depth</u>. For identity versions, targets were identical to prime items presented *n* back. For all tasks, instructions were as follows: *"Push the button when the word (sentence) you just heard <u>is the same as</u> the one [n] back."* Only depth versions of the *PhonoBack* and *SemBack* were administered. We anticipated that the depth version of the *SynBack* would be too challenging for this population, thus it was not administered. For the *PhonoBack* depth, participants responded when target items rhymed with the prime presented *n* back (e.g., cat – rat). For the *SemBack* depth, participants responded when target items matched the category of the prime presented *n* back (e.g., grapes – lime).

<u>SOAP</u>. Love and Oster (2002) developed the *Subject-relative, Object-relative, Active, Passive Test of Syntactic Complexity* (SOAP) and have demonstrated its validity and sensitivity for certain comprehension abilities in brain-damaged populations, as well as its ability to differentiate between subgroups of aphasia. Briefly, the SOAP requires participants to listen to a sentence produced by the experimenter and then point to the one picture, among two foils, that corresponds to the sentence. The test sentences conform to the following syntactic structures and are processed with differential success, depending on each aphasic individual's comprehension

deficits: subject-relative, object-relative, active, and passive. Because it contains 10 trial sentences from each of the four syntactic structures, the SOAP provides a sensitive and selective profile of an individual's comprehension ability across a range of processing difficulty.

Experimental Procedures

Assessment was completed prior to the experimental sessions. During the assessment phase, informed consent was obtained, the WAB was administered, and vision and hearing screenings were conducted. For the experimental study, each participant attended three sessions in a sound-insulated room. All participants received all 11 *n*-back conditions and the SOAP. The *PhonoBack* and *SemBack* identity versions were completed in the first session and the depth versions completed in the second session. Presentation order for the *PhonoBack* and *SemBack* was counterbalanced across participants and sessions. During the third session, the *SynBack* and SOAP were administered; presentation order was counterbalanced across participants. Participants were given ample time to respond during the SOAP; the *n*-back tasks were internally time-driven by a 4000ms stimulus onset asynchrony (SOA) regardless of stimulus length.

Practice items for the *n*-back tasks were administered to ensure that participants understood the instructions and were comfortable performing the tasks. Participants completed practice items on the computer identical to the experimental *n*-back tasks. To reduce any chance of task perseveration from one condition to the next, task training and practice preceded each condition. The participant was instructed to press a button on a button response box when the item heard matched the item *n* items back.

Stimuli were played through computer speakers or headphones at a volume comfortable for each participant. Accuracy and response times (RT) were recorded by stimulus presentation software with millisecond precision. Because participants were not specifically instructed to respond with any rapidity – only “quickly, as another item will be coming up soon”, RTs are not viewed here as an index of processing time and were not subjected to further analysis. Administration and scoring of the SOAP were performed according to the procedures developed and standardized by Love and Oster (2002).

RESULTS

N-back

To compare accuracy performance across levels of processing for the different *n*-back tasks, the *SynBack* data were not included because participants did not complete *SynBack* Depth tasks. A repeated measures analysis of variance (ANOVA) of information type (phonological, semantic) by level of processing (Identity, Depth) by *n*-back level (1-back, 2-back) was performed. Data are not available for one participant who was unable to complete the *PhonoBack* depth task. The main effect for information type was significant, $F(1,8) = 5.40$, $p < .05$, as were the main effects for level of processing, $F(1,8) = 12.89$, $p < .01$, and *n*-back level, $F(1,8) = 75.57$, $p < .0001$. Participants were more accurate on the *SemBack* task compared to the *PhonoBack*. Participants also were more accurate at the Identity level than Depth level and on the 1-back compared to the 2-back. The interactions were not significant. To compare participants’ accuracy performance across the different *n*-back tasks a repeated measures ANOVA of information type (phonological, semantic, syntactic) by *n*-back level was performed. Significant main effects were found for information type, $F(2,18) = 5.72$, $p < .05$, and *n*-back level, $F(1,9) = 21.24$, $p < .01$. Planned comparisons were performed. Though participants’ accuracy scores were better during *SemBack* tasks compared to *PhonoBack* and *SynBack* tasks, no significant findings emerged when controlling for family-wise error using an adjusted p of .0167 (.05/3). See Figures 1-3 for participants’ accuracy performance on the *n*-back tasks.

