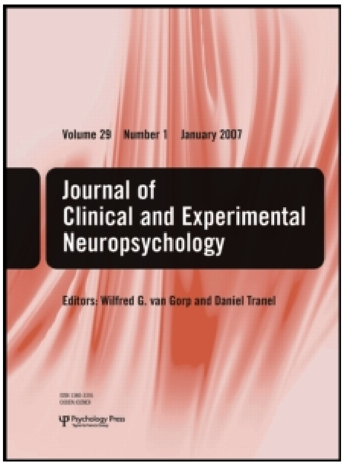

Journal of Clinical and Experimental Neuropsychology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713657736

Florida Apraxia Battery-Extended and Revised Sydney (FABERS): Design, description, and a healthy control sample

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First published on: 08 April 2009

JOURNAL OF CLINICAL AND EXPERIMENTAL NEUROPSYCHOLOGY
2009, i*First*, 1–19

Psychology Press
Taylor & Francis Group

Florida Apraxia Battery–Extended and Revised Sydney (FABERS): Design, description, and a healthy control sample

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There exist few clinical assessments for limb apraxia, a disorder of learned, purposeful action, that enable clinicians to distinguish pathological from normal variance in limb praxis performance. We describe a theoretically motivated, comprehensive assessment battery for limb apraxia and present control comparison scores for 16 older healthy normal individuals on subtests designed to distinguish the integrity of components of the praxis system.

Keywords: Limb praxis; Apraxia; Cognitive assessment; Pantomime.

INTRODUCTION

Limb apraxia is a disorder of learned, purposeful action of the arm and hand that cannot be accounted for by elementary motor or sensory, comprehension, or gnosis deficits (Heilman & Rothi, 1993; Kertesz, 1979; Liepmann, 1905/1980). Commonly occurring as the result of left cerebrovascular accident (CVA), it is prevalent in rehabilitation and nursing home settings (30–51.3%; Donkervoort, Dekker, van den Ende, Stehmann-Saris, & Deelman, 2000; Zwinkels, Geusgens, van de Sande, & Van Heugten, 2004) and enduring (Donkervoort, Dekker, & Deelman, 2006; Foundas, Raymer, Maher, Rothi, & Heilman, 1993) and is reported to be one of the most disabling and lasting cognitive consequences of stroke (Foundas et al., 1995; Hanna-Pladdy, Heilman, & Foundas, 2003; Smania et al., 2006; Sundet, Finset, & Reinvang, 1988). While limb apraxia would appear to be an important target for rehabilitation in stroke survivors, very few apraxia treatment studies exist (see Buxbaum et al., 2008, for review; Code & Gaunt, 1986; Ochipa, Maher, & Rothi, 1995; Pilgrim & Humphreys, 1994; Smania et al., 2006; Smania, Girardi, Domenicali, Lora, & Aglioti, 2000). Further, and directly related to this report, few clinical measures exist to examine limb apraxia (De Renzi, 1985; Dobignyroman, Dieudonnemoinet, Tortrat, Verny, & Forette, 1998; Duffy & Duffy, 1990; Giannakopoulos et al., 1998). In this paper we describe a comprehensive assessment battery for limb apraxia based upon a cognitive neuropsychological model of limb praxis (Rothi, Ochipa, & Heilman, 1991, 1997a) and provide control comparison praxis scores for 16 healthy controls.

The praxis system may be depicted by multicomponent models (Rothi et al., 1991; Rothi et al., 1997a; Roy, 1983, 1985). Although these models can serve to underscore the complexity of the praxis system and in turn the various ways in which it can break down to produce apraxia, there

We thank the participants for their contribution to this study. This research was funded by a National Health and Medical Research Council (NH&MRC) Dora Lush Biomedical Scholarship to the first author.
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http://www.psypress.com/jcen DOI: 10.1080/13803390902791646

are few standardized assessment measures that assist clinicians to distinguish (a) the integrity of various aspects of the praxis system (via relational comparison of test performance) and (b) pathological from normal variance in performance. The cognitive neuropsychological model that attempts to explain praxis processing has been developed by Rothi and colleagues (see Rothi et al., 1991; Rothi et al., 1997a) focusing on pantomimed gestures. It is drawn from the original work of Liepmann (1900/1977; 1905/1980) as well as Roy and Square's model of normal praxis processing (Roy, 1983, 1985), with additional evidence from dissociating pantomime recognition, production, and imitation performances from pathological populations culled from the literature. The model, shown in Figure 1, has a number of key features:

1. *Conceptual and lexical components*. The principle distinction is made between conceptual knowledge of actions (the action semantic system) and a lexical store of representations for previously seen or produced actions (the action lexicon).
2. *Action lexicons*. The action input lexicon (AIL) includes memories of *seen* actions—for example, pantomimes and actions with objects—and is a common pathway used in both recognition and imitation of familiar pantomimes. The action output lexicon (AOL) contains memories of previously *produced* action and is accessed in pantomime production.
3. *Direct translation from visual analysis to innervatory patterns*. Novel or meaningless action stimuli such as single postures and/or sequences of movements require analysis and direct translation from visual to motor innervatory patterns. It is proposed that the nonlexical route is used to imitate meaningless actions.
4. *Multimodal input pathways*. Different presemantic pathways are proposed to process actions elicited via different stimulus modalities: the object recognition route (pantomime to object or picture), the auditory processing route (pantomime to verbal command), and the temporal visual processing route for observed pantomime (pantomime to imitation or seen movement).
5. *Separation of the action semantic system (ASS) from both AIL and AOL*. Somewhat

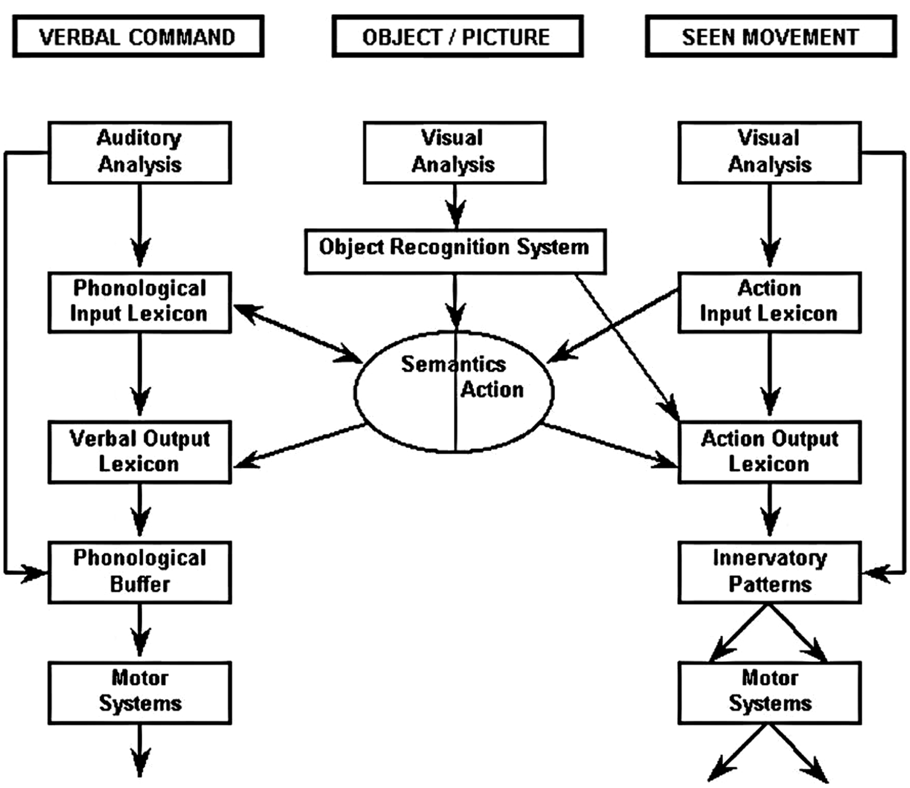

Figure 1. The cognitive neuropsychological model of praxis processing adapted from Rothi, Ochipa, and Heilman (1997a). *Note*. From *Apraxia: The neuropsychology of action* (pp. 29–49), by L. J. G. Rothi and K. M. Heilman, 1997, Hove, UK: Psychology Press. Copyright 1997 by Taylor and Francis Books UK. Adapted with permission.

independent from knowledge of physical characteristics of a movement represented in the action lexicons, the understanding and control of actions depend on associative and mechanical conceptual knowledge about how the action is performed represented by the action semantic system.

6. *Separation of the action semantic system (ASS) from a nonaction, central semantic system*. Rothi and colleagues (1997a) propose that the action semantic system is distinct from a nonaction, central, semantic system. Verbal semantic knowledge about objects and actions is seen as partially represented independently of action knowledge (see Raymer & Ochipa, 1997).
7. *Two independent domains of action semantic knowledge*. Heilman, Maher, Greenwald, and Rothi (1997) claim that action semantic knowledge may have distinct components including associative knowledge of action/tool relationships and the knowledge of the mechanical advantages of tools.
8. *Differential representation of transitive and intransitive pantomimes*. Rothi et al. (1997a) also propose that transitive action or gestures (requiring the use of an object, such as brushing teeth with a toothbrush) are represented differentially from intransitive pantomimes (movements that do not require an object, such as indicating "go away").

The model's advantage over traditional accounts of ideomotor and ideational apraxia still in use is that predictions can be made and tests specifically designed to assess the integrity of the above modules and routes between modules (Hanna-Pladdy & Rothi, 2001). Diagnosis involves converging evidence from accuracy and qualitative error data from multiple action tasks that examine each pathway and module represented (De Renzi, 1985; Rothi, Raymer, & Heilman, 1997b). Pantomime input pathways are examined via pantomime recognition and discrimination tasks. Pantomime output pathways are examined using pantomime expression and imitation tasks. Conceptual knowledge of actions is assessed by examining error data from these measures. This is complemented with declarative tasks of action knowledge that examine the knowledge of tool–object–action relationships by eliminating the potentially confounding requirement to produce the action itself. By using the same stimuli in each action subtest, the subtest variables remain constant, and the clinician can examine the integrity of each pathway/module within a participant's performance. Predicted patterns of pantomime performance and breakdown for each component (i.e., AIL, ASS, AOL, and direct route) as well as other properties (i.e., modality, associative versus mechanical knowledge, action versus verbal semantic knowledge, and transitivity) are outlined in Table 1.

Thus the model assists clinicians and researchers to make judgments about the relative functioning of the various praxis components and to establish the principal levels of praxis breakdown. Currently, there are no published control data on the range of gestural and action semantic tasks proposed by Rothi and colleagues in the original Florida Apraxia Battery. The aims of this study are to:

1. Describe a comprehensive, revised, relational assessment battery for limb apraxia associated with brain damage, the Florida Apraxia Battery–Extended and Revised Sydney (FABERS), based upon a multicomponent cognitive neuropsychological model of limb praxis proposed by Rothi et al. (1997a).
2. Establish the interrater reliability for the qualitative pantomime expression error scoring system in evaluating participants' pantomime expression performance.
3. Provide control comparison scores (percentile ranks) for 16 healthy controls on the complete battery to enable comparisons across subtests and determine the relative integrity of praxis system components.

METHOD

Description of battery design and procedures

The tasks included in the Limb Praxis Assessment Battery were selected from an existing battery—the Florida Apraxia Battery (FAB; Rothi et al., 1997b) and other published measures in original or slightly modified form. Where appropriate, tasks utilized the same core items of the FAB, which contains 20 common tools (transitive items) and 10 intransitive pantomime items. Importantly, this allows comparison with previous studies using the FAB and because the FAB provides more items than are present in other apraxia batteries (De Renzi, 1985; Dobignyroman et al., 1998; Giannakopoulos et al., 1998). One item (icepick) was replaced with a more culturally familiar item to Australian participants that required a similar action (potato masher), and two practice items were added to all tasks. The tests are described briefly below in relation to the pathway and/or component they assess as described in

TABLE 1
The predicted patterns of pantomime performance breakdown on the praxis model

Deficit	*Pantomime recognition/ discrimination*	*Verbal semantics*	*Declarative action semantics*	*Transitive and intransitive pantomime expression tasks*	*Meaningless imitation*	*Errors*
Action input lexicon deficit	Impaired	Intact/impaired[a]	Intact	Intact	Intact	Motoric foils
Action semantic deficit	Impaired (discrimination less so due to intact AIL)	Intact/impaired[a]	Impaired	Impaired	Intact	Conceptual, i.e., content errors
Action output lexicon deficit	Intact	Intact/impaired[a]	Intact	Impaired	Intact	Spatial and temporal errors
Direct route (visual analysis to innervatory patterns) deficit	Intact	Intact/impaired[a]	Intact	Intact	Impaired	Spatial and temporal errors
Modality-specific deficit	—	—	—	Dissociating pantomime on photo, command and imitation modalities	—	—
Dissociation of action semantics from nonaction semantics	—	Dissociating performance on verbal and action semantic declarative tasks	—	—	—	
Associate vs. mechanical knowledge	—	—	Dissociating associative (*tool–action and tool–object knowledge)* and mechanical knowledge	—	—	—
Transitivity-specific deficit	—	—	—	Dissociating transitive and intransitive pantomime	—	—

Note. Praxis model (Rothi, Ochipa, & Heilman, 1997a). AIL = action input lexicon.
[a]As verbal semantics is proposed to be distinguished from action semantics, verbal semantics may be intact or impaired. Its presence here is used to test the distinction between action and verbal semantic knowledge.

Table 1. All tests were administered to healthy controls in one 2-hour session.

Pantomime recognition and discrimination

Two measures of receptive pantomime processing were used to assess the integrity of the input pathways, including the action input lexicon (AIL) and access to the action semantic system (ASS). Pantomime recognition was examined using a pantomime-to-photograph matching task based on the 20 transitive items of the FAB (see Appendix A). Participants were required to point to the photograph of a tool that matched the target action pantomimed by the examiner (maximum score of 20). As well as the target, three foils were included to provide further insight into the level of pantomime recognition breakdown (Bell, 1994; Lambier & Bradley, 1991). Foils to test for AIL breakdown included tools with *motorically similar* pantomimes that did not belong to the same immediate semantic category (e.g., paintbrush and hammer). Foils to test for action semantic breakdown included *functional associates* of the target tool (e.g., paintbrush and paint tin). Finally, *semantic category* foils (e.g., paintbrush and paint roller) were included to determine whether breakdown in nonaction semantic knowledge contributed to pantomime recognition breakdown. Some of these foils were also visually related to the target tool. Items and foils are presented in Appendix A.

A pantomime discrimination task was used to assess the participants' ability to identify whether a pantomime of tool use was produced accurately for the named tool. A realistic or correct pantomime was defined as an everyday action that was performed with a temporal, spatial, and manipulative framework that might be ordinarily expected. Pantomimes were selected from the core FAB items. To create unrealistic pantomimes, correct pantomimes were altered either temporally or spatially, to create an unrealistic looking pantomime, following protocols similar to those used by Rothi et al. (1991, 1997a; see Appendix B). For example, the action for saw was altered by rotating the usual grip so that the palm faced towards the ceiling. With each presentation of a realistic or unrealistic pantomime the participant was asked "Is this pantomime correct for (presented tool), yes or no?." A response was scored as correct if the participant correctly accepted a realistic pantomime or correctly rejected an unrealistic pantomime. The response was scored as incorrect if the participant incorrectly rejected a realistic pantomime or incorrectly accepted an unrealistic pantomime (maximum of 40).

Semantic memory

Conceptual knowledge of actions was assessed on dynamic pantomime tasks and tasks that did not require gestural output. Nonproduction tasks provided additional information about the action semantic system that may be obscured by AOL pantomime deficits.

Action semantic knowledge

Tool–action associative knowledge was assessed with the pantomime-to-photograph matching task, described above. *Tool–object associative knowledge* was assessed with a tool selection test described by both Ochipa, Rothi, and Heilman (1989) and Heilman et al. (1997) and revised by Macauley (1998). It contained 14 partially completed actions (e.g., a nail hit partially into a piece of wood) accompanied by three actual tools: the target tool (a hammer) and two randomized foils (see Appendix C). Participants were asked to identify the tool most appropriate for completing the task. Correct responses were those that accurately identified the appropriate tool (maximum score of 14). An alternative tool selection test, described by Ochipa et al. (1989) was administered to examine the *object–action or mechanical relationship* of tools to objects using the same items as those in the tool selection task. It presented the participants with the same partially completed actions as those judged previously but for which the appropriate tool was not present. Participants were required to select the best alternative tool with similar features and mechanical potential required to complete the task—for example, a nail half pounded into wood would be matched to the heel of a flat hard-heeled shoe (which replaces the hammer in this task) rather than foils of a utility/Stanley knife or a screwdriver (see Appendix C). The participants could not complete the task using associative knowledge as for the previous test and had to use mechanical knowledge.

Verbal–visual semantic knowledge

The use of a variety of tests has been recommended (Dumont, Ska, & Joanette, 2000; Raymer & Ochipa, 1997; Rothi et al., 1997b) to assess nonaction semantic knowledge proposed to be distinct from action semantic knowledge. This study used a word-to-picture matching task, a picture naming task, and a visual semantic association task. The first two tasks used the same 20 core FAB transitive items as measures of verbal semantic knowledge. The word-to-picture matching task was an auditory recognition task that assessed tool identification knowledge. Participants were instructed to "Point to the (name of target item)," and each item contained the same foils as those in the pantomime recognition test (see above and Appendix A). The second verbal task was a tool naming task using the same target items. Each participant was asked to name a series of photographs of tools (see Appendix D). Finally, a visual semantic association matching task as used by Dumont et al. (2000) was designed to assess nonaction semantic knowledge. The semantic association task used animals as stimuli to avoid tool-based action stimuli when assessing nonaction semantic knowledge. We used a culturally modified picture version of the animal triplet component of the Animal–Tool Triplets Test (Breedin, Martin, & Saffran, 1994). Each participant was asked to point to the two pictures from a three-item set that "went together the best." It contained 20 animal items (see Appendix E). Judgments for animals involved taxonomy (e.g., *crab, lobster*, fish), visual attribute (e.g., *rat*, squirrel, *mouse*), and environment/habitat (e.g., moose, *walrus, penguin*) knowledge.