Figures 1-3 about here

SOAP

The SOAP was administered to assess participants' auditory comprehension for four syntactic structures. Participants' erformance on the SOAP was grouped according to sentence canonicity and then subjected to statistical analysis. Using a paired sample t-test, participants comprehended the canonical sentences (i.e., active, subject-relative) significantly better than the noncanonical sentences (i.e., passive, object-relative), $t(9) = 2.90$, $p < .05$ (see Figure 4).

Figure 4 about here

Relationship between Working Memory and Language Comprehension

Friedmann and Gvion (2003) hypothesized that a verbal working memory deficit affects sentence comprehension when the type of processing required is the same for both. The sentence comprehension task (i.e, SOAP) required processing syntactic information, thus it would be expected that participants who performed poorly on the *SynBack* would also perform poorly on the more complex sentence forms (i.e., noncanonical sentences) of the SOAP. Four participants (P1, P2, P4, P6) missed more than 50% of the targets on the *SynBack* 1-back and/or 2-back tasks. These participants also evinced lower scores on the noncanonical sentences compared to the canonical sentences. Other participants (i.e., P3, P5, P8, P10) who performed adequately on the SOAP also yielded better than 50% accuracy hit rates on the *SynBack* tasks. Two participants did not fit either grouping (P7, P9); P7 performed poorly on the *SynBack* but demonstrated a stable performance across all sentence forms on the SOAP whereas P9 performed well on the *SynBack* but not on the noncanonical sentences (see Figures 3 and 4).

DISCUSSION

The primary goals of this study were to measure working memory ability for processing specific types of linguistic information and to identify whether a relationship existed between working memory ability and auditory comprehension of different syntactic structures in adults with aphasia. Participants' performance declined as *n*-back task difficulty increased. Further, participants performed more poorly on the depth versions of the *PhonoBack* and *SemBack* compared to the identity versions. Though participants overall performed better on the *SemBack* than *PhonoBack* and *SynBack* tasks, the differences were not statistically significant. Finally, participants who performed poorly on the *SynBack* also had more difficulty comprehending syntactically complex sentence structures (i.e., noncanonical sentence forms).

Working memory performance

The participants were able to perform the working memory tasks, supporting our previous work (Downey et al., 2004) that the tasks are appropriate for measuring working memory ability in adults with aphasia. As expected the participants with aphasia performed similarly to participants without neurological impairment (Jonides et al., 1997; Yoo, Paralkar, & Panych, 2004), with traumatic brain injury (Levin et al., 2004), and with schizophrenia (Callicott et al., 2000) in previous studies using an *n*-back task; that is, participants' accuracy declined as the *n*-back increased.

Previous *n*-back studies have manipulated stimulus type to tap different types of working memory, such as spatial, visual, auditory, and verbal (e.g., Hinkin et al., 2002; Kubat-Silman, Dagenbach, & Absher, 2002; McEvoy, Smith, & Gevins, 1998). No known study to date has manipulated *n*-back stimuli to tap different types of linguistic information – as we did. Many of the participants' performances differed across the *n*-back tasks. For example, for some participants (i.e., P1, P2, P4, P6) had better hit rates on the *SemBack* tasks compared to the *PhonoBack* and *SynBack* tasks, suggesting that these individuals with aphasia demonstrate differential difficulty processing distinct types of linguistic information. That is, they had more difficulty processing phonological and syntactic information versus lexico-semantic. Belleville, Caza, and Peretz (2003) found that individuals with anterior lesions present with structural (i.e., phonological, syntactic) deficits and a relative strength in processing lexico-semantic information. Though our participants who demonstrated this differential performance did present with anterior damage at the cortical and/or subcortical level, other participants who performed similarly across the three *n*-back tasks also presented with anterior damage. Further, many of the participants presented with damage in both anterior and posterior brain regions. At this point, our results do not support any hypotheses regarding the relationship between lesion location and processing of different types of linguistic information.