Pantomime expression

Several measures of pantomime expression were used to examine the praxis production system. The system was examined by varying input modality (e.g., pantomiming from a photo, a command, and seen pantomime), transitivity status of pantomimes (i.e., transitive pantomimes that involve tool use and intransitive pantomimes that did not), and meaning content of the action (i.e., imitation of meaningful pantomimes and meaningless hand postures and movement sequences). Some previous investigations have used imitation only (Duffy & Duffy, 1989; Duffy, Watt, & Duffy, 1994), or have compared transitivity performance across different modalities rather than directly within the same modality (Cubelli, Marchetti, Boscolo, & Della Sala, 2000), which may not fully account for modality-specific effects. Additionally, some studies have combined the assessment of meaningless and meaningful gestures into one mixed task (Cubelli et al., 2000; De Renzi, 1985; De Renzi & Lucchelli, 1988). Cubelli and colleagues concede that meaningful items could be preferentially processed by the direct route because they can be processed by either the meaningful or the meaningless routes. Many studies use imitation of movements and postures, but some have examined the meaningful/meaningless dichotomy via a mixture of imitation and/or verbal commands (Barrett et al., 1998; Derouesne, Lagha-Pierucci, Thibault, Baudouin-Madec, & Lacomblez, 2000; Rapcsak, Croswell, & Rubens, 1989; Willis, Behrens, Mack, & Chui, 1998), which may not test the direct route as movements are transformed, not from a visual temporal image, but from a verbal command. Some researchers have limited assessment of meaningful pantomime imitation to intransitive pantomimes rather than also including transitive pantomime imitation (Cubelli et al., 2000; De Renzi, Motti, & Nichelli, 1980; Lucchelli, Lopez, Faglioni, & Boller, 1993). This may distort a comparison between meaningless tasks and transitive tasks, because it has been suggested that intransitive imitation is well performed even by severely apraxic subjects (Belanger, Duffy, & Coelho, 1996).

The stimuli from the FAB, described by Rothi et al. (1997a) and modified as described earlier, were chosen to assess pantomime expression across the above dimensions. The FAB stimuli consist of 30 items containing 20 transitive and 10 intransitive pantomimes (see Appendix D). As recommended by Rothi et al. (1997a), participants were encouraged to actually imagine using the tool. All participants were instructed to use their nondominant hand (left) so that the control data can be used to compare participants with neurological damage such as left CVA in clinical assessment.

Pantomime expression via the object/picture recognition route was examined with a pantomime-to-photograph task (see Appendix D). Each participant was shown a photograph of an object and was asked, "Show me how you use this." Only transitive items were used for this condition due to difficulties in providing unambiguous picture stimuli for intransitive pantomimes. *Pantomime expression via the auditory processing route* was examined with a pantomime-to-command task involving both transitive and intransitive pantomimes. Each participant was given a command—for example, "Show me how you use a hammer to pound in a nail." *Pantomime expression via the indirect/lexical route* was examined with a pantomime imitation task involving both transitive and intransitive pantomimes on the same core items as those above. Each participant was instructed to copy the examiner's pantomime exactly after the examiner had completed the whole pantomime.

Scoring for meaningful pantomime expression tasks: Each participant's pantomime performance was videotaped and scored according to the scoring system recommended by Rothi and colleagues (Rothi, Heilman, Mack, Verfaillie, & Brown, 1988; Rothi et al., 1997b). All meaningful pantomimes were evaluated according to three dimensions: content, spatial characteristics, and temporal characteristics (see Appendix F). Any errors in these dimensions were noted. If a pantomime was unrecognizable or the participant did not respond, this was also noted in a separate category termed "Other" errors (Rothi et al., 1997b). To obtain a quantitative score, if no errors were observed, the pantomime was given a score of 1. If any errors in the above dimensions were observed, the pantomime was considered incorrect and was scored 0. The maximum score was 20 for the transitive tasks and 10 for the intransitive tasks. To obtain qualitative information about error patterns for each dimension, each incorrect pantomime was then classified as impaired in content (C) or spatiotemporal (ST) characteristics or other (O). Spatial and temporal errors were combined into one total, and other errors were considered separately because it is sometimes difficult to decide whether unrecognizable errors represent very severe spatiotemporal errors or content-based errors. The procedure used by Raymer, Maher, Foundas, Heilman, and Rothi (1997) for scoring body part as tool (BPT) errors as incorrect only if participants were unsuccessful in modifying their error with cuing was used in this study.

Action production via the direct nonlexical route was examined by eliciting imitation of meaningless postures and movement sequences using the meaningless imitation subtest of the short form of the Limb Apraxia Test (LAT; see Duffy, Duffy, & Uryase, 1989, for test items). The LAT consists of five "conditioning items" (e.g., hand placed palm up on table) and 10 core items of differing motoric complexity with a total of 17 movement components. For example, one item consisted of two movement sequences (e.g., extend arm in front of body, parallel to table, palm down with fist open, and close fist), while another had one movement sequence (e.g., put hand on opposite shoulder with palm down). In the FABERS each component was scored using the plus/minus scoring as described in Duffy et al. (1989) for any deviation of spatial or temporal characteristics of the action. The total score is the number of movement components scored as correct with a maximum score of 17. This task was chosen over other tests of imitation because it was desirable to include movements of the upper limb only, in interpersonal and intrapersonal space, single and sequenced, without objects, and to separate meaningless imitation from other meaningful imitation tasks. Point to point agreement was calculated between Rater 1 (E.P.) and Rater 2 (C.S.) for five randomly selected items across all participants, at 100%.

Participants

A total of 16 healthy controls, 8 men and 8 women, participated in the study and were recruited from the Sydney Metropolitan Region. Their mean age was 70.1 years (SD = 8.7, range 55–83), and mean years of education was 12.4 years (SD = 2.8, range 9–17). All were right-handed, as determined by the Edinburgh Handedness Questionnaire Inventory (Oldfield, 1971) and fluent in written and spoken English. None of the participants had a self-reported history of neurological, psychiatric, cognitive, or motor disorders. Participants were screened for cognitive impairment with the Mini Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975), and all scored 27/30 or higher (mean = 29.3, SD = 0.9, range 27–30). All participants passed a visual screening measure where they were asked to match five black-and-white pictures and five photographs to an identical picture/photograph in a four-image array. This format was consistent with study assessment tasks. This research was conducted under the guidelines of the National Health and Research Council Australia and approval from the University of Sydney Human Research Ethics Committee. All participants gave informed, written consent to participate in the study.

DATA ANALYSIS

Descriptive statistics

Data were examined using SPSS statistical software (SPSS Inc., 2001). Prior to creation of standard scores, raw data were analyzed using descriptive statistics (means, standard deviations and ranges) and were tested for normal distribution with visual inspection techniques and the Kolmogorov–Smirnov statistic.

Interrater reliability on pantomime expression qualitative scoring

The two raters (E.P. and C.S.) are both speech pathologists with over 10 and 30 years clinical experience, respectively. They were initially trained using prototypical and nonstudy pantomime samples to achieve consensus on the rating system. Once raters had reached over 90% interrater agreement on training samples, 50% of items from each meaningful pantomime expression task (i.e., 10/20 items for transitive tasks and 5/10 items for intransitive tasks) were randomly selected for rating by both raters to provide a reliability analysis. Therefore, 40/80 pantomimes for each of the 16 participants were rated by two raters. A larger sample than 20% was chosen to allow an adequate number of items on the smaller tests to be rated and to provide for sufficient occurrence of incorrect items within a healthy sample and that could then be further analyzed for rating of error type. Interrater reliability was initially calculated via point-to-point agreement on the accuracy score (correct/incorrect) for the two raters. Following this, items that were agreed by both raters to be incorrect were compared on error class and type. Any remaining disagreement on errors was reconciled by consensus rating. As all remaining FABERS tasks required participants to respond in a forced-choice format, reliability ratings were not conducted for these tasks.

Control comparison scores (percentile ranks) and associations between FABERS tests

For ease of comparison across tasks, raw scores for each test equivalent to every 10th percentile were calculated and are reported. Raw scores below the 10th percentile in our data may indicate pathological performance. The means and standard deviations calculated for each test in the FABERS allow any individual's score to be converted to a *z* score as a general guideline of performance. Again for ease of comparison the *z* scores were calculated to match each 10th percentile. For example, anyone with a *z* score of less than –1.281 on a test in the FABERS would be in the bottom 10% for that task. Potential associations between the praxis battery tests were examined using a zero-order correlation matrix.

RESULTS

Descriptive statistics and distribution of data of the Praxis Assessment Battery

Means, standard deviation, ranges, and Kolmogorov–Smirnov *Z* statistics on the tests described above are presented for the 16 healthy participants in Table 2. Of the 13 tests, 5 had small, significant Kolmogorov–Smirnov *Z* statistics ($p < .01$), indicating that control data differ significantly from a normal distribution. Distributions on the auditory word-to-picture match task, the tool selection and alternate tool selection tests, and the intransitive pantomime-to-command and intransitive pantomime-to-imitation tasks were all negatively skewed due to

TABLE 2
Scores for healthy adults on each test in the FABERS

	Test	*Maximum score*	*M*	*SD*	*Range*	*Kolmogorov–Smirnov Z*
Pantomime reception	P'MIME DISCR	40	36.44	1.59	34–39	0.60
	P'MIME REC	20	18.75	1.00	17–20	0.90
Verbal semantics	AUD REC	20	19.94	0.25	19–20	2.15**
	NAM	20	18.81	0.83	17–20	1.11
	AT	20	19.25	0.77	18–20	1.08
Action semantics	TS	14	13.81	0.54	12–14	2.04**
	ATS	14	13.94	0.25	13–14	2.15**
Transitive and intransitive pantomime expression	TRANS PHOTO	20	16.13	1.89	12–19	0.96
	TRANS COMM	20	17.13	1.82	13–19	0.90
	TRANS IMI	20	18.75	1.52	15–20	1.26
	INTRANS COMM	10	9.63	0.62	8–10	1.66**
	INTRANS IMI	10	9.94	0.25	9–10	2.15**
Meaningless imitation errors	M'LESS IMI	17	16.50	0.52	16–17	1.33
	Total meaningful pantomime error data					
	ST		7.31	4.73	1–17	
	C		0.44	0.81	0–3	
	O		0.44	0.63	0–2	

Note. FABERS = Florida Apraxia Battery–Extended and Revised Sydney. AT = animal triplet, ATS = alternative tool selection, AUD REC = auditory recognition, C = content error, INTRANS COM = intransitive pantomime expression to command, INTRANS IMI = intransitive pantomime expression to imitation, M'LESS IMI = meaningless imitation, NAM = naming, O = other error, P'MIME REC = pantomime recognition, P'MIME DISCR = pantomime discrimination, ST = spatiotemporal error, TRANS COMM = transitive pantomime expression to command, TRANS IMI = transitive pantomime expression to imitation, TRANS PHOTO = transitive pantomime expression to photograph, TS = tool selection.
**$p < .01$.

ceiling effects. The remaining eight tests had large nonsignificant Kolmogorov–Smirnov *Z*s, indicating that data were generally consistent with a normal unimodal distribution. Summary error data presented in Table 2 represent the total error scores of participants on all meaningful pantomime expression tasks. Detailed error data for the pantomime recognition task and individual pantomime expression tasks are presented in Tables 3 and 4, respectively.

Receptive pantomime processing

An average of 3 errors were made on the pantomime discrimination task (maximum score 40), with participants accepting spatially incorrect pantomimes as correct pantomimes and also rejecting accurate pantomimes as inaccurate. On the pantomime recognition task, participants made an average of 2 errors each (maximum score 20). Only a small number of errors were made ($n = 20$). Half of these were semantic category related (e.g., pepper grinder for salt shaker), with a smaller number of functional associate errors (e.g., screw instead of screwdriver) and motorically similar errors (e.g., screwdriver instead of key; see Table 3).

TABLE 3
Healthy control error data from the pantomime recognition task

Foil type	*Pantomime recognition* *M*	*SD*	*Range*	*Total no. of errors (all 16 participants)*	*Proportion of sample*
Semantic category	0.63	0.81	0–2	10	.5
Associative	0.25	0.58	0–2	4	.2
Motoric	0.25	0.45	0–1	4	.2
No response	0.13	0.34	0–1	2	.1

Visual–verbal semantic knowledge

Participants performed almost at ceiling on the auditory word-to-picture match task and the animal triplet task. Participants made an average of 1 error each on the photograph naming task; however, number of errors ranged from 0–3 for the 16 participants. Errors were mostly close semantic associates and very occasionally "no response," where the participant had forgotten the specific name of the tool (e.g., wire cutters), although they had been able to recognize the tool.

Action semantic knowledge

Results for tool–action associative knowledge are reported for the pantomime recognition task in Table 2. Tool–action associative knowledge assessed

TABLE 4
Healthy control error data for each meaningful pantomime task and overall total

Test	*Error type*	*M*	*SD*	*Range*	*Total no. of errors (all participants)*	*Proportion of sample*
TRANS PHOTO	ST	3.40	2.03	1–8	51	.85
	C	1.33	0.58	0–2	4	.06
	O	1.00	0.00	0–1	5	.08
TRANS COMM	ST	2.88	1.82	1–7	46	1.0
	C	0			0	0
	O	0			0	0
TRANS IMI	ST	2.00	1.49	0–5	20	1.00
	C	0			0	0
	O	0			0	0
INTRANS COMM	ST	1.00	0.00	0–1	1	.16
	C	1.00	0.00	0–1	3	.50
	O	1.00	0.00	0–1	2	.33
INTRANS IMI	ST	1.00	0.00	0–1	1	1.00
	C	0			0	0
	O	0			0	0
Total	ST	7.31	4.73	1–17	117	.89
	C	0.44	0.81	0–3	7	.06
	O	0.44	0.63	0–2	7	.05

Note. C = content error, INTRANS COM = intransitive pantomime expression to command, INTRANS IMI = intransitive pantomime expression to imitation, O = other error, ST = spatiotemporal error, TRANS COMM = transitive pantomime expression to command, TRANS IMI = transitive pantomime expression to imitation, TRANS PHOTO = transitive pantomime expression to photograph.

by the tool selection task revealed almost ceiling performance, as did the mechanical knowledge measure and the alternative tool selection task (see Table 2).

Pantomime expression

Scores on the intransitive pantomime command and imitation tasks were almost at ceiling. On the intransitive imitation task, 15 of the participants scored 10/10 with only 1 participant scoring 9/10 and making a spatiotemporal error (see Table 2). For the command task, 11 participants scored at ceiling, 4/16 participants made one error, and 1 participant made two errors. Errors comprised a very small number of content, spatiotemporal, and other errors. Content errors included a "no response" error when a participant was unsure about how to signal "crazy," and unrecognizable or related responses.

In contrast, participants made substantially more errors on the transitive pantomime tasks, and the majority of these errors were spatiotemporal in nature (see Table 4). They consisted mostly of internal configuration errors (e.g., a loose, wider grip for screwdriver), external configuration errors (e.g., combing hair with hand further away from the head than typical comb distance would allow), and amplitude errors (e.g., very small tapping movements for hammer). Most errors (n = 60) were observed on the pantomime task that provided the least contextual information to the participant—that is, pantomime to photo including a very small number of content (n = 4) and other (n = 5) errors. For example, 1 participant performed a paint *roller* action instead of a *brush* action and was scored content error ("related"), while another participant indicated she did not know how to show wire cutters and scored other ("no response"). There were fewer total numbers of errors on the transitive command and imitation tasks (range 13–19 on the command task and 15–20 on the imitation task). Only spatiotemporal errors were made by participants on these tasks. In contrast with the photograph task, no content or other errors were observed on the transitive command and imitation tasks. Additionally, healthy controls made two BPT errors (classed as spatiotemporal) on the pantomime-to-photograph task but subsequently self-corrected these. Healthy participants made no uncorrected BPT errors.

Meaningless imitation

The distribution of the scores on this task was uniform. The mean score was 16.50/17. Half the participants (n = 8) scored at ceiling, and remaining participants made a single error.

Interrater reliability on qualitative scoring of pantomime expression

Point-to-point interrater reliability for pantomime accuracy was greater than 94% (transitive pantomime: to photograph = 94.38%, to command = 96.88%, to imitation = 98.13%; intransitive pantomime: to command = 98.75, to imitation = 100%). Interrater reliability for error classification within the agreed-to errors (n = 66 overall) was 89–95% (transitive pantomime: to photograph = 89.05%, to command = 91.61%, to imitation = 95.00%). As with other pantomime research (McDonald, Tate, & Rigby, 1994), there were so few errors in the intransitive tasks that it was not meaningful to calculate reliability on allocation to error categories. As agreement was acceptable, the remaining pantomime expression items for each participant were scored by one rater (E.P.). Where there were uncertainties about the rating of any remaining test items, ratings were discussed with Rater 2, and consensus rating was applied.

Percentile ranks and correlational data

Table 5 presents the raw data described above converted to percentile ranks. Raw scores below the normal 10th percentile may be considered impaired. For example, a score of less than 34 on the pantomime discrimination test would be in the bottom 10%. On the five tests with skewed distributions due to ceiling effects identified above, making more than one error on any task would indicate performance outside the normal range on that task.

The zero-order correlation matrix revealed few intercorrelations among the FABERS measures. Strong positive correlations were observed, however, between nearly all transitive pantomime task comparisons (to photograph and to command: ρ = .64, $p < .01$; to photograph and to imitation: ρ = .73, $p < .01$; to command and to imitation: ρ = .52, $p < .05$). No significant correlations were observed between transitive and intransitive pantomime tasks, nor between the two intransitive pantomime tasks. Tool naming was highly, positively correlated with pantomime to transitive pantomime to command (ρ = .72, $p < .01$), and the tool selection task also correlated positively with the transitive pantomime-to-photograph task (ρ = .54, $p < .05$). Significant negative correlations were observed between the meaningless imitation task and the pantomime recognition task (ρ = –.65, $p < .01$), and between the transitive pantomime imitation task and the animal triplets (ρ = –.52, $p < .05$). No other correlations were significant.