Sentence comprehension and WM

Our results add to previous findings indicating that individuals with aphasia may exhibit differential difficulty processing distinct types of linguistic information, such as phonological, semantic, and syntactic (Angrilli et al., 2003; Martin et al., 2003; Vallar et al., 1992; Waters & Caplan, 1996; 1999) which may contribute to their overall difficulties with language. Friedmann and Gvion (2003, 2006) demonstrated that individuals with conduction aphasia presenting with a phonological working memory deficit struggle when comprehending sentences that require phonological reactivation, yet have minimal difficulty comprehending syntactically complex sentences. Thus, demonstrating that a linguistic-specific working memory deficit does affect sentence comprehension when that specific type of processing (i.e., semantic, syntactic, phonological) is required. We found similar results with a different type of linguistic process –

syntactic. The participants who demonstrated a syntactic working memory deficit had the most difficulty comprehending syntactically complex sentences.

Though all participants demonstrated a decline in accuracy as the *n*-back task increased in difficulty, four participants' working memory for syntactic information was severely stressed as the *SynBack* level increased and these participants' performance on the sentence comprehension task also deteriorated as task difficulty increased, that is comprehending noncanonical sentences forms compared to canonical sentence forms. Further, those participants who performed better on the *SynBack* overall and had a smaller decline in performance from the 1-back to 2-back on the *SynBack* did not have any trouble comprehending the more syntactically complex sentences.

<u>Conclusions and future directions</u>

Results of this preliminary study investigating working memory ability and its relationship with sentence comprehension ability in aphasia are promising. First, we demonstrated that working memory ability for different types of linguistic information can be measured in adults with aphasia. Further, it had been hypothesized that a syntactic working memory deficit may contribute to the syntactic comprehension deficit found in some individuals with aphasia. However, prior to this study this hypothesis had not been tested and no measure of working memory ability for syntactic information had been proposed. Though these results are preliminary they add to the growing literature that favors the separate working memory abilities for different types of linguistic information view. To further evaluate the relationship between working memory and language comprehension, the next step in this line of research is to include sentence comprehension tasks that require different types of processing as well as working memory tasks for different types of linguistic information and include adults with aphasia with distinct lesion sites (i.e., anterior v. posterior).

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Table 1. Clinical and demographic data for participants.

Pt[1]	Age	Educ[2]	Sex	m/p CVA[3]	WAB AQ[4]	Lesion Information
1	51	16	M	51	58	Left middle cerebral artery (MCA) infarct; upper left temporal & parietal lobes & left basal ganglia
2	62	20+	M	31	81.7	Left temporal & frontal lobes; insular region
3	44	17	M	17	68.1	Left basal ganglia & contiguous portions of the subinsular cortex; portions of left frontal & temporoparietal lobes
4	76	12	M	152	48.1	Left frontotemporal cerebral infarct
5	47	16	F	104	91.1	No data available
6	55	20	M	27	88.6	Left MCA
7	45	17	M	56	72.3	Left MCA infarct with small intracerebral acute hematoma
8	56	14	M	88	91.9	Left frontal cortical region; left basal ganglia
9	80	8	M	144	92.4	left frontal area
10	80	12	M	62	84.7	Superior aspect of left perisylvian region extending to frontoparietal convexity
Mean	59.6	14.0		73.2	56.5	

[1]patient; [2]years of education completed; [3] months post cerebrovascular accident; [4]Western Aphasia Battery Aphasia Quotient