TABLE 5

Healthy control participant scores on the FABERS with comparison percentile ranks and *Z*-scores for percentile bounds

		Test												
		Pantomime reception		*Verbal semantics*			*Action semantics*		*Transitive and intransitive pantomime expression*					*Meaningless Imitation*
Z-score	*Percentile ranks*	*P'MIME DISCR*	*P'MIME REC*	*AUD REC*[a]	*NAM*	*AT*	*TS*[a]	*ATS*[a]	*TRANS PHOTO*	*TRANS COMM*	*TRANS IMI*	*INTRANS COMM*[a]	*INTRANS IMI*[a]	*M'LESS IMI*
1.281	90	38.3/40	20/20	20/20	20/20	20/20	14/14	14/14	18.3/20	19/20	20/20	10/10	10/10	17/17
0.841	80	38/40	20/20	20/20	19.6/20	20/20	14/14	14/14	17.6/20	19/20	20/20	10/10	10/10	17/17
0.522	70	37.9/40	19/20	20/20	19/20	20/20	14/14	14/14	17/20	18/20	20/20	10/10	10/10	17/17
0.252	60	37/40	19/20	20/20	19/20	20/20	14/14	14/14	17/20	18/20	19.2/20	10/10	10/10	17/17
0	50	36.5/40	19/20	20/20	19/20	19/20	14/14	14/14	17/20	17.5/20	19/20	10/10	10/10	16.5/17
–0.252	40	36/40	18.8/20	20/20	19/20	19/20	14/14	14/14	16/20	17/20	19/20	10/10	10/10	16/17
–0.522	30	36/40	18/20	20/20	18.1/20	19/20	14/14	14/14	15.1/20	17/20	19/20	9.1/10	10/10	16/17
–0.841	20	34.4/40	18/20	20/20	18/20	18.4/20	14/14	14/14	14.4/20	15.4/20	17.4/20	9/10	10/10	16/17
–1.281	10	34/40	17/20	19.7/20	17.7/20	18/20	12.7/14	13.7/14	12.7/20	13.7/20	15.7/20	8.7/10	9.7/10	16/17

Note. FABERS = Florida Apraxia Battery–Extended and Revised Sydney. AT = animal triplet, ATS = alternative tool selection, AUD REC = auditory recognition, C = content error, INTRANS COM = intransitive pantomime expression to command, INTRANS IMI = intransitive pantomime expression to imitation, M'LESS IMI = meaningless imitation, NAM = naming, O = other error, P'MIME REC = pantomime recognition, P'MIME DISCR = pantomime discrimination, ST = spatiotemporal error, TRANS COMM = transitive pantomime expression to command, TRANS IMI = transitive pantomime expression to imitation, TRANS PHOTO = transitive pantomime expression to photograph, TS = tool selection.

[a]Indicates that for these subtests ceiling effects were observed, and any error in clinical populations would indicate pathological performance.

DISCUSSION

We have described a comprehensive, relational assessment battery for limb apraxia associated with brain damage, the Florida Apraxia Battery–Extended and Revised Sydney (FABERS), established interrater reliability for the qualitative pantomime expression scoring system, and provided control comparison scores for 16 healthy elderly controls across the battery.

The FABERS eliminated some of the limitations of previous research identified above by inclusion of a number of more carefully controlled production- and non-production-based action semantic knowledge tests to remove the confound of action output lexicon (AOL) deficits when examining action semantic knowledge. Further, it separates transitive and intransitive pantomimes, and also meaningless postures and movement sequences from meaningful pantomimes, so that more confident conclusions can be drawn regarding the integrity of separate hypothesized input pathways and the direct and indirect imitation routes. The advantage of the FABERS over the original FAB is that it contains a nonverbal nonaction semantic task (animal triplets), a meaningless imitation task, and provision of standard and percentile scores for all tasks across a group of 16 healthy control participants. This advantage allows comparison across different FABERS measures within individuals, indicating their strengths and weaknesses on various aspects of the praxis system. Although the model distinguishes between physical characteristics of a movement represented in the action lexicons and conceptual knowledge in the action semantic system, some studies in the area of embodiment cognition suggest that perceptual (or sensorimotor) representations and conceptual representations may be based on the same systems rather than more encapsulated functions (Barsalou, 1999; van Dantzig, Pecher, Zeelenberg, & Barsalou, 2008). While Rothi and colleagues consider that action semantics does contain motor information important to the object representation (e.g., mechanical knowledge) (Raymer & Ochipa, 1997), the embodiment literature offers opportunity for further development of the model in terms of how multimodal sensorimotor representations are organized in relation to these theories. However, to date, embodied cognition has not produced clear indications for clinical application in assessment or treatment of limb apraxia, and standardized assessments based on the model are yet to be developed. The FABERS therefore provides an important foundation tool for current clinical use and further development of the cognitive neuropsychological model of praxis. Researchers who do not subscribe to a cognitive neuropsychological approach can also utilize FABERS subtests as tasks in action-related research.

The Florida Apraxia Battery–Extended and Revised Sydney (FABERS)

Distribution of scores

The pattern of distribution of FABERS scores was unimodal and normal except on five tests with simpler formats (auditory word-to-picture match task, the tool selection and alternate tool selection tests, and the intransitive pantomime-to-command and intransitive pantomime-to-imitation tasks) that had a negative skew due to ceiling effects. This is consistent with previous studies that have shown that both pantomime recognition tasks and intransitive pantomime tasks are performed better than transitive pantomime expression tasks in controls (Dumont et al., 2000; Mozaz, Rothi, Anderson, Crucian, & Heilman, 2002; Rapcsak et al., 1989). It is not surprising that intransitive pantomimes that typically have less complex movements and standardized cultural consistency were performed well in healthy controls. Participants with neurological damage (e.g., CVA), however, may find these subtests more difficult, and even one error may indicate abnormal performance (Rothi et al., 1997b).

Error types

Very few studies in the literature that provide control data on pantomime expression tasks report qualitative data on error patterns. Our finding that pantomime expression errors consisted almost totally of spatiotemporal errors is consistent with the few studies that report control data (Maher, Rothi, & Heilman, 1997; McDonald et al., 1994). On transitive pantomime expression tasks, other or content errors were only observed on the pantomime-to-photo task, perhaps due to the more limited instruction provided (e.g., participants were shown the photographed hammer only with verbal instruction "show me how you use this"). By comparison, the pantomime-to-command task gave the participants more specific information about both the action and the target associated object (e.g., "Show me how you use a hammer to pound a nail"), and the imitation task gave them complete pantomime to copy. Some participants appeared to have very precise pantomime expression performance with detailed attention to imagined grips and spacing of the action in relation to the target associated object. However, despite instruction to actually imagine they were using the tool, other participants made spatiotemporal errors on pantomime expression tasks. These errors appeared to be related to imprecision of their replicated grip of the to-be-pantomimed tool and incorrect spatial relationships between their pantomimed action and the associated object. Thus, some participants may have been more casual in their approach to the pantomime expression tasks. All types of errors were observed on the pantomime recognition task; however numbers were small, and it is difficult to compare to other research as few studies include all foil types in their assessment.

Interrater reliability on the pantomime expression qualitative scoring system

Acceptable interrater reliability was established for all pantomime expression subtests of the FABERS, and percentage agreement was comparable to that of other studies using similar scoring systems (Maher et al., 1997; McDonald et al., 1994). Reliability scores were not as high on the transitive pantomime-to-photograph task as on both command and imitation tasks. The reduced instruction on this task, as described above, is likely to allow more opportunity for individualized actions that were more likely to be interpreted differently by different raters. While acceptable levels of interrater reliability were observed between two experienced and trained raters on the reported pantomime expression tasks, this does not indicate that the tasks would be reliably scored by other raters with different levels of experience. Clinicians and researchers are advised to reestablish reliability for new applications of the scoring system.

Healthy control performance on the FABERS

Control comparison scores

The distribution of control performance and cutoff scores for pantomime expression tasks (60–65%) in the present study is similar to the 50% cutoff criteria for the Florida Apraxia Screening Test - Revised (FAST-R) (a short limb praxis test screening pantomime to command with the FAB items; Rothi et al., 1997b). Other studies have reported cutoff scores at 85–98% (Derouesne et al., 2000; Dumont et al., 2000) using different items and different requirements for correct pantomime performance. Our study clearly shows that control accuracy differs on transitive and intransitive tasks, and thus praxis batteries should consider transitive and intransitive tasks separately. Additionally, the percentile ranks calculated in the present study will allow clinicians to compare performance on one subtest to that on another to assist with determining the relative performance and integrity of model components in individual clients. The reader should bear in mind the relatively small number of control participants in this study ($n = 16$). Nevertheless, in an area with a paucity of healthy control data and of assessment resources, readers are provided with age-, gender-, and education-matched control comparisons to guide assessment and interpretation of apraxic impairment in clinical populations—for example, people with dementia and CVA. Future research with larger samples is required to extend understanding of normal performance.

Associations between subtests

The significant positive associations found between transitive pantomime expression tasks in healthy controls would be expected between tasks with various input modalities (photograph, command, and imitation) with a common output route (i.e., semantics to the AOL and motor systems), assuming controls had no impairments in presemantic processing in any modality. Evidence from kinematic analysis of healthy participants performing complex pantomime shows very little difference in the temporal structure of the pantomime performance across different modalities (Weiss, Jeannerod, Paulignan, & Freund, 2000). Weiss et al. found the temporal structure of a pantomime (pouring a drink from a bottle and drinking with a glass) in 12 healthy participants via command, imitation, visual presentation, and with object was relatively stable. In our study, however, transitive and intransitive pantomime tasks did not correlate with each other. It is possible that ceiling effects on the intransitive pantomime tasks made ranks correlations less meaningful on these tasks.

CONCLUSION

The FABERS is a reliable and comprehensive battery of subtests for the assessment of praxis skills. Provision of standard scores across different FABERS measures allows comparison of the relative integrity of praxis system components as described by Rothi and colleagues (Rothi et al., 1997a). It provides researchers and clinicians with resources/stimuli and control data for continuing research into action processing in emerging models.

Original manuscript received 3 November 2008
Revised manuscript accepted 31 January 2009
First published online day month year

REFERENCES

Barrett, A. M., Schwartz, R. L., Raymer, A. L., Crucian, G. P., Rothi, L. G., & Heilman, K. M. (1998). Dyssynchronous apraxia: Failure to combine simultaneous preprogrammed movements. *Cognitive Neuropsychology*, *15*, 685–703.

Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences*, *22*, 577–660.

Belanger, S. A., Duffy, R. J., & Coelho, C. A. (1996). The assessment of limb apraxia—an investigation of task effects and their cause. *Brain & Cognition*, *32*, 384–404.

Bell, B. D. (1994). Pantomime recognition impairment in aphasia: An analysis of error types. *Brain and Language*, *47*, 269–278.

Breedin, S. D., Martin, N., & Saffran, E. M. (1994). Category specific semantic impairments: An infrequent occurrence. *Brain and Language*, *3*, 383–386.

Buxbaum, L. J., Haaland, K. Y., Hallett, M., Wheaton, L., Heilman, K. M., Rodriguez, A., et al. (2008). Treatment of limb apraxia: Moving forward to improved action. *American Journal of Physical Medicine and Rehabilitation*, *87*, 149–161.

Code, C., & Gaunt, C. (1986). Treating severe speech and limb apraxia in a case of aphasia. *British Journal of Disorders of Communication*, *21*, 11–20.

Cubelli, R., Marchetti, C., Boscolo, C., & Della Sala, S. (2000). Cognition in action: Testing a model of limb apraxia. *Brain & Cognition*, *44*, 144–165.

De Renzi, E. (1985). Methods of limb apraxia examination. In E. A. Roy (Ed.), *Neuropsychological studies of apraxia and related disorders* (pp. 45–61). Amsterdam: Elsevier.

De Renzi, E., & Lucchelli, F. (1988). Ideational apraxia. *Brain*, *111*, 1173–1185.

De Renzi, E., Motti, F., & Nichelli, P. (1980). Imitating gestures: A quantitative approach to ideomotor apraxia. *Archives of Neurology*, *37*, 6–10.

Derouesne, C., Lagha-Pierucci, S., Thibault, S., Baudouin-Madec, V., & Lacomblez, L. (2000). Apraxic disturbances in patients with mild to moderate Alzheimer's disease. *Neuropsychologia*, *38*, 1760–1769.

Dobignyroman, N., Dieudonnemoinet, B., Tortrat, D., Verny, M., & Forette, B. (1998). Ideomotor apraxia test—a new test of imitation of gestures for elderly people. *European Journal of Neurology*, *5*, 571–578.

Donkervoort, M., Dekker, J., & Deelman, B. (2006). The course of apraxia and ADL functioning in left hemisphere stroke patients treated in rehabilitation centres and nursing homes. *Clinical Rehabilitation*, *20*, 1085–1093.

Donkervoort, M., Dekker, J., van den Ende, E., Stehmann-Saris, J. C., & Deelman, B. G. (2000). Prevalence of apraxia among patients with a first left hemisphere stroke in rehabilitation centres and nursing homes. *Clinical Rehabilitation*, *14*, 130–136.

Duffy, J. R., & Duffy, R. J. (1989). The Limb Apraxia Test: An imitative measure of upper limb apraxia. In T. E. Prescott (Ed.), *Clinical aphasiology* (Vol. 18, pp. 145–158). Boston: College Hill.

Duffy, J. R., & Duffy, R. J. (1990). The assessment of limb apraxia: The Limb Apraxia Test. In G. R. Hammond (Ed.), *Advances in psychology: Cerebral control of speech and limb movement* (pp. 503–531). Amsterdam: Elsevier Science.

Duffy, J. R., Duffy, R. J., & Uryase, D. (1989). The Limb Apraxia Test: Development of short form. In T. E. Prescott (Ed.), *Clinical aphasiology* (Vol. 18, pp. 161–171). Boston: College-Hill.

Duffy, R. J., Watt, J. H., & Duffy, J. R. (1994). Testing causal theories of pantomimic deficits in aphasia using path analysis. *Aphasiology*, *8*, 361–379.

Dumont, C., Ska, B., & Joanette, Y. (2000). Conceptual apraxia and semantic memory deficit in Alzheimer's disease: Two sides of the same coin? *Journal of the International Neuropsychological Society*, *6*, 693–703.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state." A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research.*, *12*, 189–198.

Foundas, A. L., Macauley, B. L., Raymer, A. M., Maher, L. M., Heilman, K. M., & Gonzalez Rothi, L. J. (1995). Ecological implications of limb apraxia: Evidence from mealtime behavior. *Journal of the International Neuropsychological Society*, *1*, 62–66.

Foundas, A. L., Raymer, A. M., Maher, L. M., Rothi, L. J. G., & Heilman, K. M. (1993). Recovery in ideomotor apraxia. *Journal of Clinical & Experimental Neuropsychology*, *15*, 44.

Giannakopoulos, P., Duc, M., Gold, G., Hof, P. R., Michel, J. P., & Bouras, C. (1998). Pathologic correlates of apraxia in Alzheimer disease. *Archives of Neurology*, *55*, 689–695.

Hanna-Pladdy, B., Heilman, K. M., & Foundas, A. L. (2003). Ecological implications of ideomotor apraxia: Evidence from physical activities of daily living. *Neurology*, *60*, 487–490.

Hanna-Pladdy, B., & Rothi, L. J. G. (2001). Ideational apraxia: Confusion that began with Liepmann. *Neuropsychological Rehabilitation*, *11*, 539–547.

Heilman, K. M., Maher, L. M., Greenwald, M. L., & Rothi, L. J. G. (1997). Conceptual apraxia from lateralized lesions. *Neurology*, *49*, 457–464.

Heilman, K. M., & Rothi, L. J. G. (1993). Apraxia. In K. M. Heilman & E. Valenstein (Eds.), *Clinical neuropsychology* (3rd ed.). New York: Oxford University Press.

Kertesz, A. (1979). Apraxia. In A. Kertesz (Ed.), *Aphasia and associated disorders. Taxonomy, localisation, and recovery* (pp. 231–251). New York: Grunne and Stratton.

Lambier, J. D., & Bradley, D. (1991). The effect of physical similarity on pantomime recognition in aphasia. *Aphasiology*, *5*, 23–37.

Liepmann, H. (1977). The syndrome of apraxia based on a case of unilateral apraxia. (A translation from Monatschrift fur Psychiatrie und Neurologie, 1900, 8, 15–44.). In D. A. Rottenberg & F. H. Hockberg (Eds.), *Neurological classics in modern translation*. New York: Macmillan Publishing Co. (Original work published 1900)

Liepmann, H. (1980). *The left hemisphere and action. (A translation from Munchener Medizinische Wochenschrift, 1905, 48–49.) Translations from Liepmann's essays on apraxia* (Research Bulletin No. 506). London, Canada: University of Western Ontario, Department of Psychology. (Original work published 1905)

Lucchelli, F., Lopez, O. L., Faglioni, P., & Boller, F. (1993). Ideomotor and ideational apraxia in Alzheimer's disease. *International Journal of Geriatric Psychiatry*, *8*, 413–417.

Macauley, B. L. (1998). *The nature of movement and action errors produced by brain-injured patients*. Gainesville, FL: University of Florida.

Maher, L. M., Rothi, L. J. G., & Heilman, K. M. (1997). Praxis performance with left versus right hemisphere lesions. *Neurorehabilitation*, *9*, 45–55.

McDonald, S., Tate, R. L., & Rigby, J. (1994). Error types in ideomotor apraxia—a qualitative analysis. *Brain & Cognition*, *25*, 250–270.