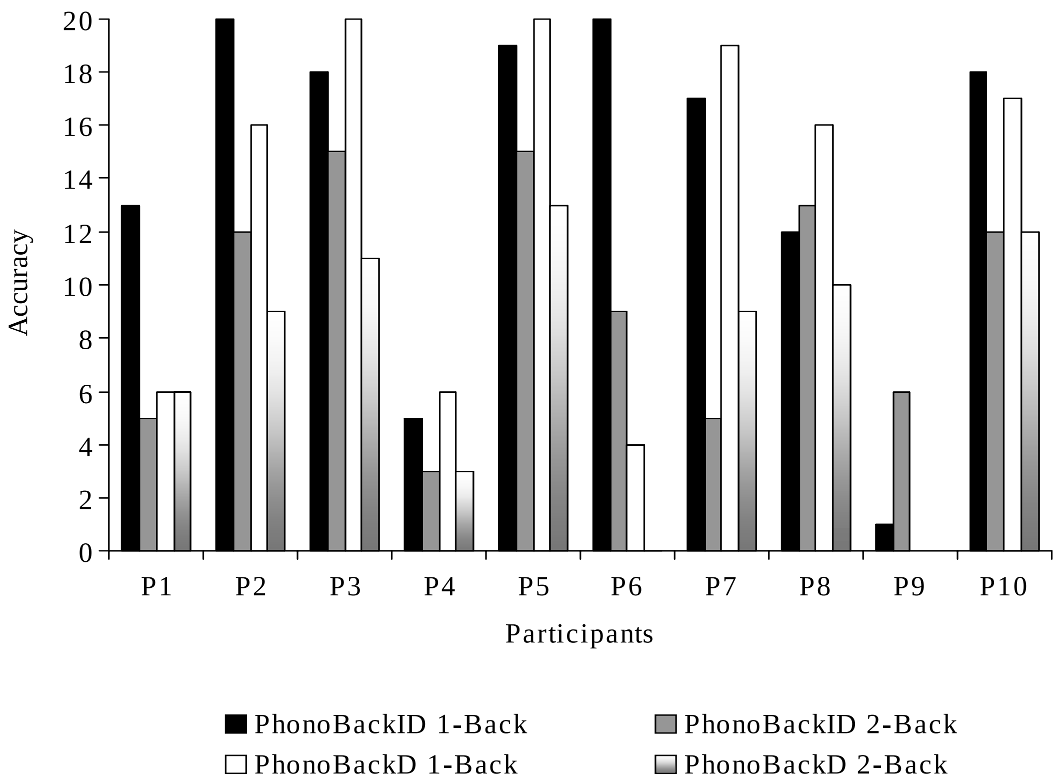
Figures

Figure 1. Participants' accuracy on the *PhonoBack* tasks.

Figure 2. Participants' accuracy on the *SemBack* tasks.

Figure 3. Participants' accuracy on the *SynBack* tasks.

Figure 4. Participants' percent accuracy on the Subject-relative, Object-relative, Active, Passive Test of Syntactic Complexity (SOAP; Love & Oster, 2002).



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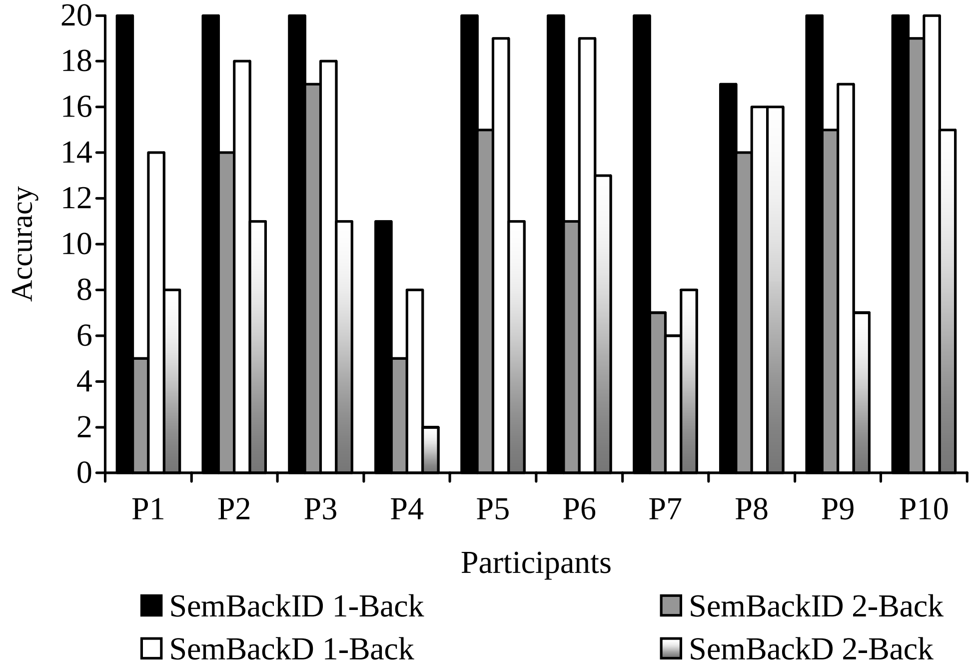