Mozaz, M., Rothi, L. J., Anderson, J. M., Crucian, G. P., & Heilman, K. M. (2002). Postural knowledge of transitive pantomimes and intransitive gestures. *Journal of the International Neuropsychological Society*, *8*, 958–962.

Ochipa, C., Maher, L. M., & Rothi, L. J. G. (1995). Treament of ideomotor apraxia. *Journal of the International Neuropsychological Society*, *2*, 149.

Ochipa, C., Rothi, L. J. G., & Heilman, K. M. (1989). Ideational apraxia: A deficit in tool selection and use. *Annals of Neurology*, *25*, 190–193.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, *9*, 97–113.

Pilgrim, E., & Humphreys, G. W. (1994). Rehabilitation of a case of ideomotor apraxia. In M. J. Riddoch & G. W Humphreys (Eds.), *Cognitive neuropsychology and cognitive rehabilitation* (pp. 271–285). Hove, UK: Lawrence Erlbaum Associates.

Rapcsak, S. Z., Croswell, S. C., & Rubens, A. B. (1989). Apraxia in Alzheimer's disease. *Neurology*, *39*, 664–668.

Raymer, A. M., Maher, L. M., Foundas, A. L., Heilman, K. M., & Rothi, L. J. G. (1997). The significance of body part as tool errors in limb apraxia. *Brain & Cognition*, *34*, 287–292.

Raymer, A. M., & Ochipa, C. (1997). Conceptual praxis. In L. J. G. Rothi & K. M. Heilman (Eds.), *Apraxia: The neuropsychology of action* (pp. 51–60). Hove, UK: Psychology Press.

Rothi, L. J. G., Heilman, K. M., Mack, L., Verfaillie, M., & Brown, P. (1988). Ideomotor apraxia—error pattern-analysis. *Journal of Clinical and Experimental Neuropsychology*, *10*, 48–48.

Rothi, L. J. G., Ochipa, C., & Heilman, K. M. (1991). A cognitive neuropsychological model of limb praxis. *Cognitive Neuropsychology*, *8*, 443–458.

Rothi, L. J. G., Ochipa, C., & Heilman, K. M. (1997a). A cognitive neuropsychological model of limb praxis and apraxia. In L. J. G. Rothi & K. M. Heilman (Eds.), *Apraxia: The neuropsychology of action* (pp. 29–49). Hove, UK: Psychology Press.

Rothi, L. J. G., Raymer, A. M., & Heilman, K. M. (1997b). Limb praxis assessment. In L. J. G. Rothi & K. M. Heilman (Eds.), *Apraxia: The neuropsychology of action. Brain damage, behaviour and cognition series*. Hove, UK: Psychology Press.

Roy, E. A. (1983). Neuropsychological perspectives on apraxia and related action disorders. In R. Magill (Ed.), *Memory and control actions*. Amsterdam: Elsevier.

Roy, E. A. (1985). *Neuropsychological studies of apraxia and related disorders*. Amsterdam: Elsevier.

Smania, N., Aglioti, S. M., Girardi, F., Tinazzi, M., Fiaschi, A., Cosentino, A., et al. (2006). Rehabilitation of limb apraxia improves daily life activities in patients with stroke. *Neurology*, *67*, 2050–2052.

Smania, N., Girardi, F., Domenicali, C., Lora, E., & Aglioti, S. (2000). The rehabilitation of limb apraxia: A study in left-brain-damaged patients. *Archives of Physical Medicine & Rehabilitation*, *81*, 379–388.

SPSS Inc. (2001). *SPSS Student Version 11.0 for Windows 98, 2000 or Windows NT*. Upper Saddle River, NJ: Prentice Hall.

Sundet, K., Finset, A., & Reinvang, I. (1988). Neuropsychological predictors in stroke rehabilitation. *Journal of Clinical & Experimental Neuropsychology*, *10*, 363–379.

van Dantzig, S., Pecher, D., Zeelenberg, R., & Barsalou, L. W. (2008). Perceptual processing affects conceptual processing. *Cognitive Science*, *32*, 579–590.

Weiss, P. H., Jeannerod, M., Paulignan, Y., & Freund, H. J. (2000). Is the organisation of goal-directed action modality specific? A common temporal structure. *Neuropsychologia*, *38*, 1136–1147.

Willis, L., Behrens, M., Mack, W., & Chui, H. (1998). Ideomotor apraxia in early Alzheimer's disease: Time and accuracy measures. *Brain & Cognition*, *38*(2), 220–233.

Zwinkels, A., Geusgens, C., van de Sande, P., & Van Heugten, C. (2004). Assessment of apraxia: Inter-rater reliability of a new apraxia test, association between apraxia and other cognitive deficits and prevalence of apraxia in a rehabilitation setting. *Clinical Rehabilitation*, *18*, 819–827.

APPENDIX A

PANTOMIME-TO-PHOTOGRAPH MATCH TEST ITEMS/AUDITORY WORD-TO-PHOTOGRAPH MATCH ITEMS

Instruction

Pantomime recognition—"Show me the one I am pretending to use"
Auditory recognition—"Point to the (name of target tool)"

	Pantomime/auditory recognition		*Errors (Circle one)*		
No.	*Action + target tool*	*Score 1 or 0*	*Semantic category*	*Function associate*	*Motoric*
P1	***Lick a stamp to** stick on envelope*		*Received stamp*	*Envelope*	*Ice-cream*
P2	*Whistle to blow*		*Referee flag*	*Stopwatch*	*Balloon*
1	**Scissors** to cut a whole piece of paper		Shears	Paper	Pliers
2	**Saw** to cut wood		Fret saw	Wood	Steak knife
3	**Bottle opener** to remove bottle cap		Can opener	Bottle	Can puncher
4	**Wire cutters** to snip a wire		Pliers	Wire	Bellows

(Continued)

Appendix A
(Continued)

5	**Salt shaker** to salt food on a table		Pepper grinder	Chips	Baby powder
6	**Glass** to drink water out of		Tea cup	Water pitcher	Banana
7	**Spoon** to stir your coffee/tea		Fork	Cup & saucer	Pencil
8	**Hammer** to pound a nail		Spanner	Nail	Potato masher
9	**Comb** to fix your hair		Brush	Hair	Hat
10	**Knife** to carve a turkey		Peeler	Fork	Saw
11	**Paint brush** to paint a wall		Paint roller	Paint can	Hammer
12	**Screwdriver** to turn a screw into wall		Chisel	Screw	Key
13	**Pencil** to write on paper		Ruler	Notepad	Needle
14	**A key** to unlock a door		Key ring	Lock	Screwdriver
15	**An iron**, to press a shirt		Coat hanger	Shirt	Scrub brush
16	**A razo**r to shave your face		Electric shaver	Shaving cream	Blusher brush
17	**A duster** to clean a blackboard		Scrubbing brush	Chalk	Iron
18	**A vegetable peeler** to shred a carrot		Vegetable knife	Carrot	Butter knife
19	**A potato masher** to mash potatoes		Meat mallet	Potato	Icepick
20	**A scoop** to serve ice-cream		Spoon	Ice-cream cone	Garden trowel
	Total	/20			

Notes. Italicized text indicates practice items; bold text indicates target items.

APPENDIX B

PANTOMIME DISCRIMINATION TEST ITEMS

Instruction

"Is this pantomime correct for (presented tool and action), yes or no?" + show picture
Bold Y or N indicates correct response.

Item		*Error/action Time 1*	*Response*	*Error/action Time 2*	*Response*
P1	***Lick a stamp to** stick on envelope*			*Concretization error*	
P2	*Whistle to blow*	*External configuration*			
1/21	**Scissors** to cut a whole piece of paper	Occurrence—single snip	Y / **N**		**Y** / N
2/22	**Saw** to cut wood		**Y** / N	Internal configuration—grip rotated, palm upwards	Y / **N**
3/23	**Bottle opener** to remove bottle cap	Hand—remove with hand	Y / **N**		**Y** / N
4/24	**Wire cutters** to snip a wire		**Y** / N	Hand error—finger	Y / **N**
5/25	**Salt shaker** to salt food on a table	Movement—as is but up and down vertically	Y / **N**		**Y** / N
6/26	**Glass** to drink water		**Y** / N	Sequencing—tip glass out then drink	Y / **N**
7/27	**Spoon** to stir your coffee/tea		**Y** / N	Movement—same grip, back & forth movement not circular	Y / **N**
8/28	**Hammer** to pound a nail	Amplitude—minute movements	Y / **N**		**Y** / N
9/29	**Comb** to fix your hair		**Y** / N	Internal configuration—open palm	Y / **N**
10/30	**Knife** to carve a turkey		**Y** / N	Body part as tool—finger	Y / **N**
11/31	**Paint brush** to paint a wall		**Y** / N	Amplitude—small action	Y / **N**
12/32	**Screwdriver** to turn a screw into wall	Internal configuration—large grip	Y / **N**		**Y** / N
13/33	**Pencil** to write on paper	Concretization—write on arm	Y / **N**		**Y** / N
14/34	**A key** to unlock a door	Sequencing—turn key first, THEN insert	Y / **N**		**Y** / N
15/35	**An iron**, to press a shirt		**Y** / N	Concretization—iron arm	Y / **N**
16/36	**A razo**r to shave your face	Body part as tool—use finger	Y / **N**		**Y** / N
17/37	**A duster** to clean a blackboard		**Y** / N	Amplitude—small movements	Y / **N**
18/38	**A vegetable peeler** to shred a carrot		**Y** / N	Timing—very slow action	Y / **N**
19/39	**A potato masher** to mash potatoes	External configuration—Same action, next to right cheek	Y / **N**		**Y** / N
20/40	**A scoop** to serve ice-cream	Timing—very fast scooping	Y / **N**		**Y** / N
		Total	/20	Total	/20
				Overall total	/40

Notes. Italicized text indicates practice items; bold text indicates target items.