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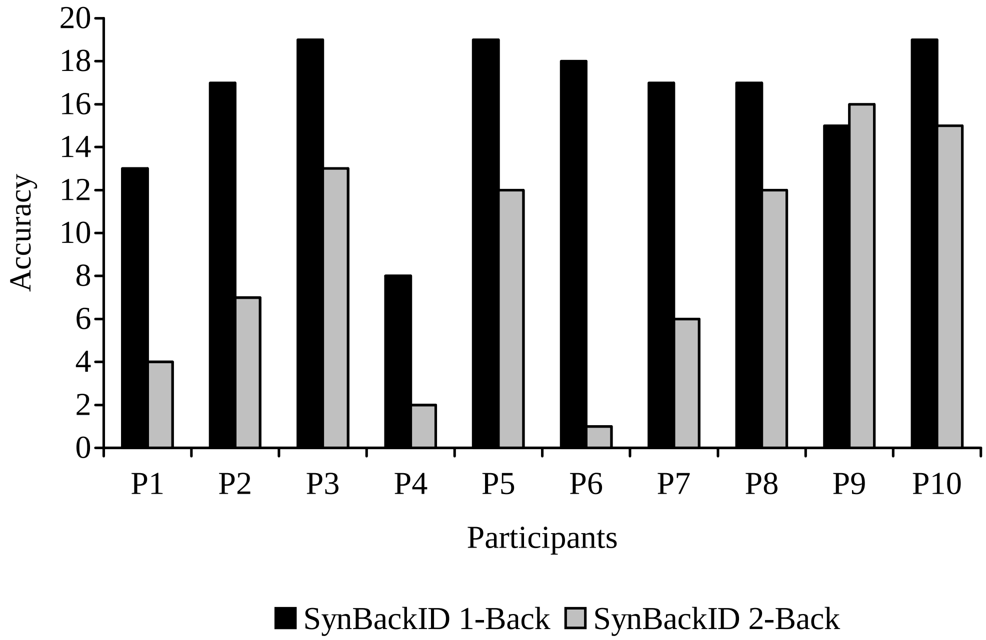
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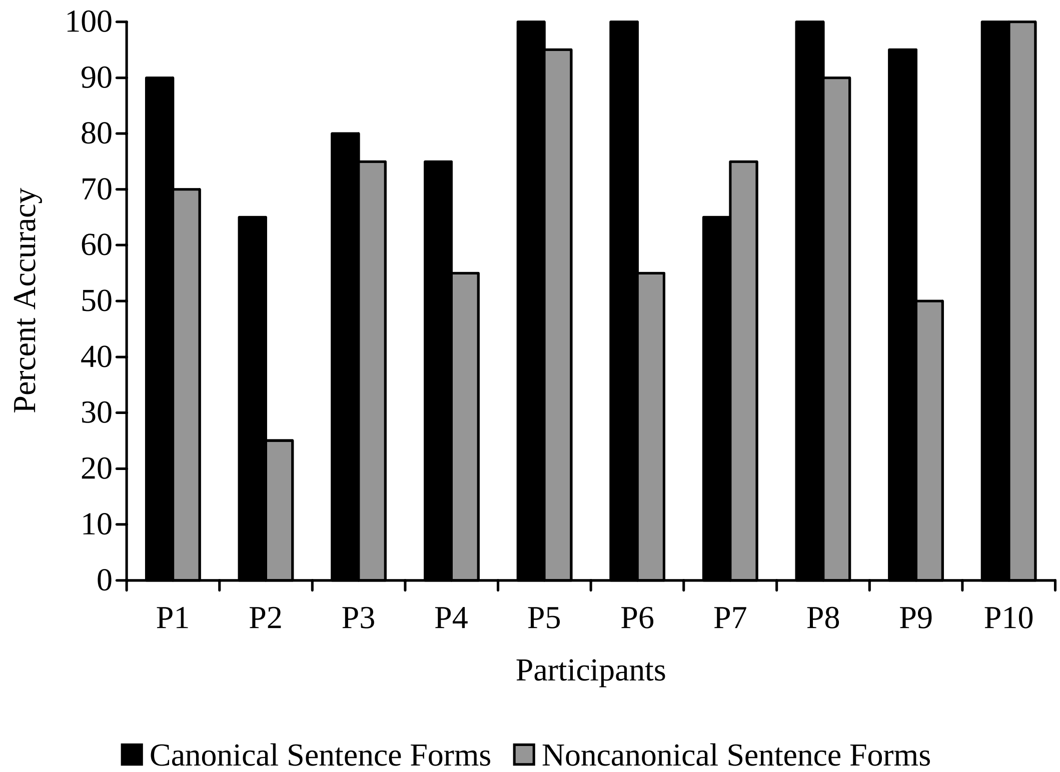
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