APPENDIX C

TOOL SELECTION AND ALTERNATE TOOL SELECTION TEST ITEMS
TOOL SELECTION

Instruction

"Which of these three tools is best used to finish this task?" Bold items indicated target item.

No.	*Partial action*	*Score 1 or 0*	*1*	*2*	*3*
P1	*half opened can*		***can opener***	*saw*	*chisel*
P2	*nail half in wood*		*screwdriver*	***hammer***	*needle*
1	bit half in wood		staple remover	wrench	**hand drill**
2	partially sawn board		scissors	hammer	**saw**
3	partially knitted item		can opener	**needle**	scissors
4	half drawn picture		chisel	needle	**pen**
5	nail bent in wood		**hammer**	wrench	saw
6	partially cut cardboard		pen	**scissors**	staple remover
7	screw half in wood		hammer	Stanley knife[a]	**screwdriver**
8	staple half out of paper		wire cutters	can opener	**staple remover**
9	partially cut wire		hand drill	hammer	**wire cutters**
10	nut & bolt partially in wood		hammer	**wrench**	screwdriver
11	chisel wood		tin opener	hole puncher	**chisel**
12	punch hole in leather		**hole puncher**	pen	Stanley knife[a]
13	cut balsa wood		hole puncher	**Stanley knife**[a]	tin opener
14	open evap milk can		**tin opener**	wire cutters	hand drill
	Total	/14			

Notes. Italicized text indicates practice items; bold text indicates target items.
[a]Stanley knife may also be termed utility knife.

ALTERNATE TOOL SELECTION

Instruction

"The commonly used tools have been taken away. Tell me, which tool is the BEST to finish the task." Bold items indicated target item.

No.	*Partial action*	*Score 1 or 0*	*1*	*2*	*3*
P1	*half opened can*		***old can opener***	*screwdriver*	*oyster knife*
P2	*nail half in wood*		*Stanley knife*[a]	***shoe***	*screwdriver*
1	bit half in wood		kitchen scissors	Stanley knife[a]	**pliers**
2	partially sawn board		oyster knife	nut crackers	**fret saw**
3	partially knitted item		pointed scissors	**chopstick**	oyster knife
4	half drawn picture		pliers	kitchen knife	**lipstick**
5	nail bent in wood		**pliers**	file knife/fret saw	chopstick
6	partially cut cardboard		screwdriver	**Stanley knife**[a]	pliers
7	screw half in wood		lipstick	file knife/fret saw	**kitchen knife**
8	staple half out of paper		old can opener	shoe	**oyster knife**
9	partially cut wire		kitchen knife	screwdriver	**kitchen scissors**
10	nut & bolt partially in wood		kitchen scissors	**nut crackers**	oyster knife
11	chisel wood		pliers	pointed scissors	**screwdriver**
12	punch hole in leather		**pointed scissors**	lipstick	old can opener
13	cut balsa wood		shoe	**screwdriver**	nut crackers
14	open evaporated milk can		**oyster knife**	pliers	chopstick
	Total	/14			

Notes. Italicized text indicates practice items; bold text indicates target items.
[a]Stanley knife may also be termed utility knife.

APPENDIX D

PANTOMIME EXPRESSION TEST ITEMS AND NAMING ITEMS

Instructions

Pantomime to photo—"Show me how you use this (show photo) (transitive only)
Pantomime to command—"Show me how you ___" (give full instruction for transitive and intransitive)
Pantomime imitation—"Copy exactly the action I do. Wait until I have finished" (transitive and intransitive)
Naming—"Tell me the name of this (show photo)" (transitive items only)

	Photo/Command/Imitation/Naming (circle one)	*Response*		*Error types (circle if observed)*		
No.	*Item*	*1 or 0*	*Content*	*Temporal*	*Spatial*	*Other*
A	*Lick* ***stamp*** *& fix on envelope*		*P, R, N-R, H*	*S, T, O*	*A, IC, BPT, EC, M*	*C, NR, UR*
B	*Blow a* ***whistle***		*P, R, N-R, H*	*S, T, O*	*A, IC, BPT, EC, M*	*C, NR, UR*
Transitive pantomimes						
1	**Scissors** to cut paper		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
2	**Saw** to cut wood		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
3	**Bottle opener** to remove a bottle cap		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
4	**Wire cutters** to snip a wire		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
5	**Salt shaker** to salt food on a table		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
6	**Glass** to drink water		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
7	**Spoon** to stir your coffee		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
8	**Hammer** to pound a nail		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
9	**Comb** to fix your hair		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
10	**Knife** to carve a turkey		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
11	**Brush** to paint a wall		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
12	**Screwdriver** to turn a screw into wall		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
13	**Pencil** to write on paper		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
14	**A key** to unlock a door		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
15	**An iron**, to press a shirt		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
16	**A razo**r to shave your face		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
17	**An eraser** to clean a chalkboard		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
18	**A vegetable peeler** to shred a carrot		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
19	**An ice pick** to chop ice		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
20	**A scoop** to serve ice-cream		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
Intransitive pantomimes						
1	Salute		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
2	Hitchhike		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
3	Stop		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
4	Go away		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
5	Wave goodbye		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
6	Come here		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
7	Someone is crazy		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
8	Be quiet		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
9	OK		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
10	To make a fist		P, R, N-R, H	S, T, O	A, IC, BPT, EC, M	C, NR, UR
		Total	*Content*	*Temporal*	*Spatial*	*Other*
	Total for transitive items	/20				
	Total for intransitive items	/10				

Notes. Italicized text indicates practice items; bold text indicates target items. Error types: P = Perseverative, R = Related, N-R = Non-related, H = Hand, A = Amplitude, IC = Internal configuration, BPT = Body part as tool, EC = External configuration, M = Movement, S = Sequencing, T = Timing, O = Occurrence, C = Concretisation, NR = No response, UR = Unrecognisable response.

APPENDIX E

TEST ITEMS FOR THE MODIFIED ANIMAL TRIPLET TESTS

Instruction

"Which two go together the best?"
Bold type indicates correct pair.

Score 1 or 0	*Item 1*	*Item 2*	*Item 3*
1	**pig**	**lamb**	horse
2	**chicken**	**turkey**	dove
3	moose	**walrus**	**penguin**
4	**rat**	squirrel	**mouse**
5	**gazelle**	camel	**antelope**
11	**frilled neck lizard**	toad	**gecko**
12	**koala**	crocodile	**kangaroo**
13	**butterfly**	**bee**	spider
14	**toad**	**frog**	turtle
15	**cassowary**	**emu**	magpie
21	**wolf**	rabbit	**fox**
22	**moose/elk**	donkey	**deer**
23	bear	**gorilla**	**monkey**
24	**porpoise**	whale	**dolphin**
25	flamingo	**eagle**	**kookaburra**
31	**crab**	**lobster**	fish
32	**leopard**	rhino	**lion**
33	**jellyfish**	shark	**octopus**
34	horse	**goat**	**sheep**
35	**elephant**	lion	**giraffe**
Animal Total /20			

Notes. Bold text indicates target items. Adapted from Breedin, Martin, and Saffran (1994). Animal test items kindly provided by E. M. Saffran (personal communication, 1999).

APPENDIX F

QUALITATIVE SCORING FOR MEANINGFUL PANTOMIME EXPRESSION TASKS BASED ON ROTHI ET AL. (1997)

Errors	*Error types*	*Descriptions*
Content (C)	Perseverative	Response includes all/part of a previous response
	Related	An accurate pantomime associated with target
	Nonrelated	An real and accurate pantomime not associated with target
	Hand	Not use a tool, e.g., rip paper when target is scissors
Spatial (S)	Amplitude	Amplification reduction or irregularity of amplitude/position in space
	Internal configuration	Abnormality of finger/hand posture with target tool
	Body part as tool (BPT)	BPT that cannot be corrected when requested
	External configuration	Abnormality of finger/hand/arm relationship to object receiving the action
	Movement	Any disturbance of the characteristic action required to complete the goal
Temporal (T)	Sequencing	Movement structure recognisable but addition, deletion or inaccurate order of sequence
	Timing	Alteration of timing/speed (including increase, decrease or irregular)
	Occurrence	Repetitive production of single movements or single production of multiple movements
Other (O)	Concretization	Pantomime on a real object not usually used in the task
	No response	Participant makes no response to request
	Unrecognizable response	Shares no spatial or temporal features of target